AeroTex Predictions for the 1st AIAA Ice Prediction Workshop

Simulations using OpenFOAM, TAC3D+ and ITA

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Vienna, Austria

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AeroTex GmbH

SIMULATION APPROACH

Simulation Approach

- OpenFOAM CFD
  - Incompressible
  - SIMPLE algorithm (Semi-Implicit Method for Pressure Linked Equations)
  - Spalart-Allmaras wall function
    - One equation model based on a modified turbulence viscosity
  - Widely used within the aerospace industry
  - Includes mesher: snappyHexMesh
    - All cases were re-meshed from the provided CAD, as there is no simple way to convert meshes to OpenFOAM format, and meshes generated in other software often causes issues

Simulation Approach (cont.)

- TAC3D+ impingement
  - AeroTex proprietary solver
  - Calls OpenFOAM to perform Lagrangian droplet tracking
    - 4th order Runge-Kutta scheme
  - Additional proprietary routines to calculate the surface collection efficiency
  - Includes automatic refinement to optimise number of trajectories launched
- ITA
  - AeroTex proprietary solver
  - Modified Messinger heat balance approach to determine freezing fraction and ice growth rates
  - Single shot prediction, based on clean surface ice growth rates

Simulation Approach (cont.)

- TAC2 / IHB
  - AeroTex proprietary
  - 2D simulation tools
  - Combined inviscid, potential flow solver with Messinger heat balance
  - Lagrangian droplet tracking (4th order Runge-Kutta)

- 2D simulations included for selected cases
  - All 2D simulations utilised a single shot to compare to 3D cases

Computational Machine

- Single machine
  - AMD Ryzen Threadripper 3970X, 32 core
  - 256GB DDR4 RAM, 2667MHz
- Meshing and aerodynamic solutions were computed using 32 cores
- Impingement solution was computed using 8 cores per droplet bin for most cases
  - Increased to 16 cores per droplet bin for largest mesh case

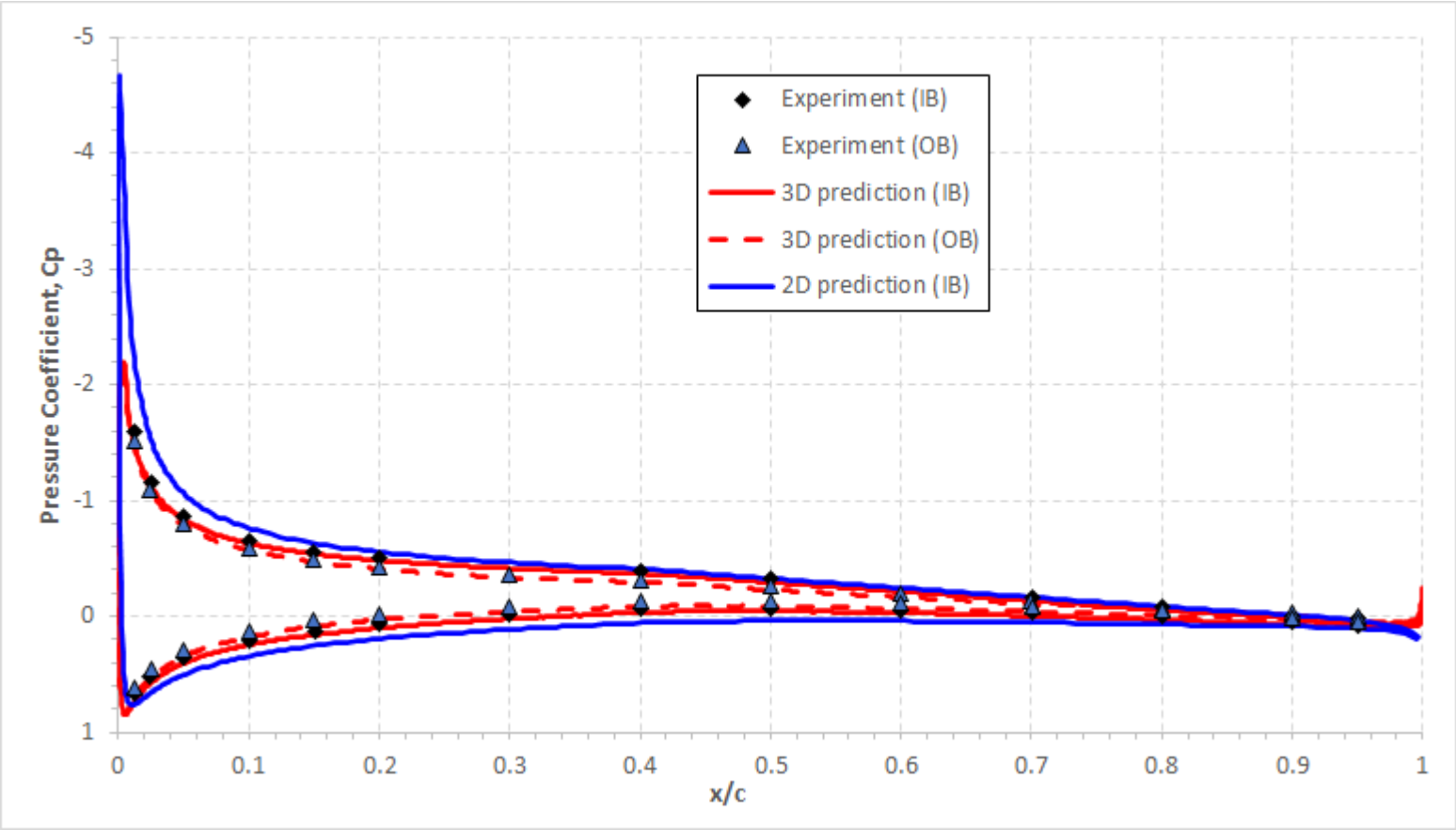
COLLECTION EFFICIENCY CASES

Case 111 and Case 112

- NACA 64A008 H-Tail, $\alpha = 6°$
  - Case 111 is MVD = 21 microns (27-bin)
  - Case 112 is MVD = 92 microns (27-bin)
- Modelled within IRT, including walls (3D)
- 9.01 million cells
- 92 micron case includes SLD corrections for splash and bounce
- Solver times:
  - Meshing = 645s (00:10:45)
  - Aerodynamics = 8390s (02:19:50)
  - Impingement = 3681s (01:01:21)

Case 111

- Pressure coefficient



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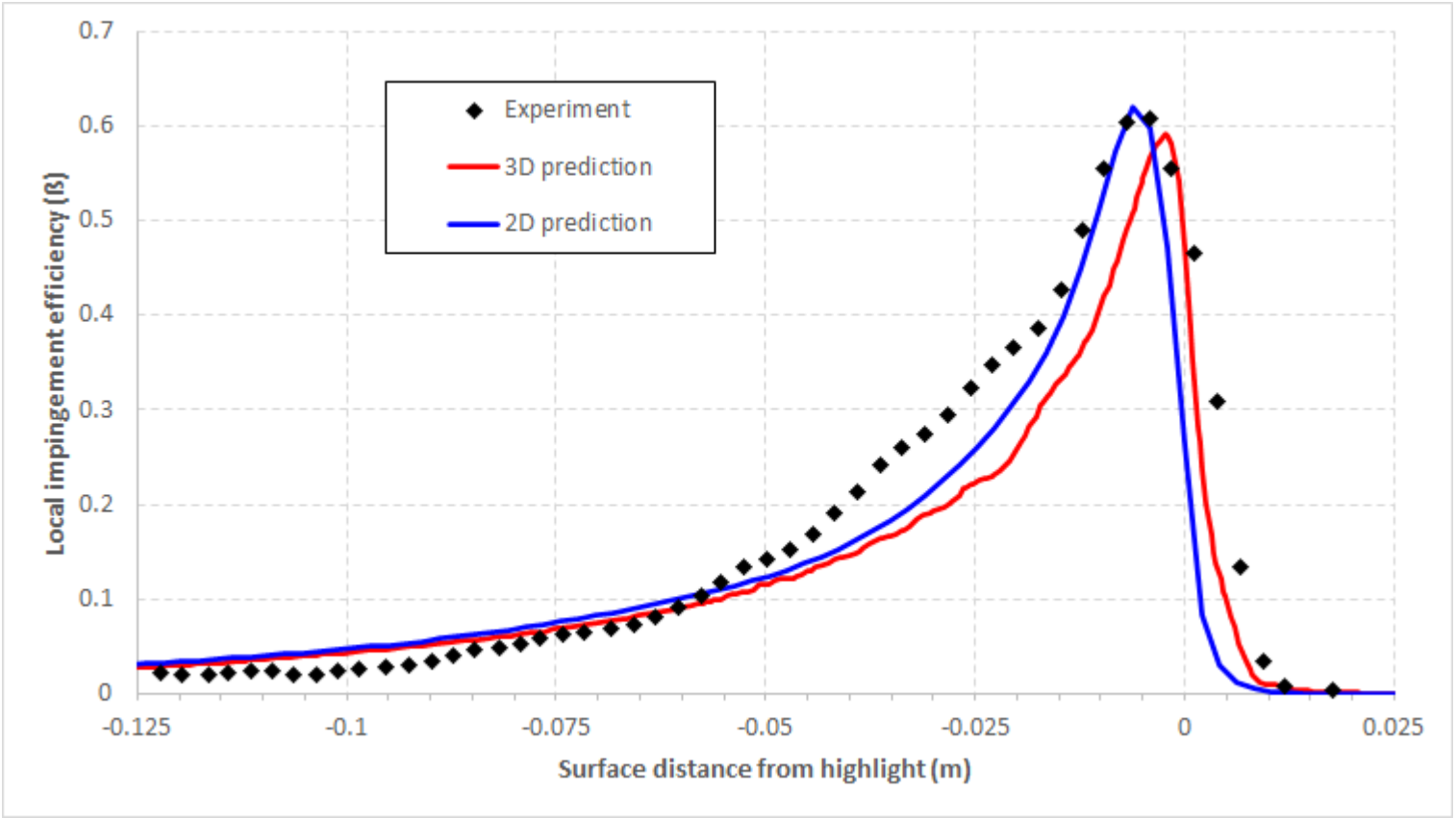
Case 111 (cont.)

- Local collection efficiency



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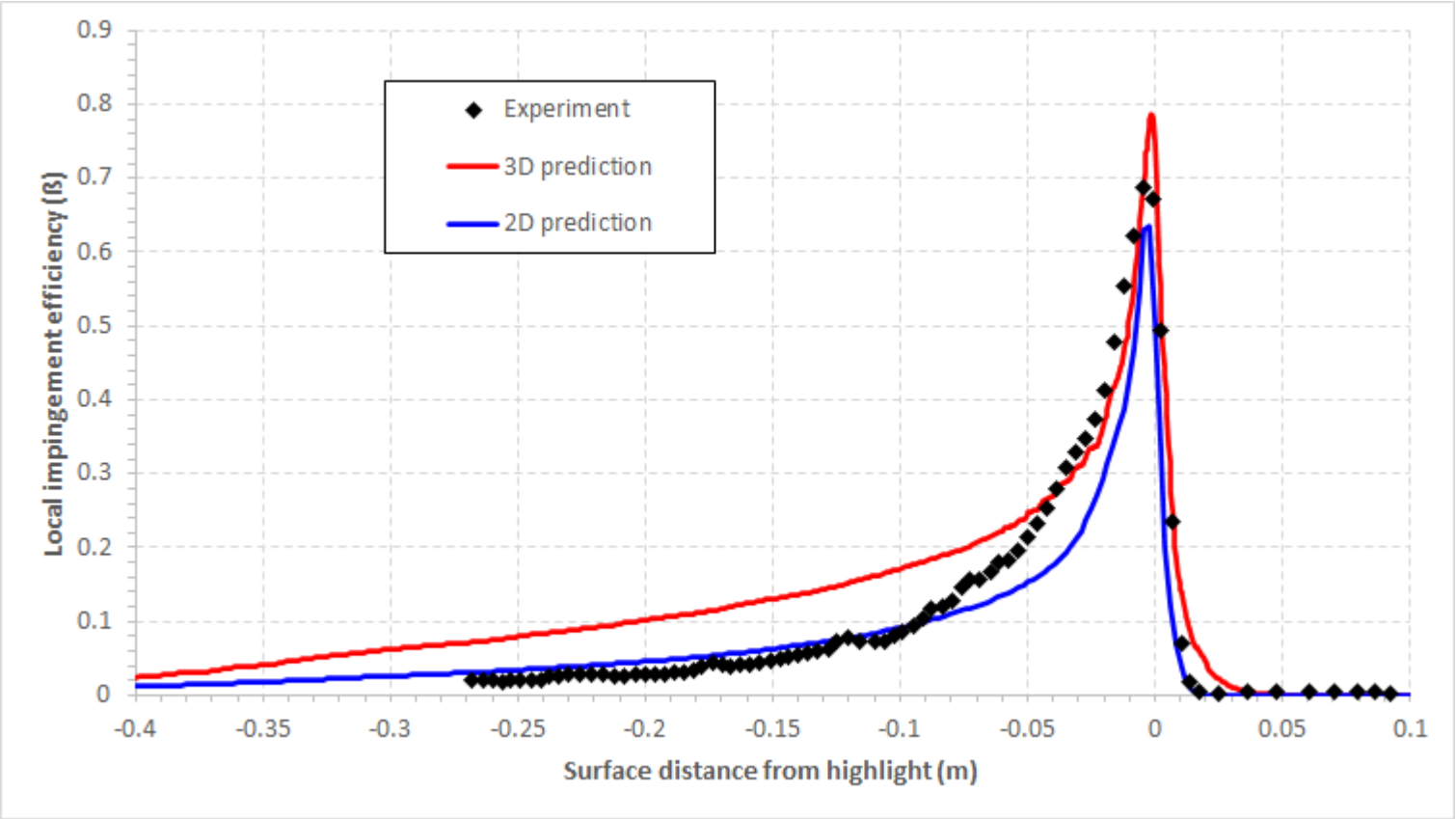
Case 112

- Local collection efficiency



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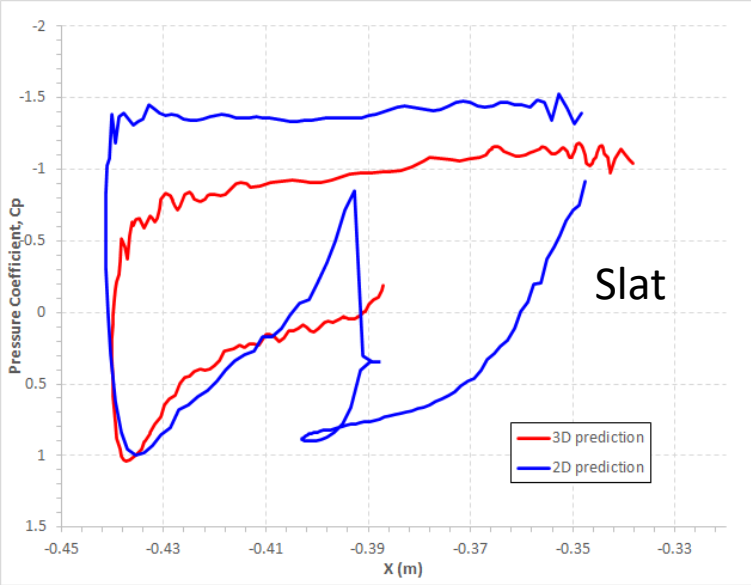
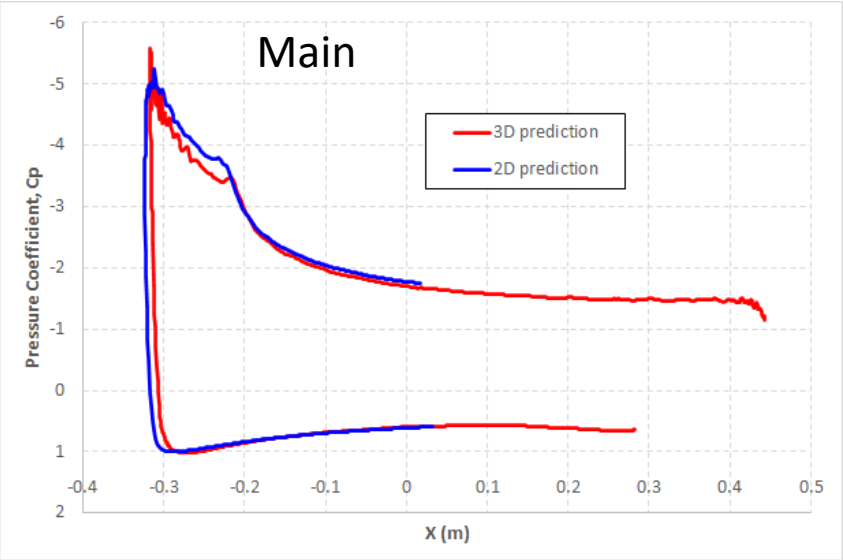
Case 121 and 122

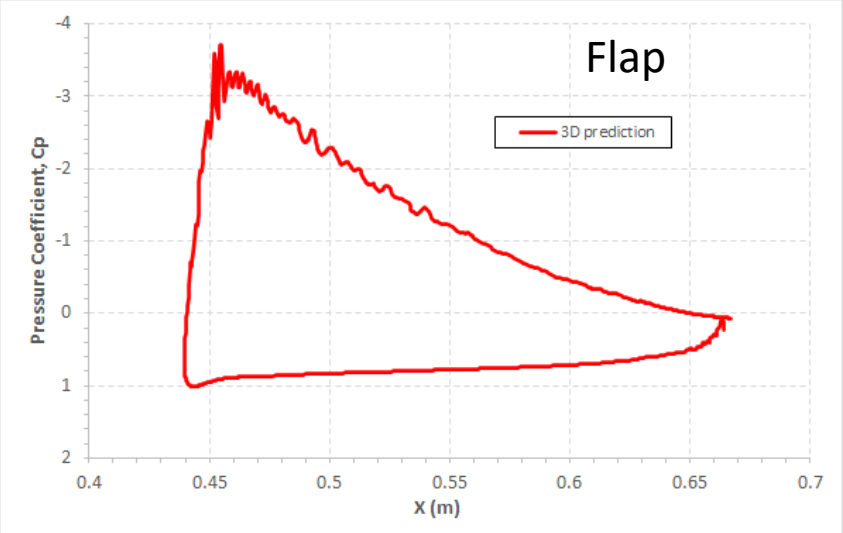
- Three-element airfoil, $\alpha = 4°$
  - Case 121 is MVD = 21 microns (27-bin)
  - Case 122 is MVD = 92 microns (27-bin)
- Modelled within IRT, including walls (3D)
- 34.32 million cells
- 92 micron case includes SLD corrections for splash and bounce
- Solver times:
  - Meshing = 5613s (01:30:33)
  - Aerodynamics = 24184s (06:43:04)
  - Impingement = 18938s (05:15:38)

Case 121

- Pressure coefficient







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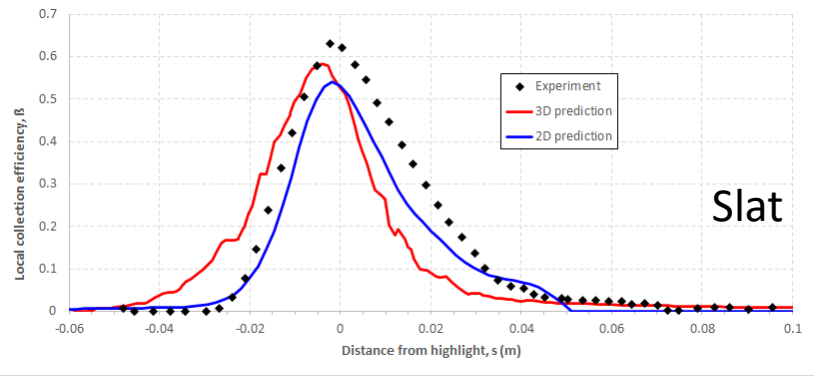
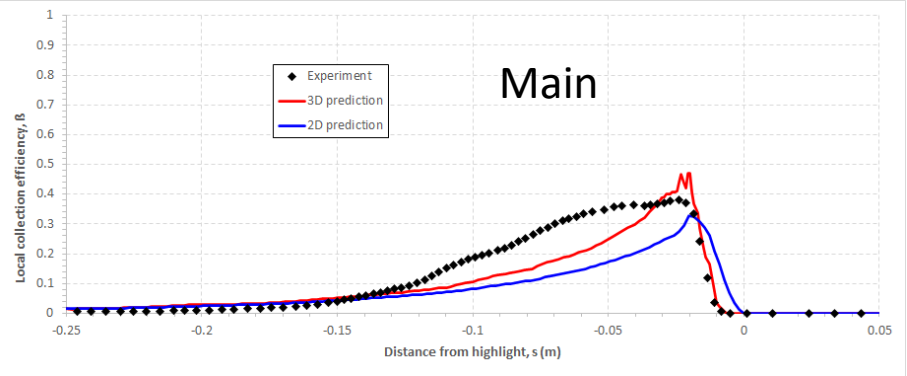
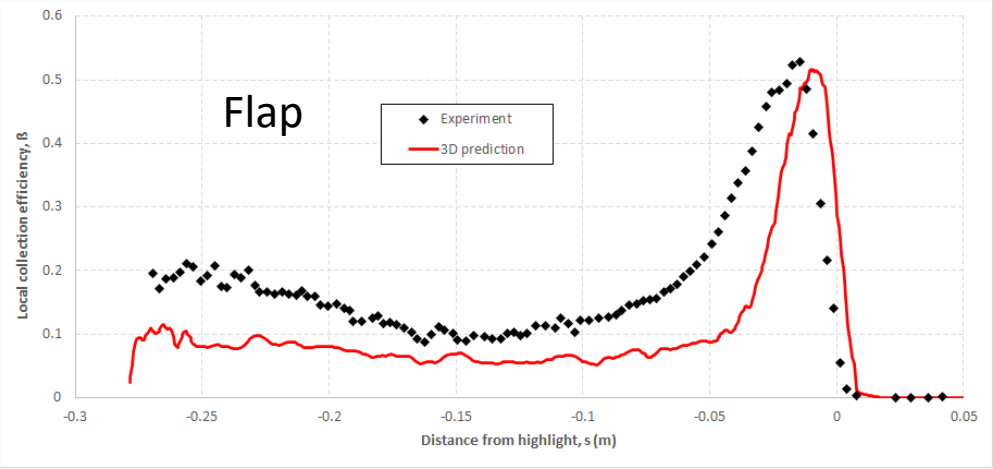
Case 121 (cont.)

- Local collection efficiency







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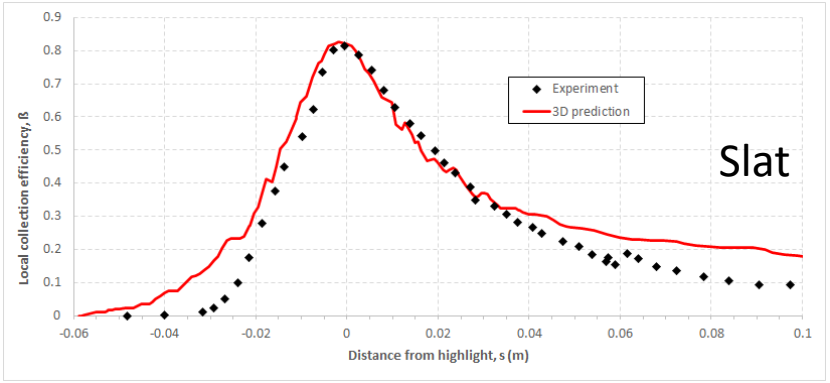
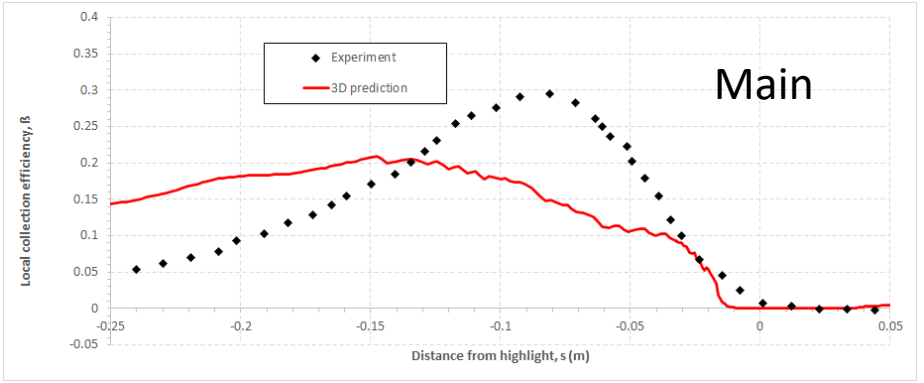
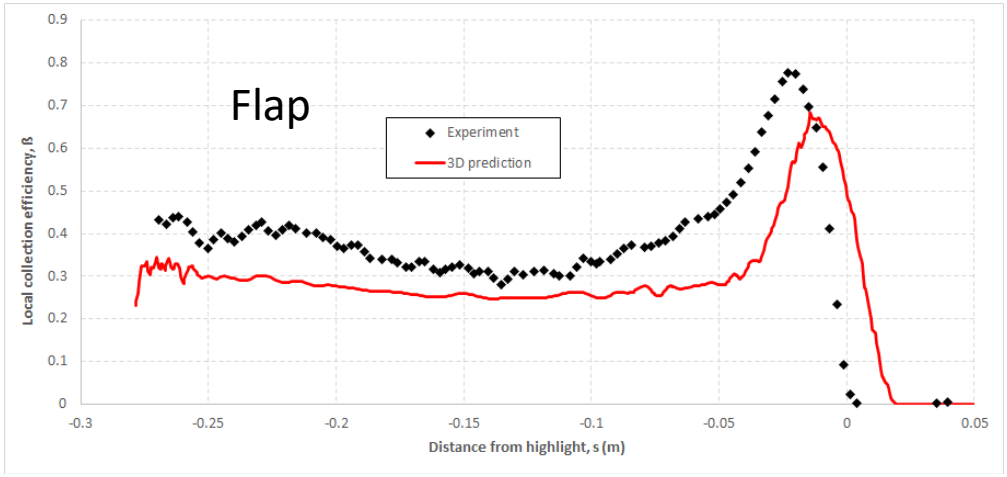
Case 122

- Local collection efficiency







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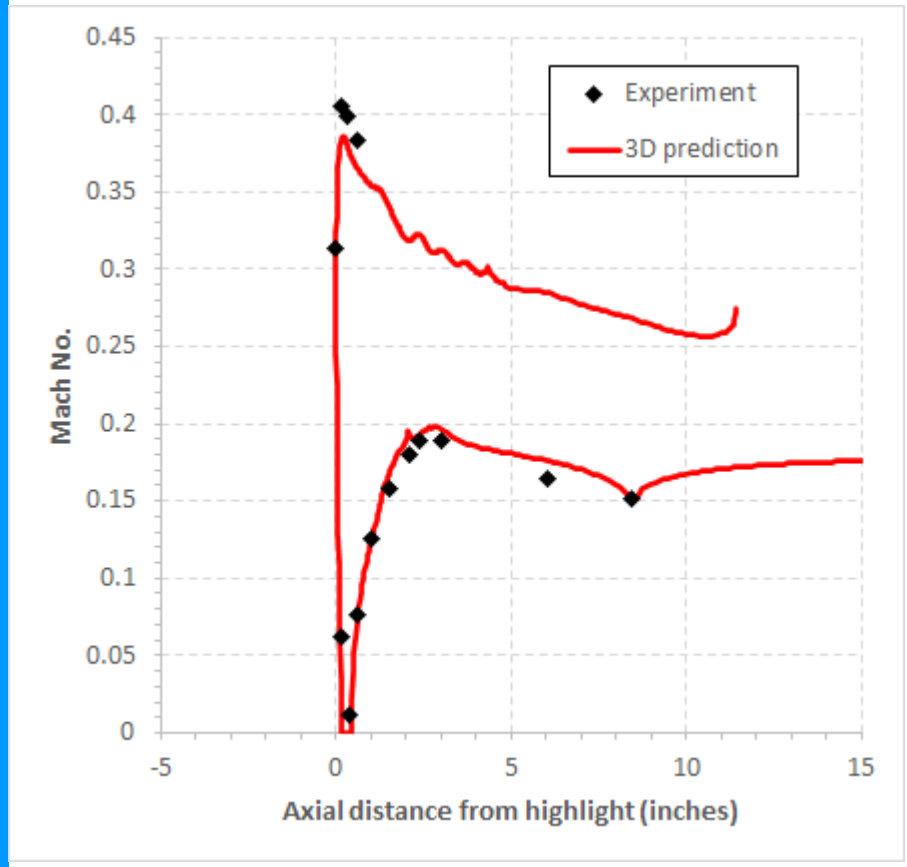
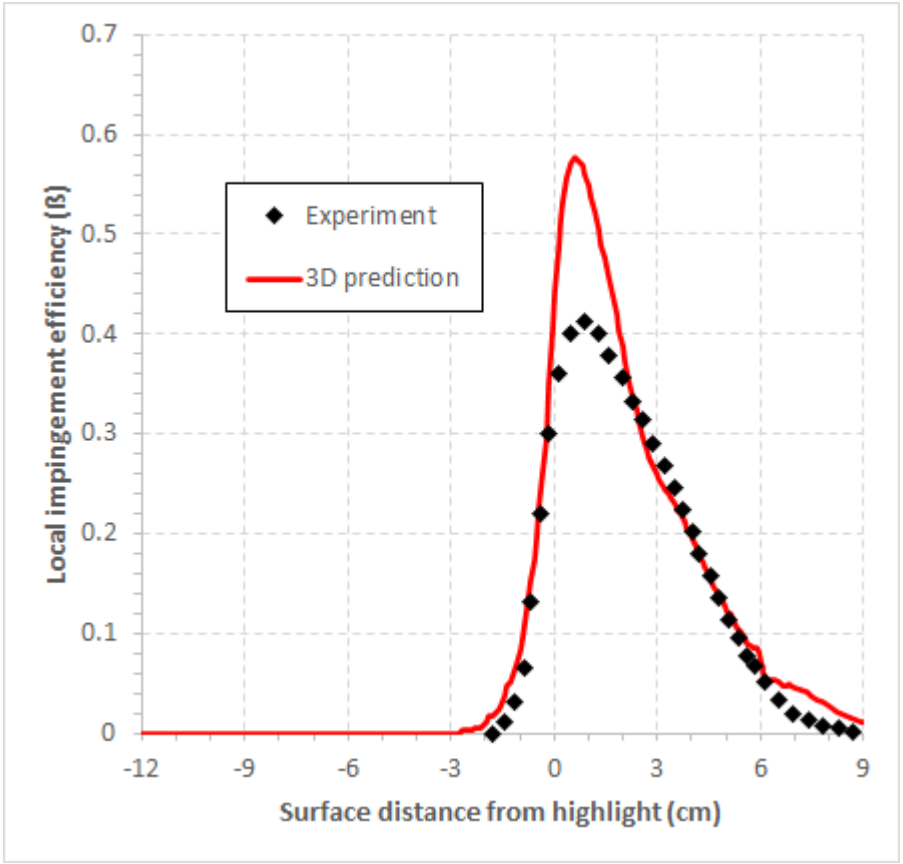
Case 131 and 132

- Axisymmetric inlet, α = 15°
  - Case 131 is lower mass flow (7.8kg/s)
  - Case 132 is higher mass flow (10.41kg/s)
- Both cases are MVD = 20 microns (7-bin)
- Modelled within IRT, including walls
- 6.57 million cells
- Solver times:
  - Meshing = 600s (00:10:00)
  - Aerodynamics = 6867s (01:54:27)
  - Impingement = 3376s (00:56:16)

Case 131

- Theta 0 deg.





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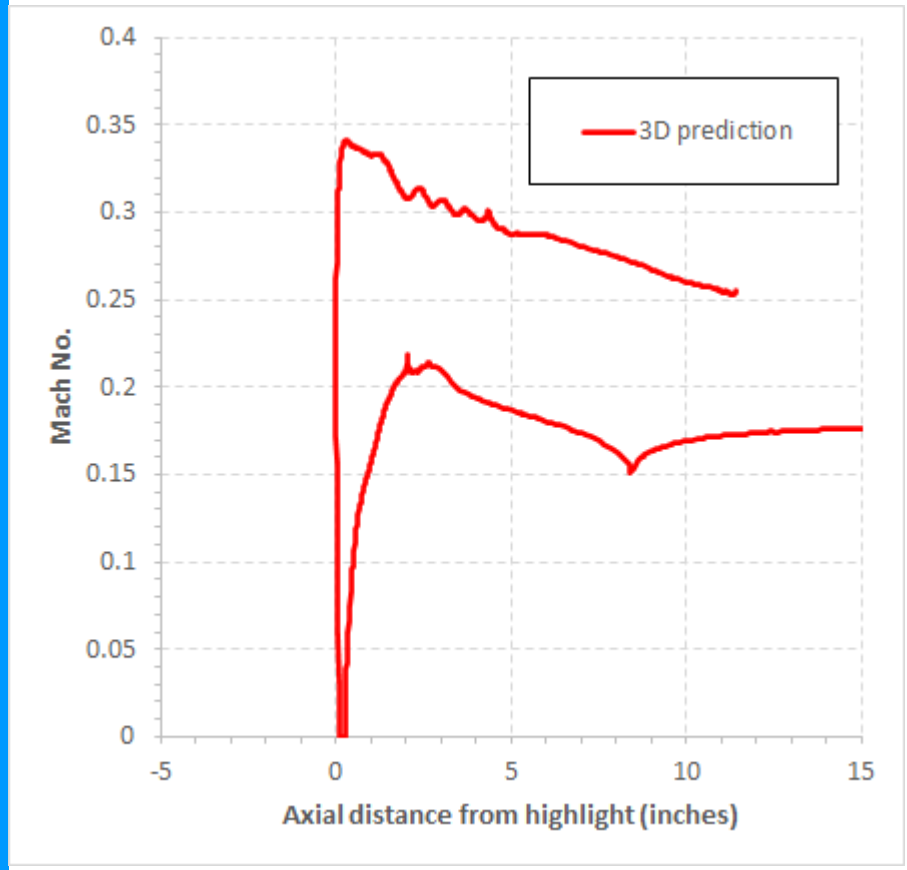
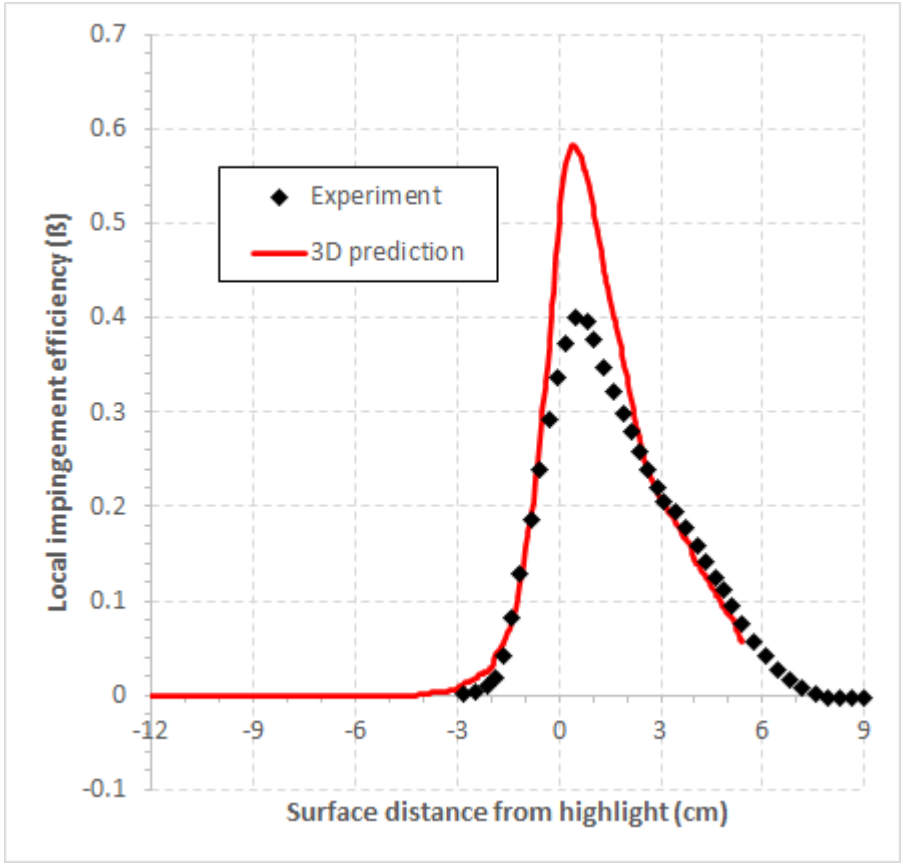
Case 131 (cont.)

- Theta 45 deg.





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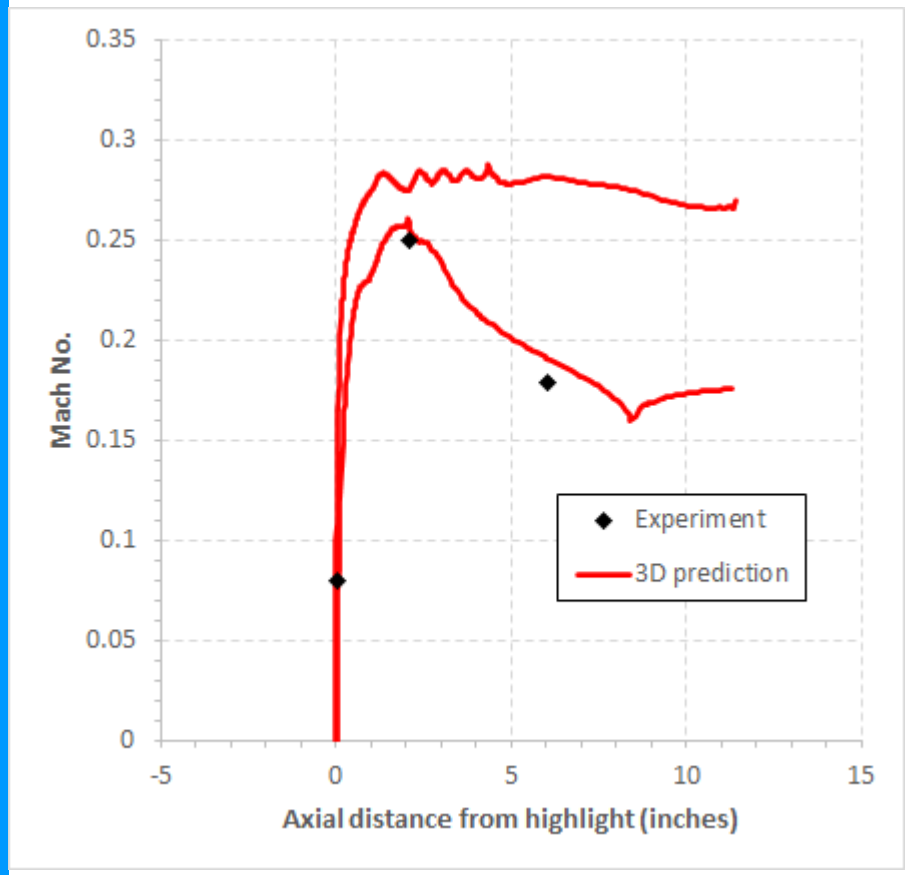
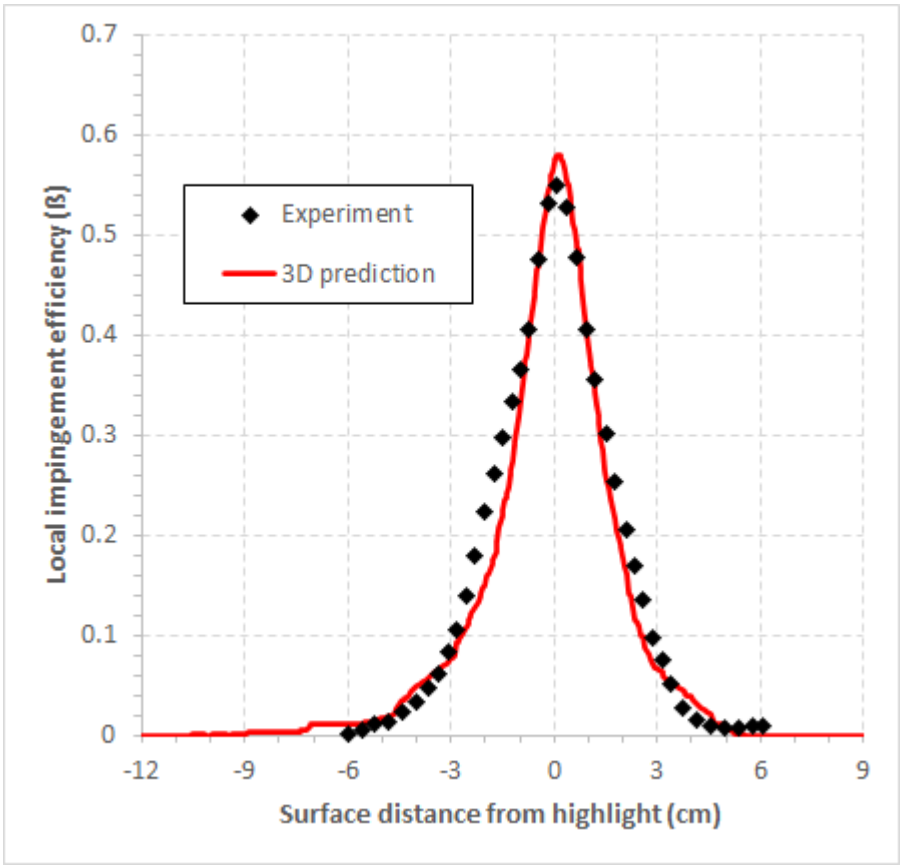
Case 131 (cont.)

- Theta 90 deg.





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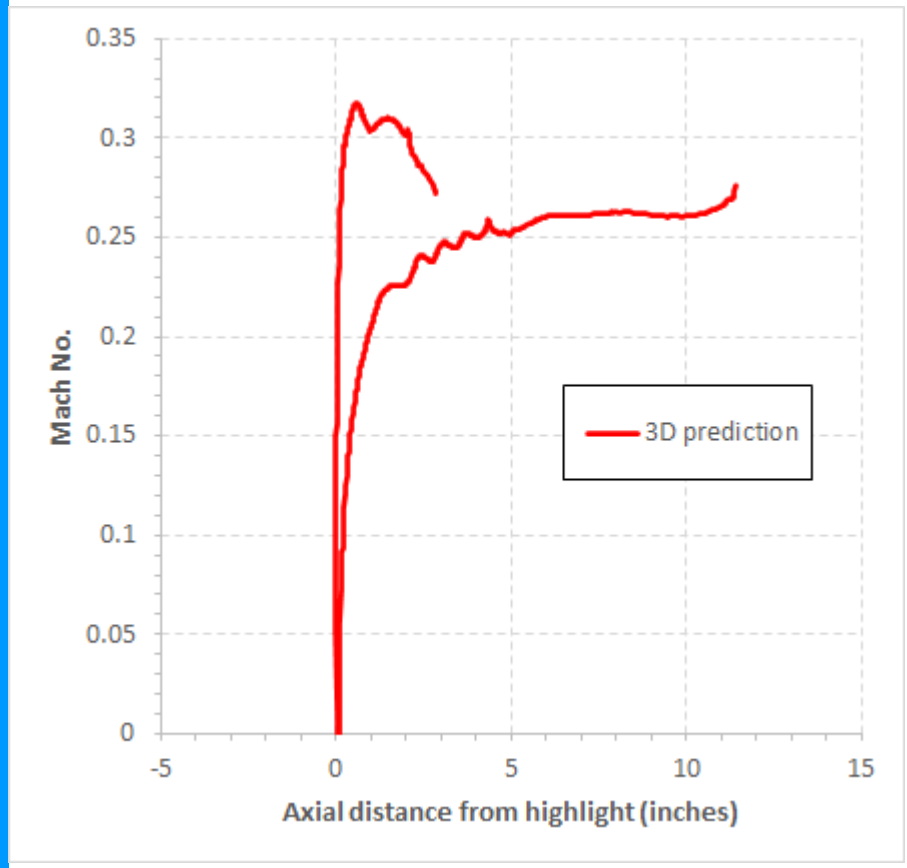
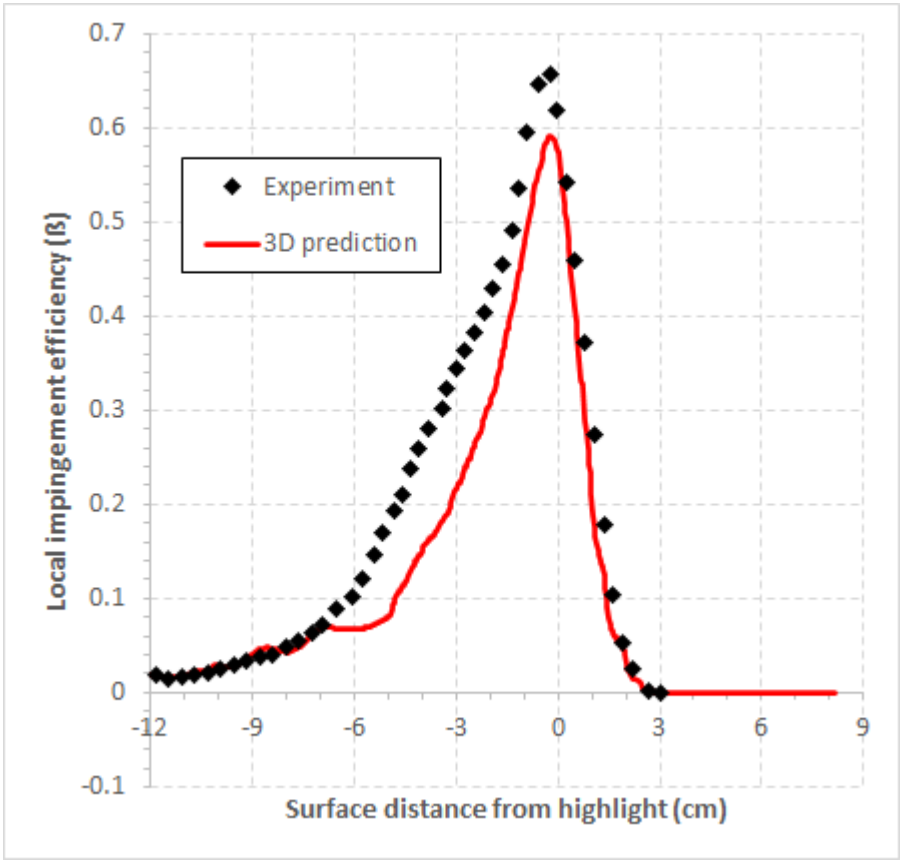
Case 131 (cont.)

- Theta 135 deg.





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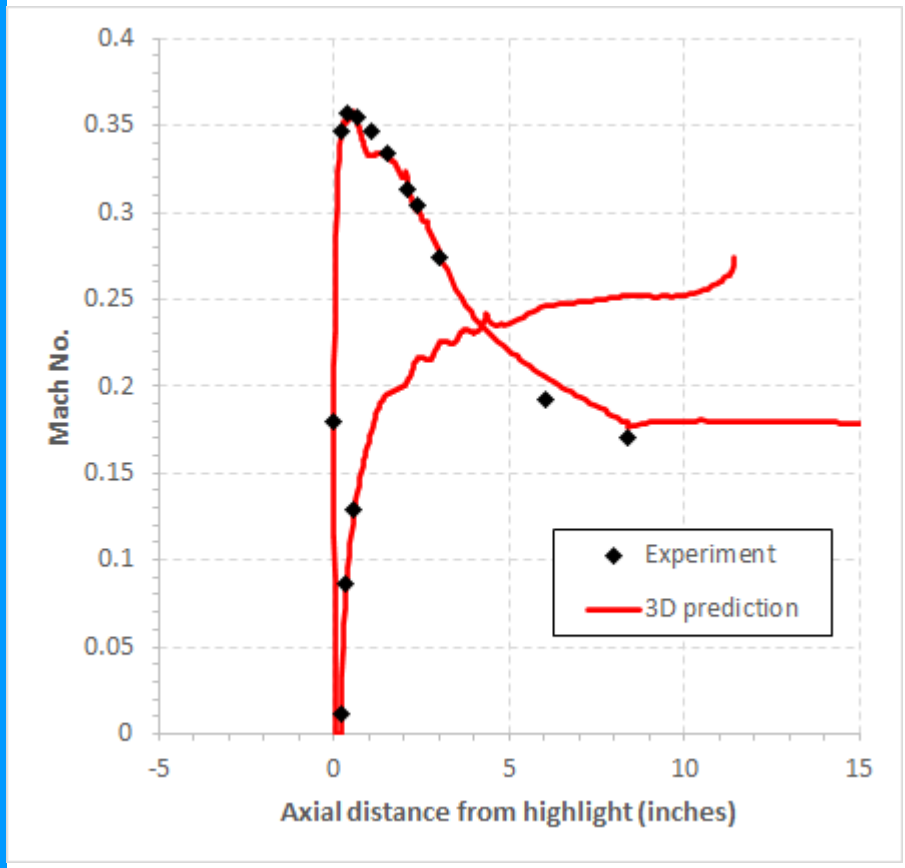
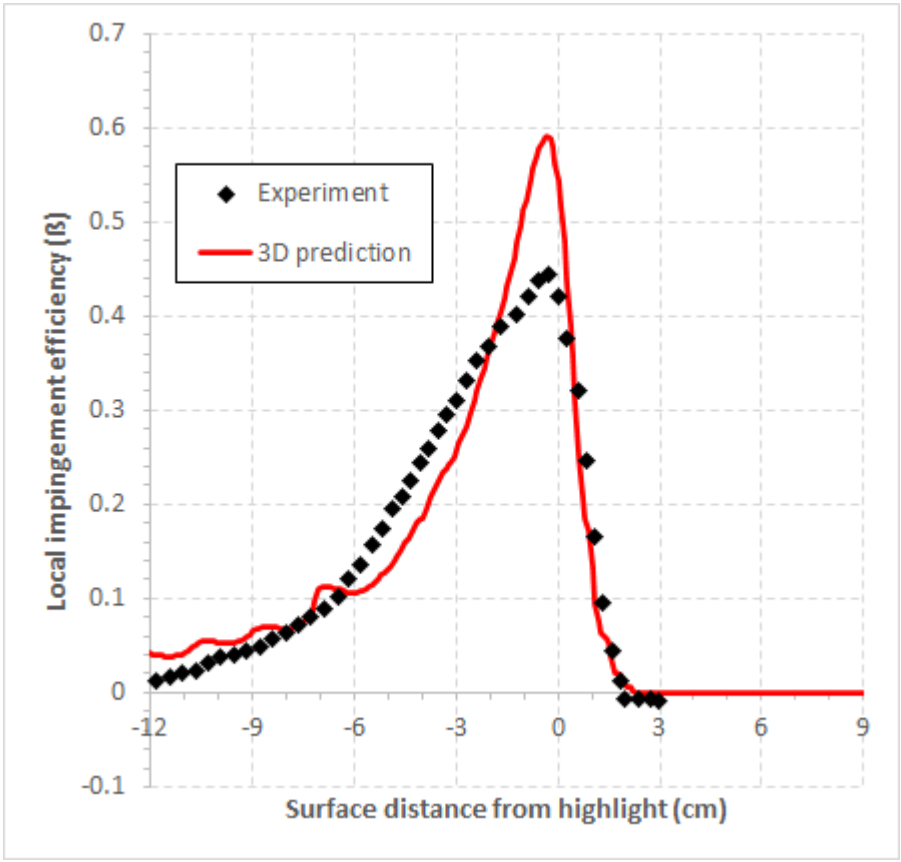
Case 131 (cont.)

- Theta 180 deg.





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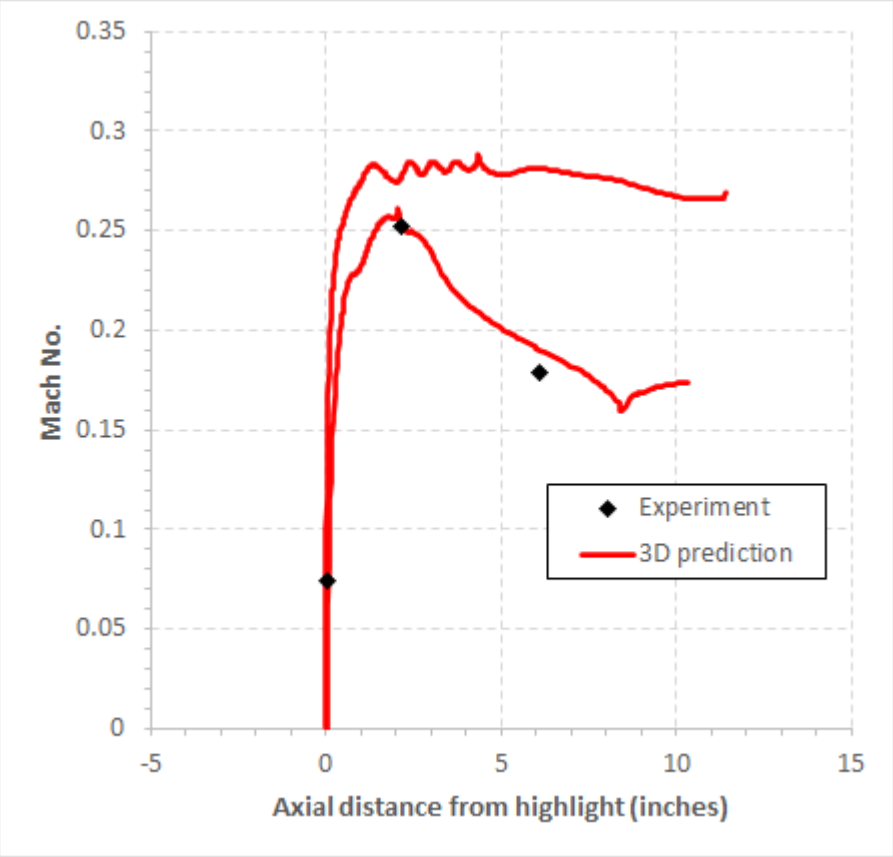
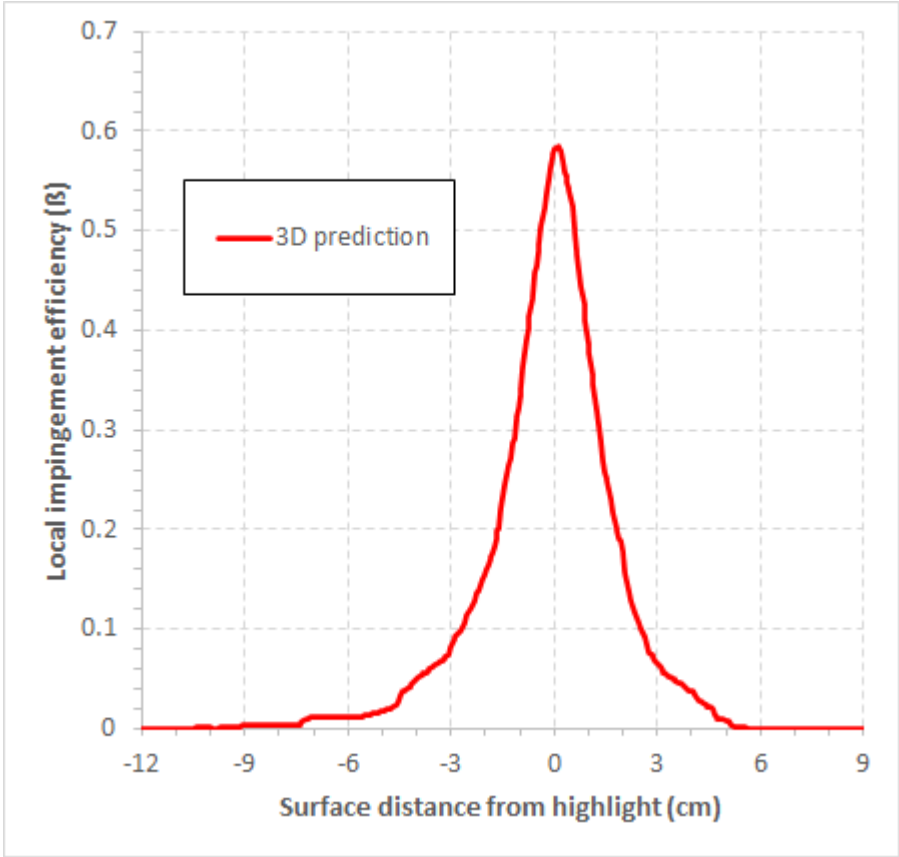
Case 131 (cont.)

- Theta 270 deg.





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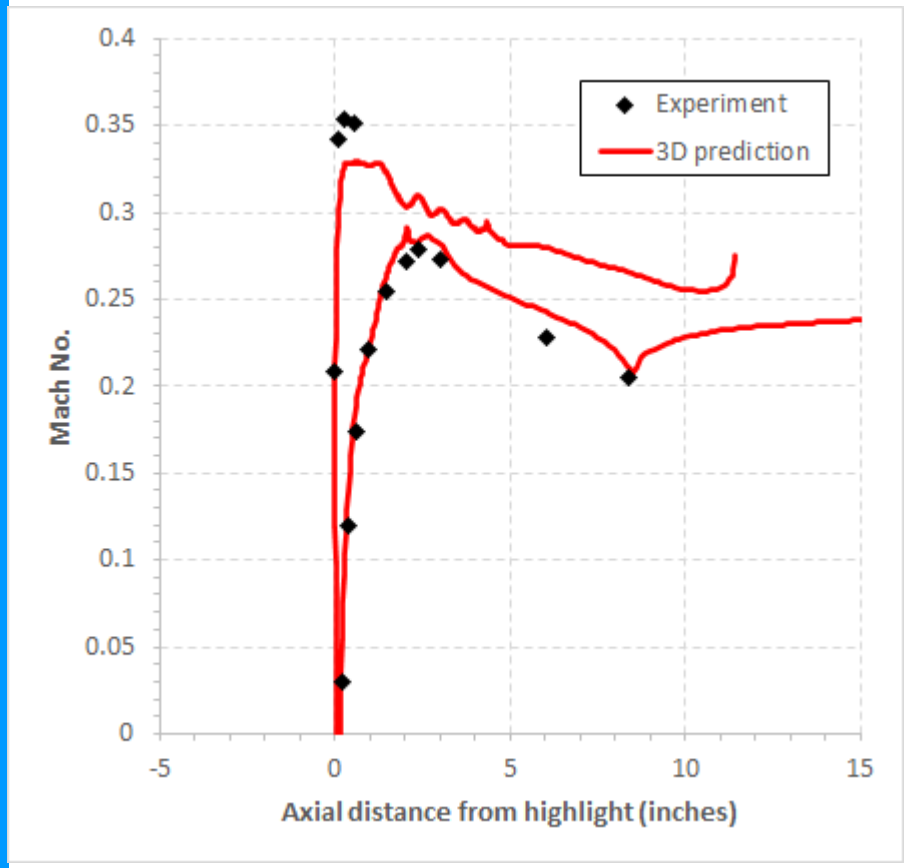
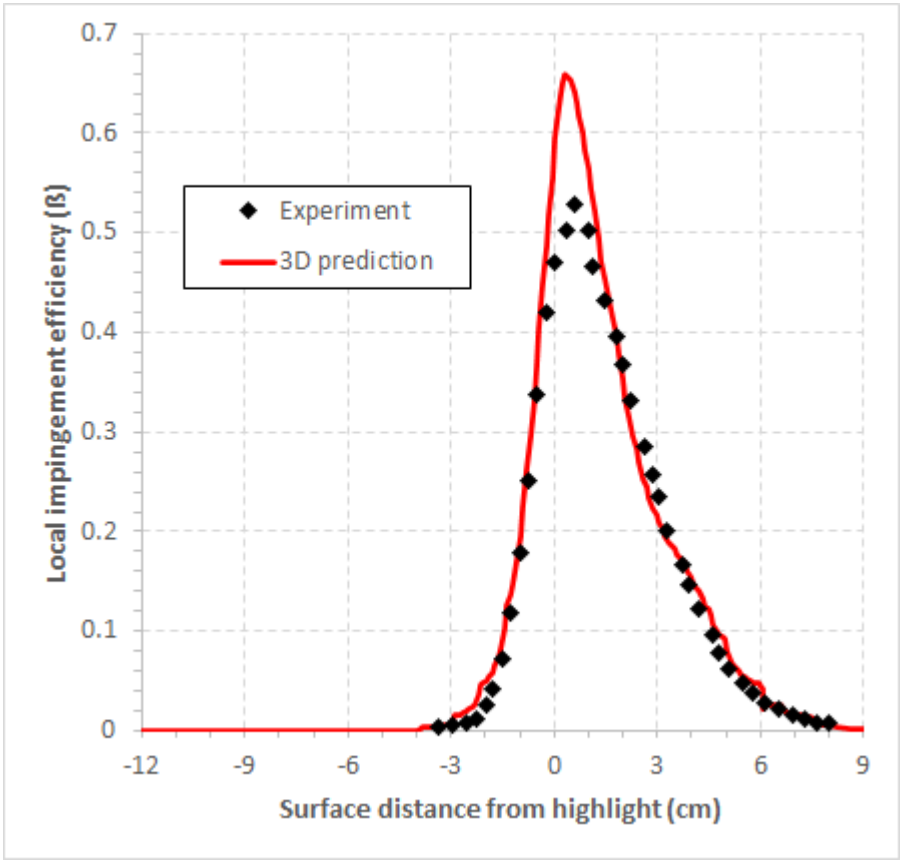
Case 132

- Theta 0 deg.





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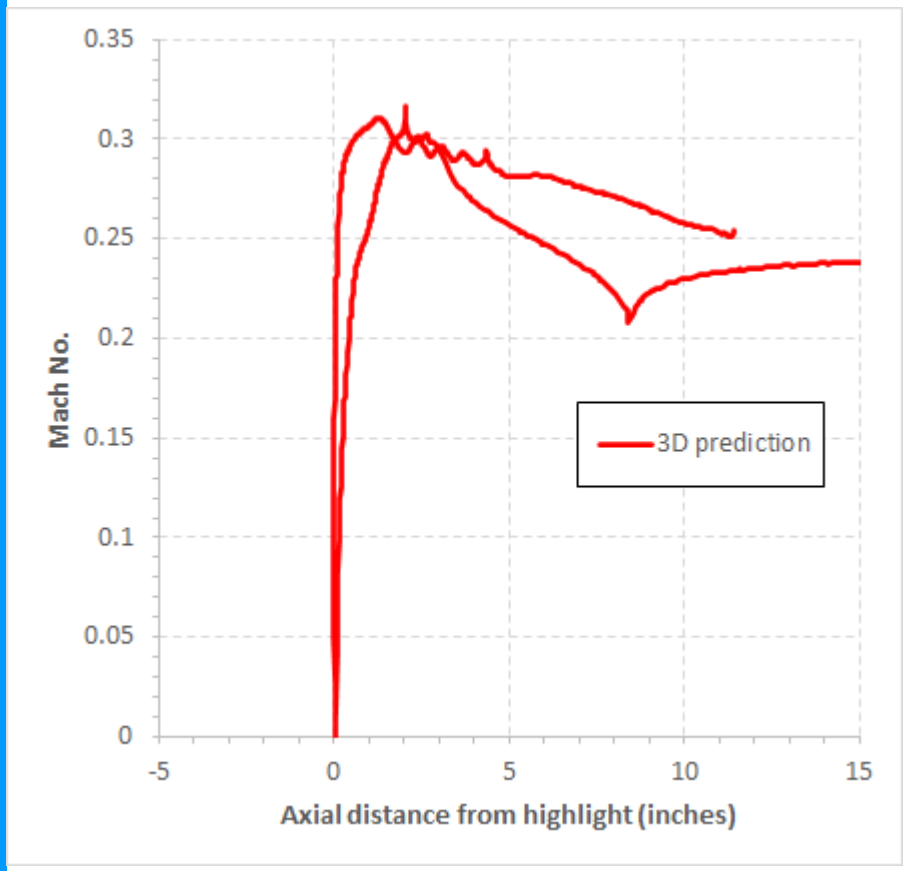
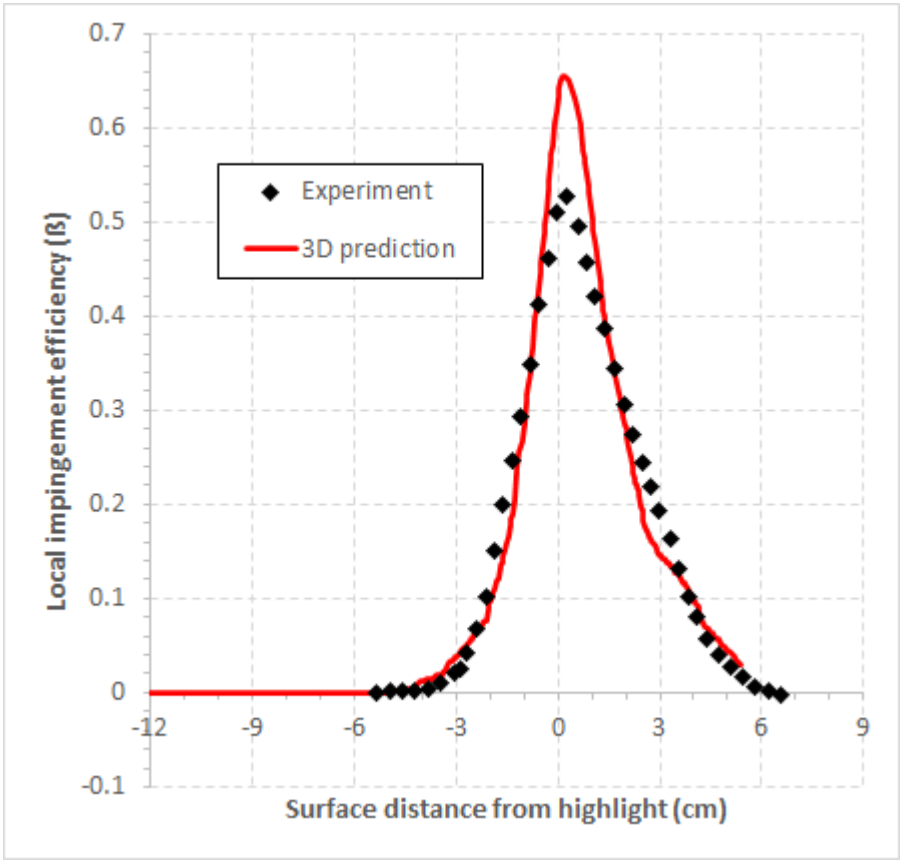
Case 132 (cont.)

- Theta 45 deg.





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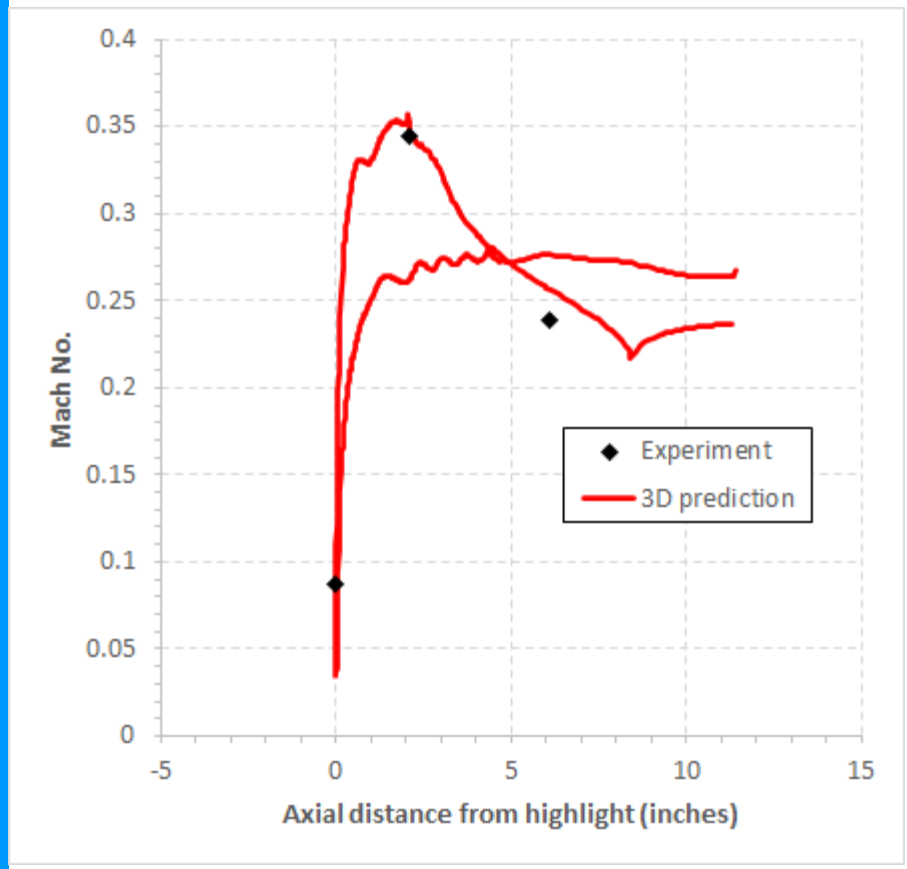
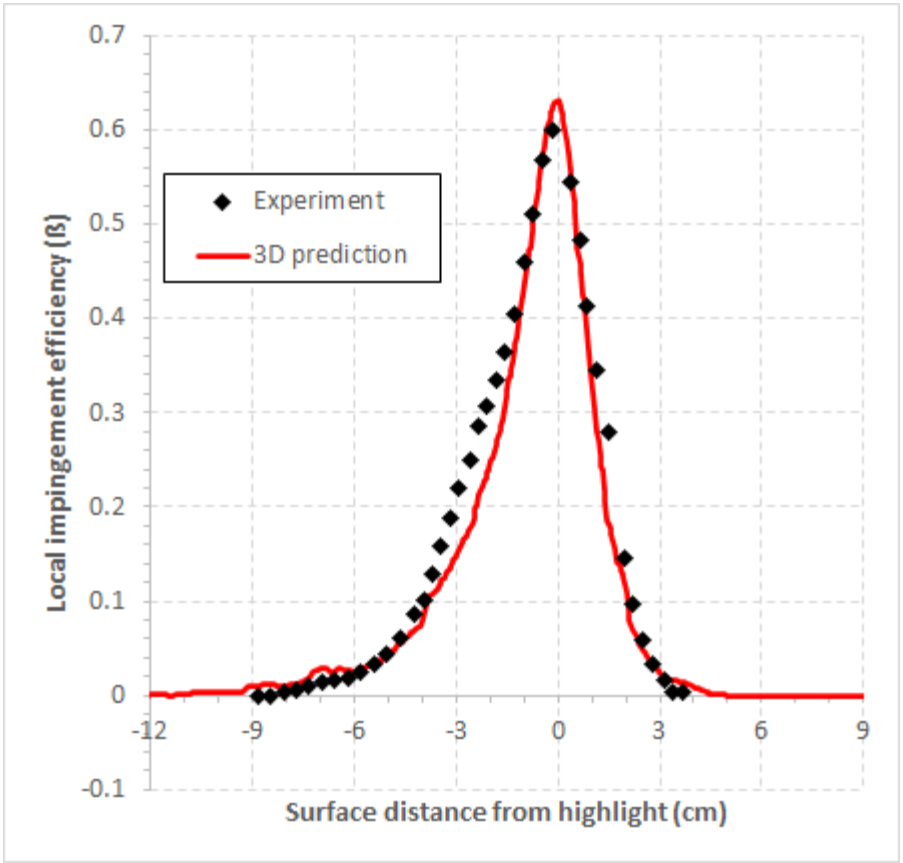
Case 132 (cont.)

- Theta 90 deg.





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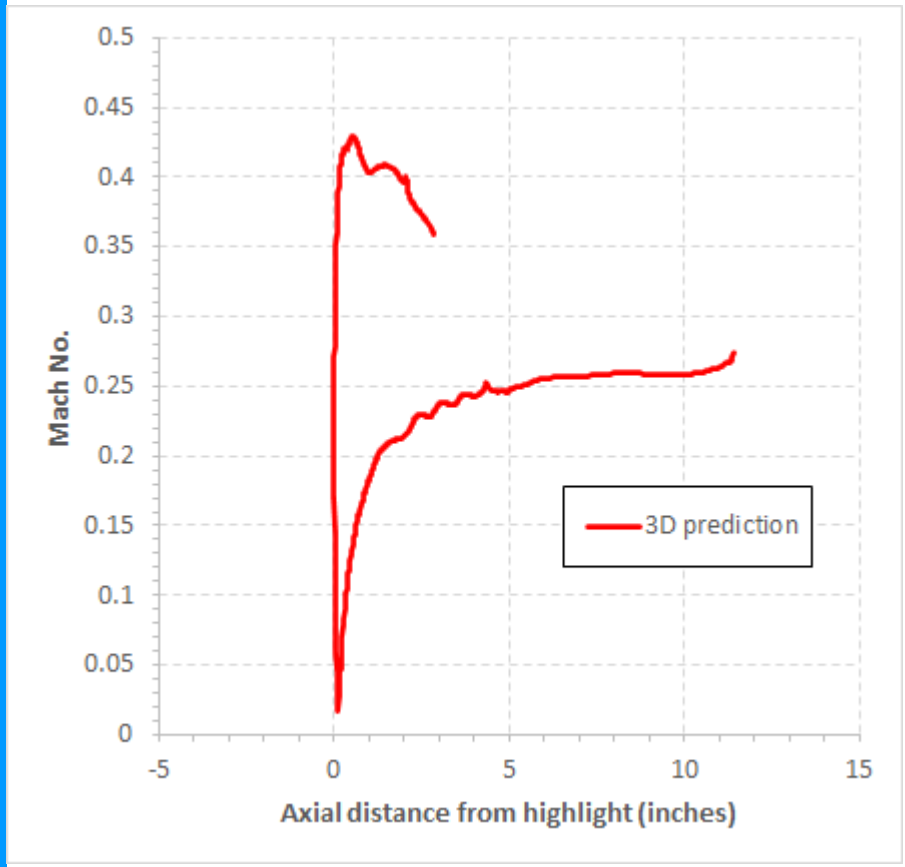
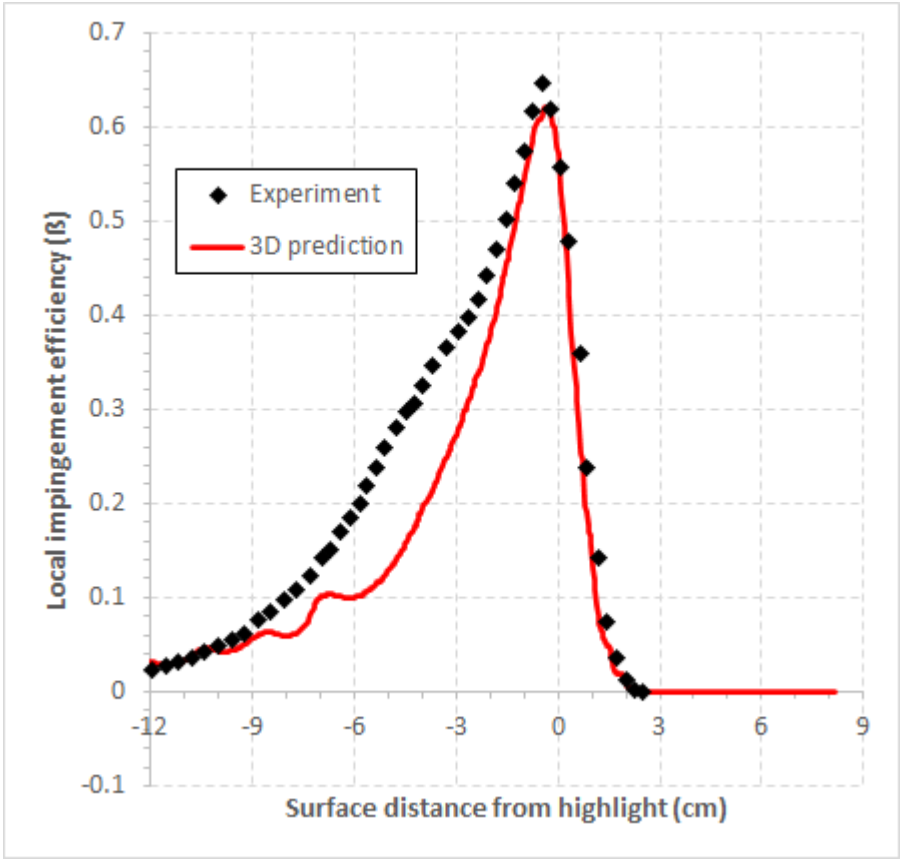
Case 132 (cont.)

- Theta 135 deg.





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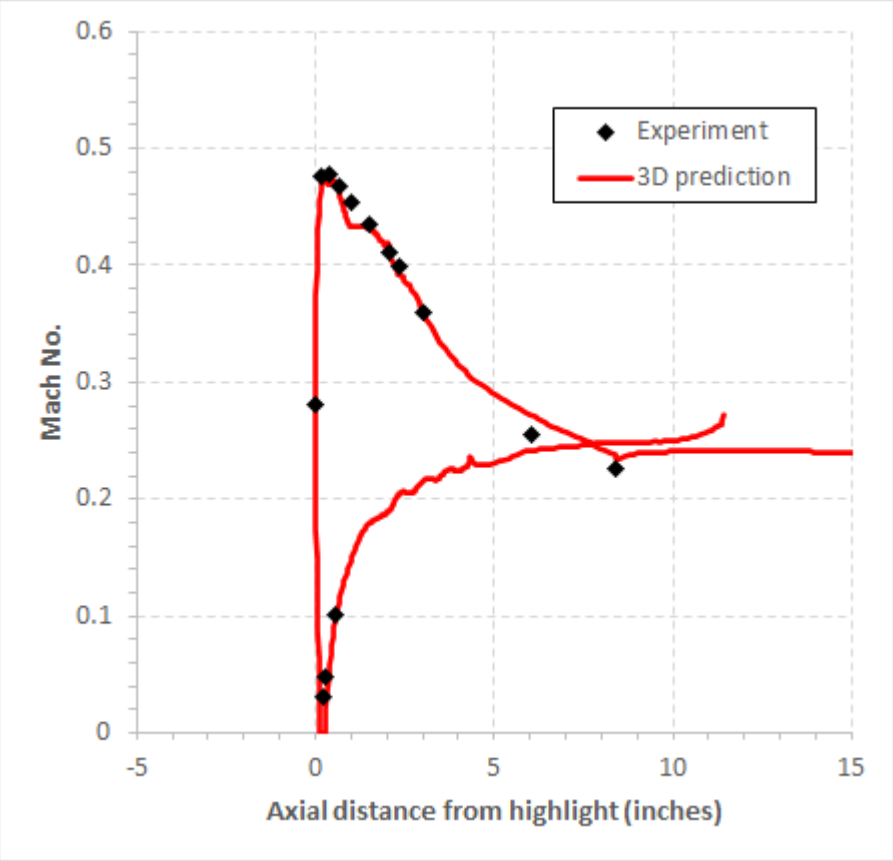
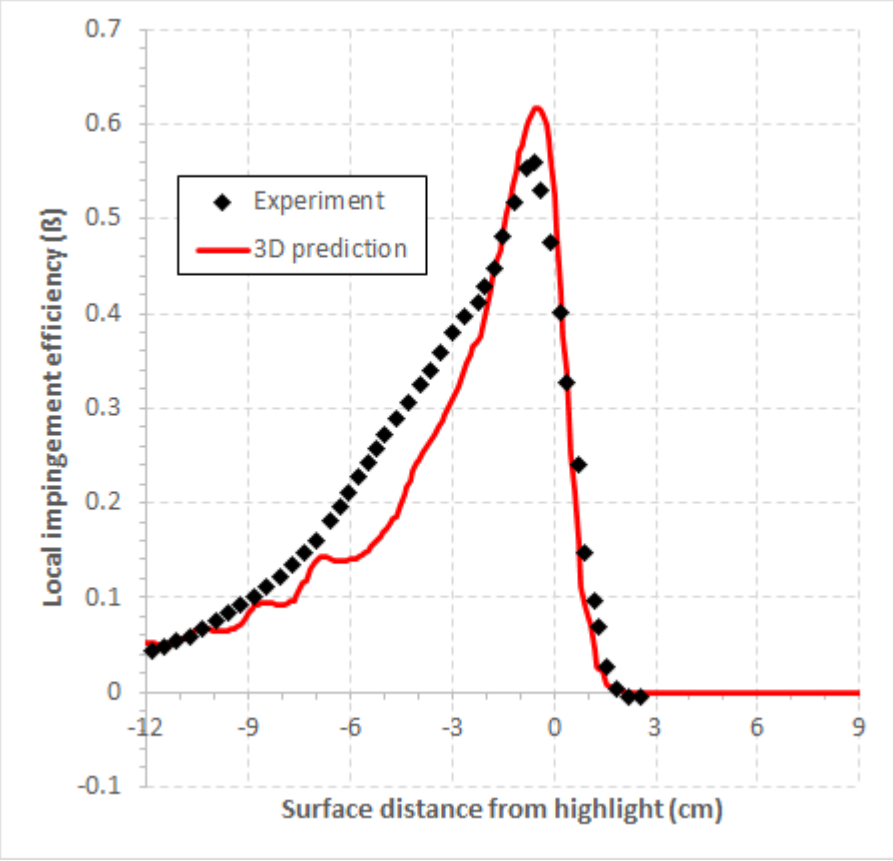
Case 132 (cont.)

- Theta 180 deg.





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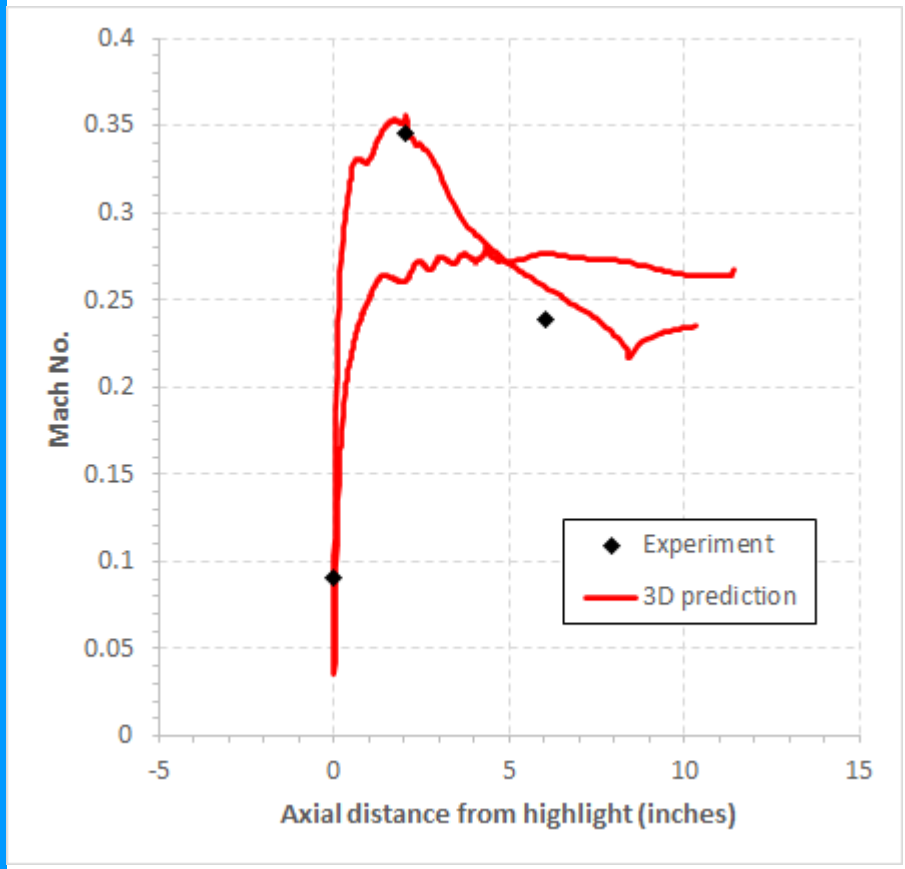
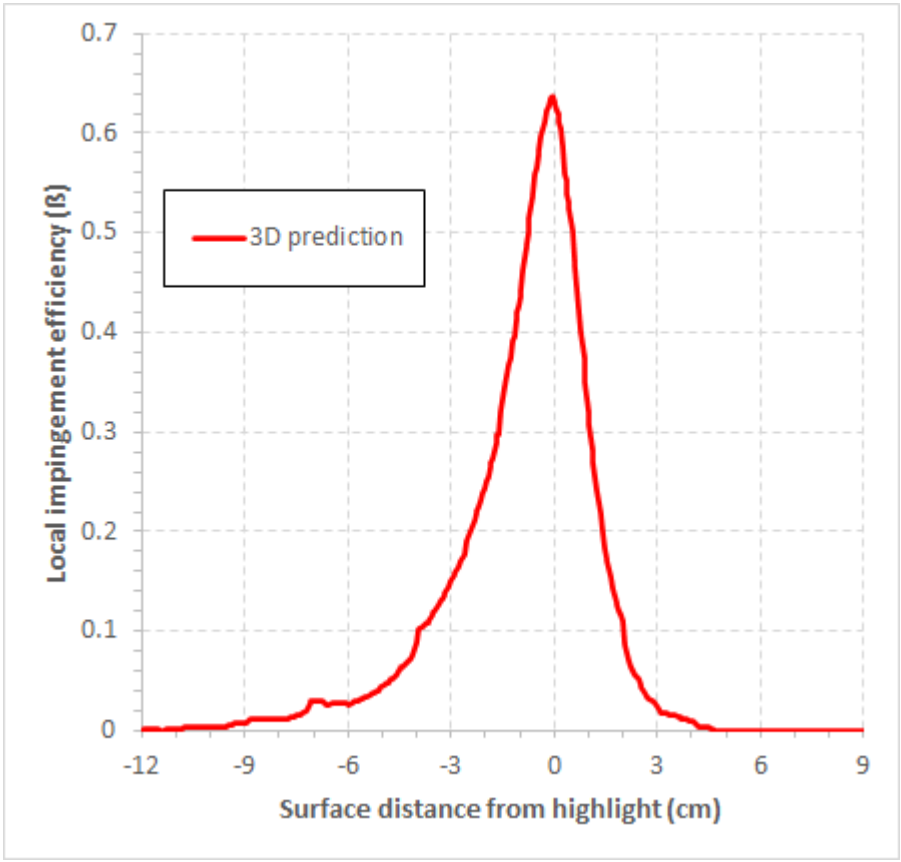
Case 132 (cont.)

- Theta 270 deg.





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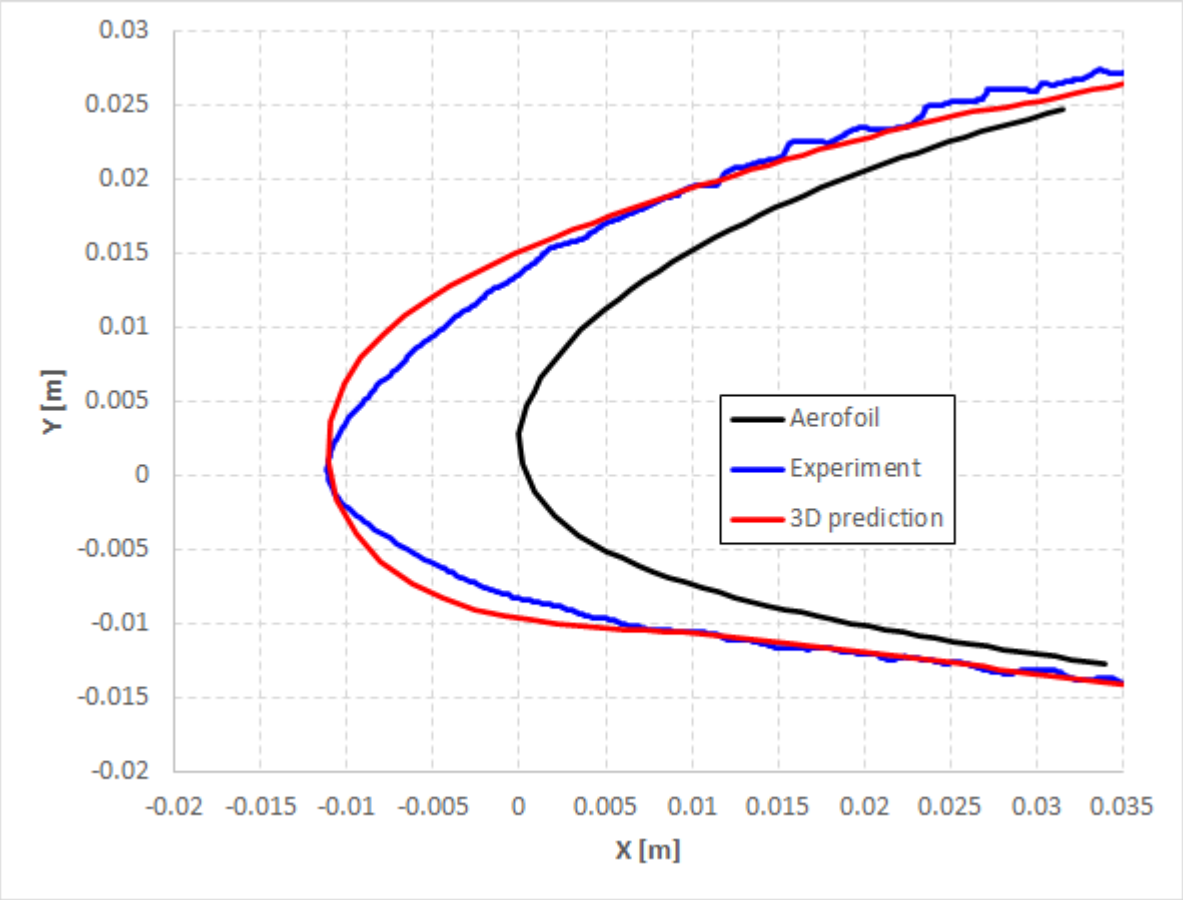
ICE ACCRETION CASES

Case 241 and 242

- 18-inch NACA23012, $\alpha = 2°$
  - Case 241 is MVD = 30microns, LWC = 0.42g/m^3, SAT = -23C
  - Case 242 is MVD = 15microns, LWC = 0.81g/m^3, SAT = -7.1C
- Modelled within IRT, including walls (3D)
- 8.40 million cells

Case 241

- Ice shape



Ice mass = 0.36kg/m

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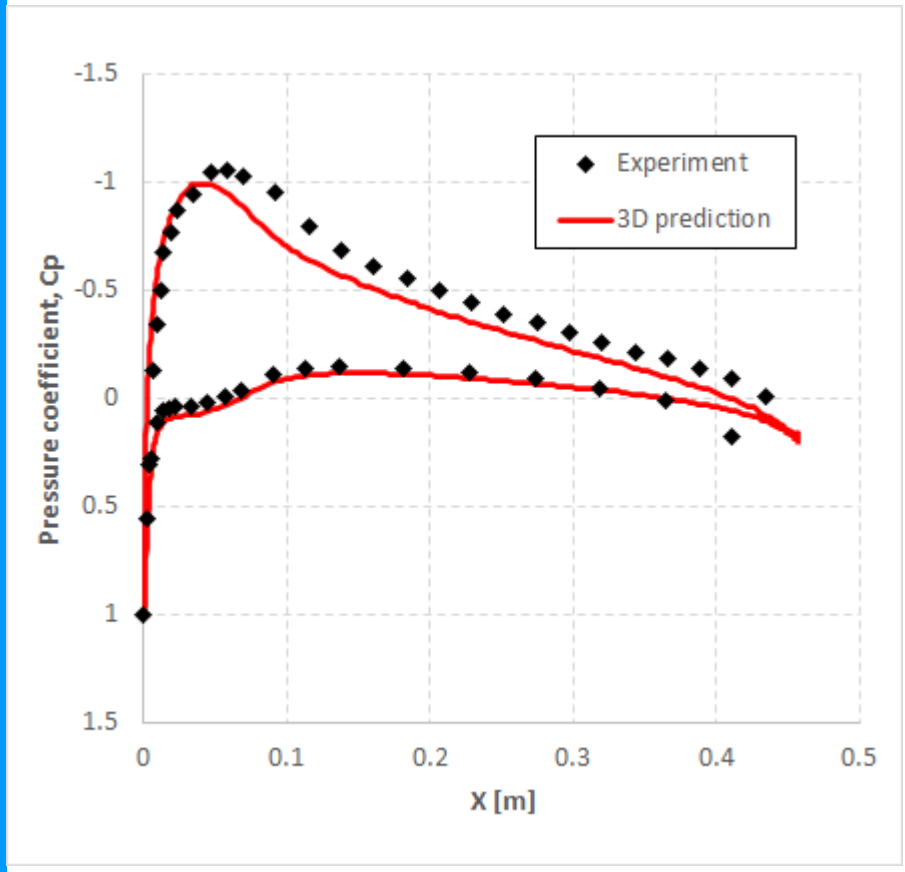
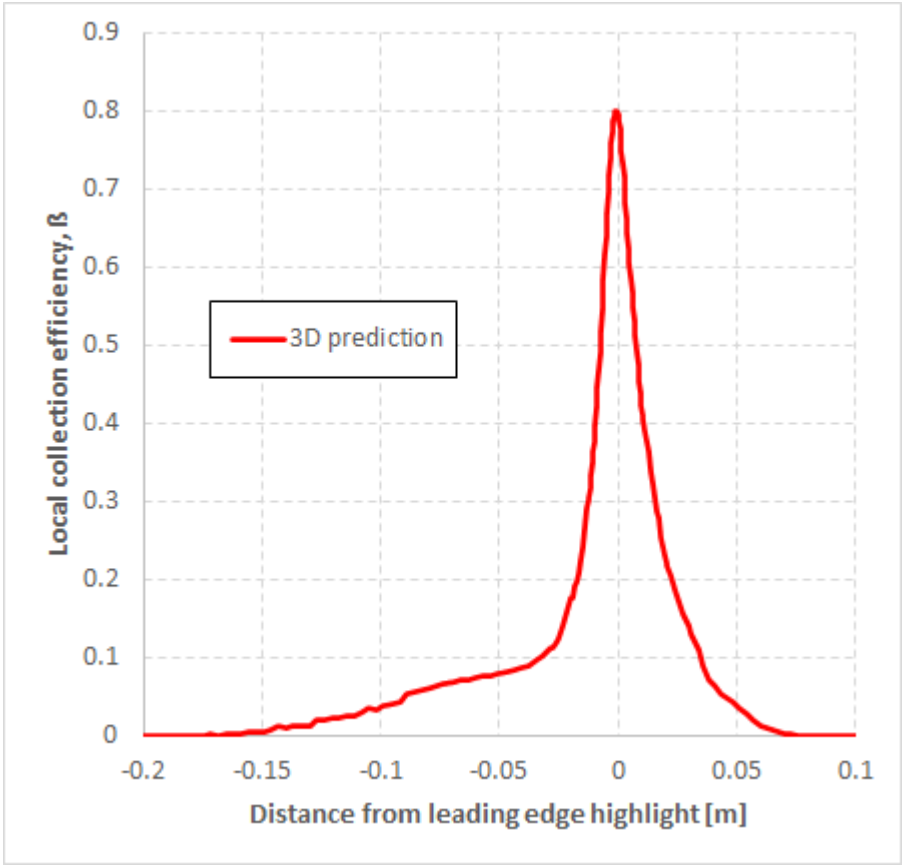
Case 241 (cont.)





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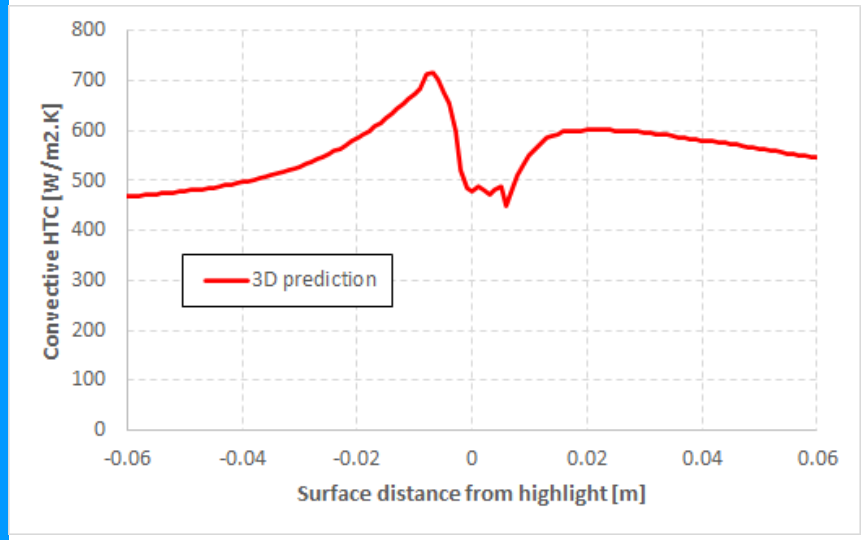
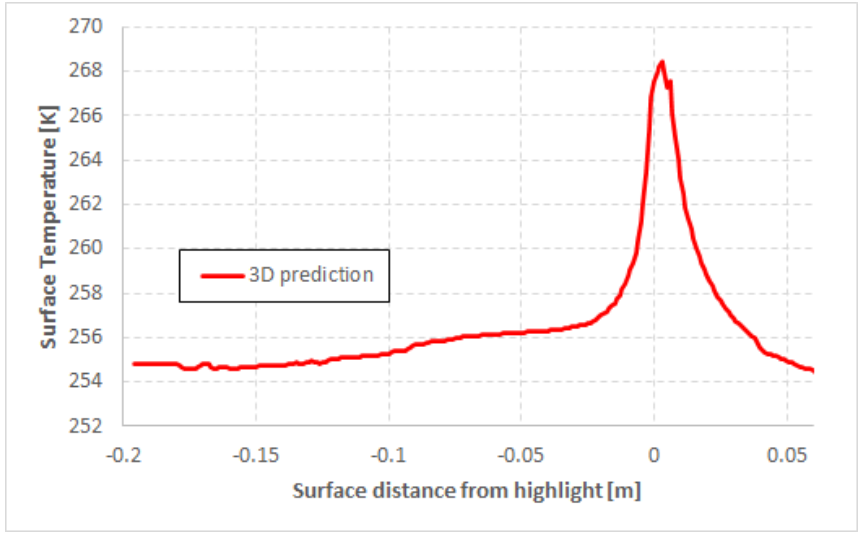
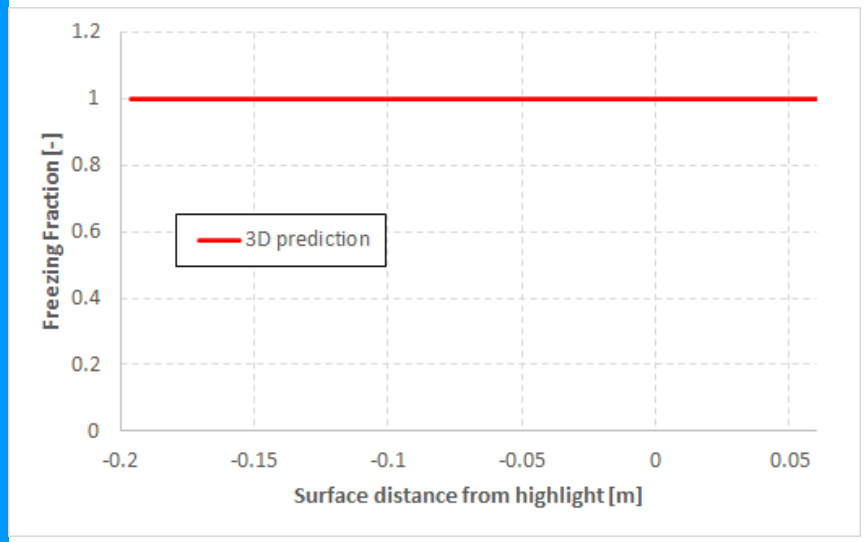
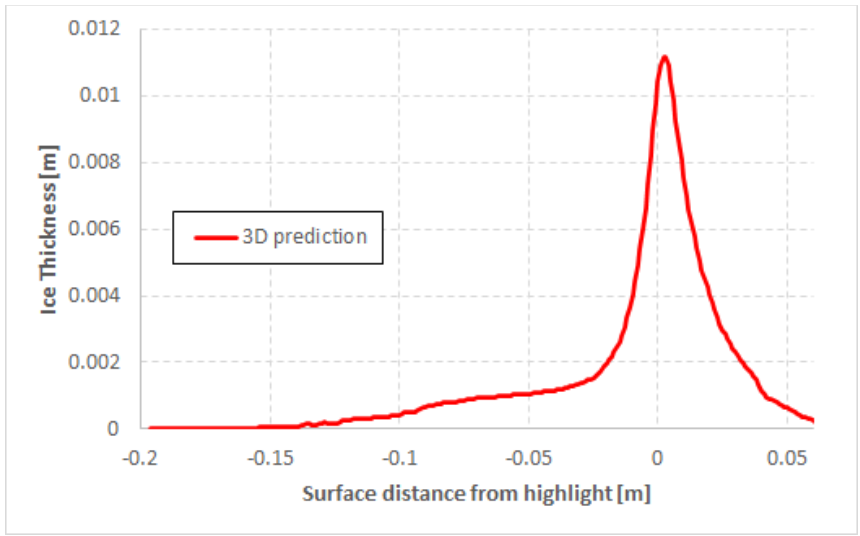
Case 241 (cont.)









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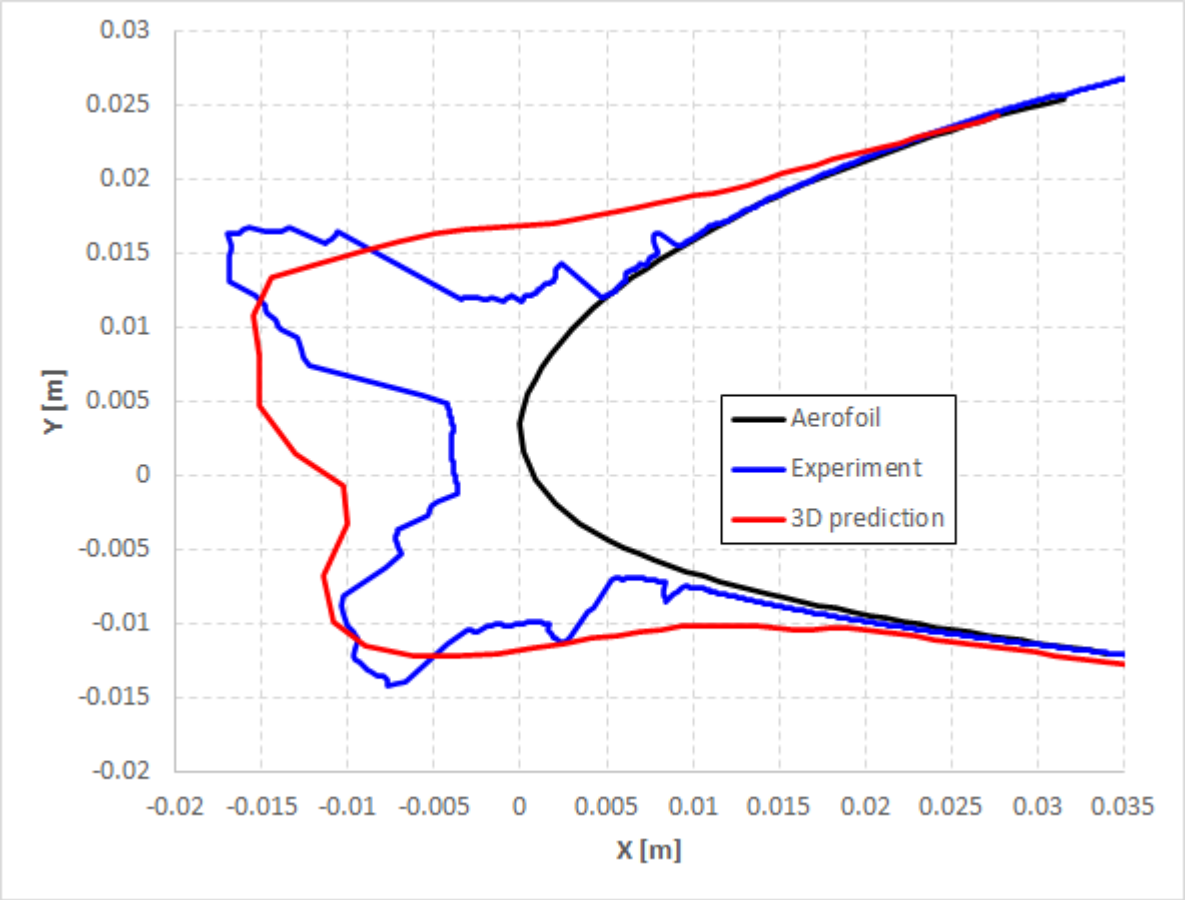
Case 242

- Ice shape



Ice mass = 0.35kg/m

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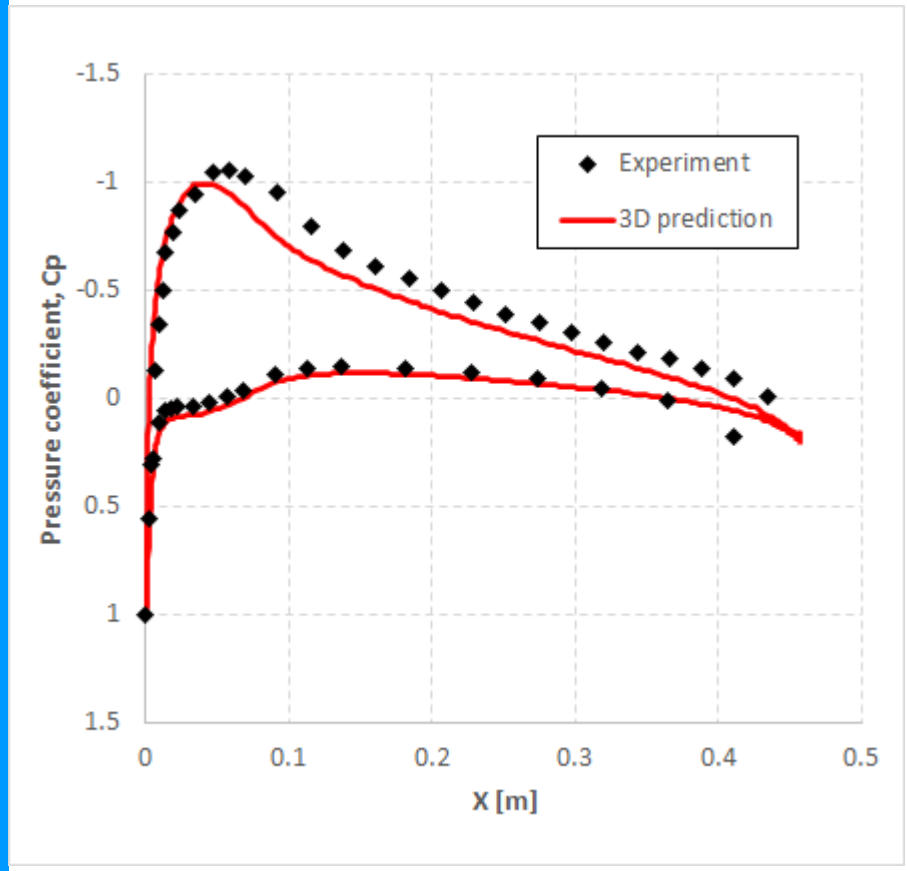
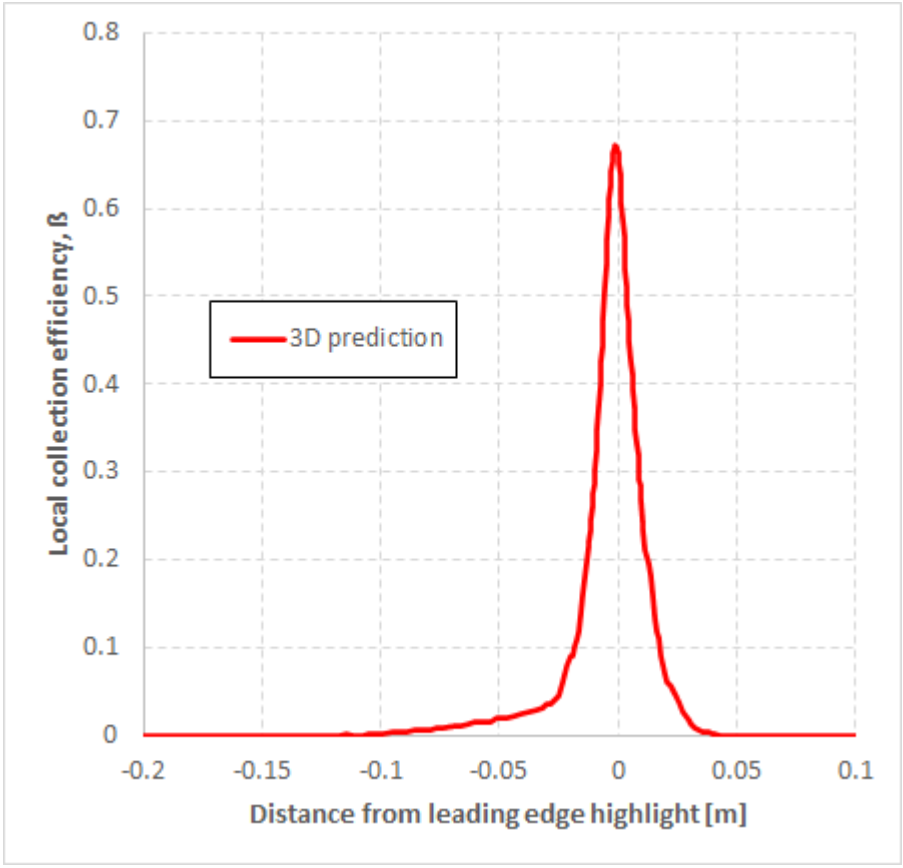
Case 242 (cont.)





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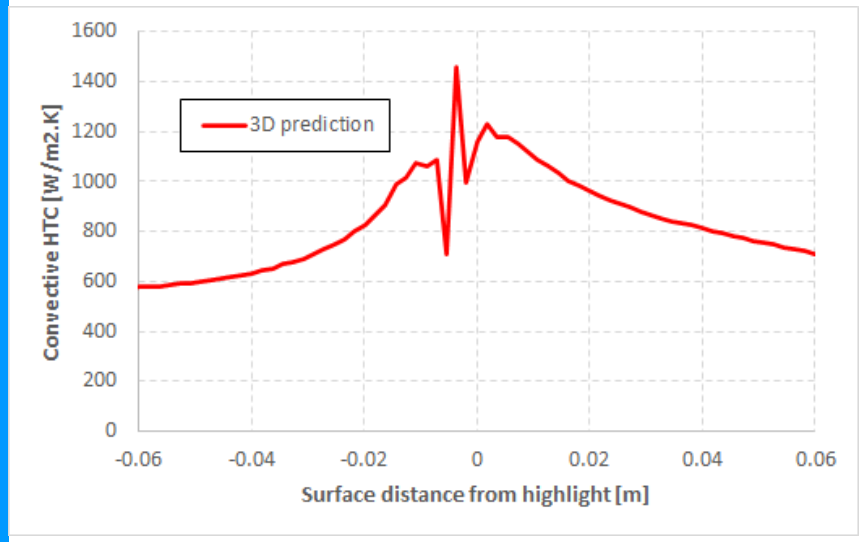
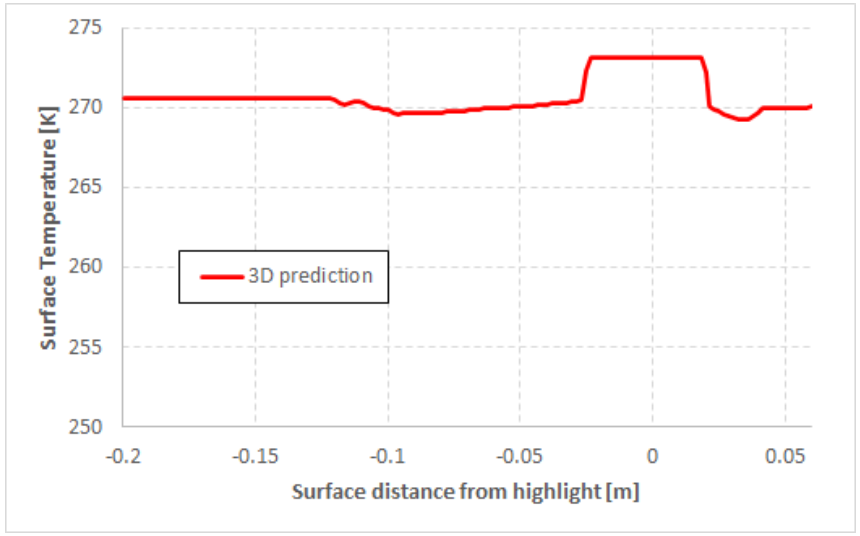
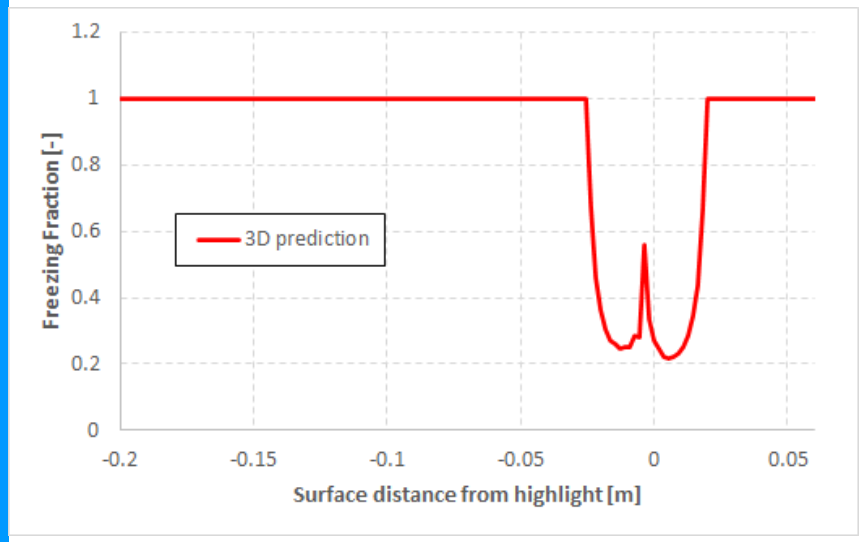
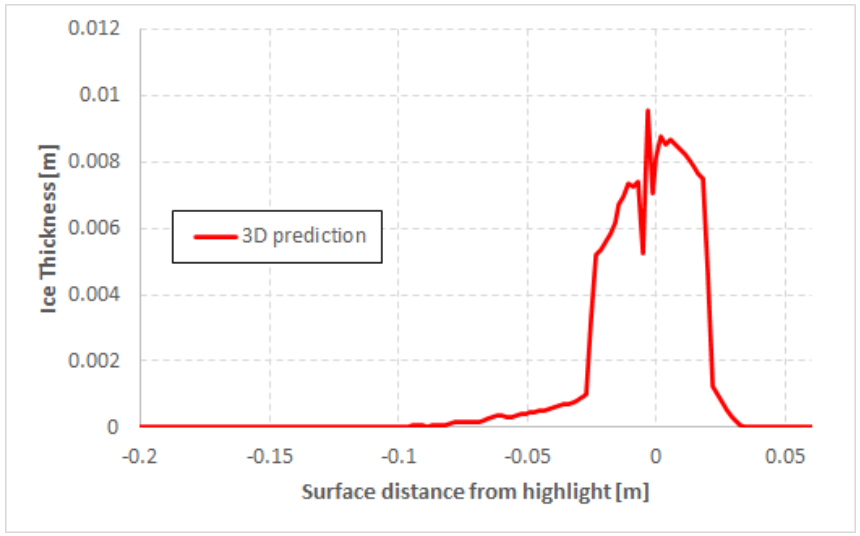
Case 242 (cont.)









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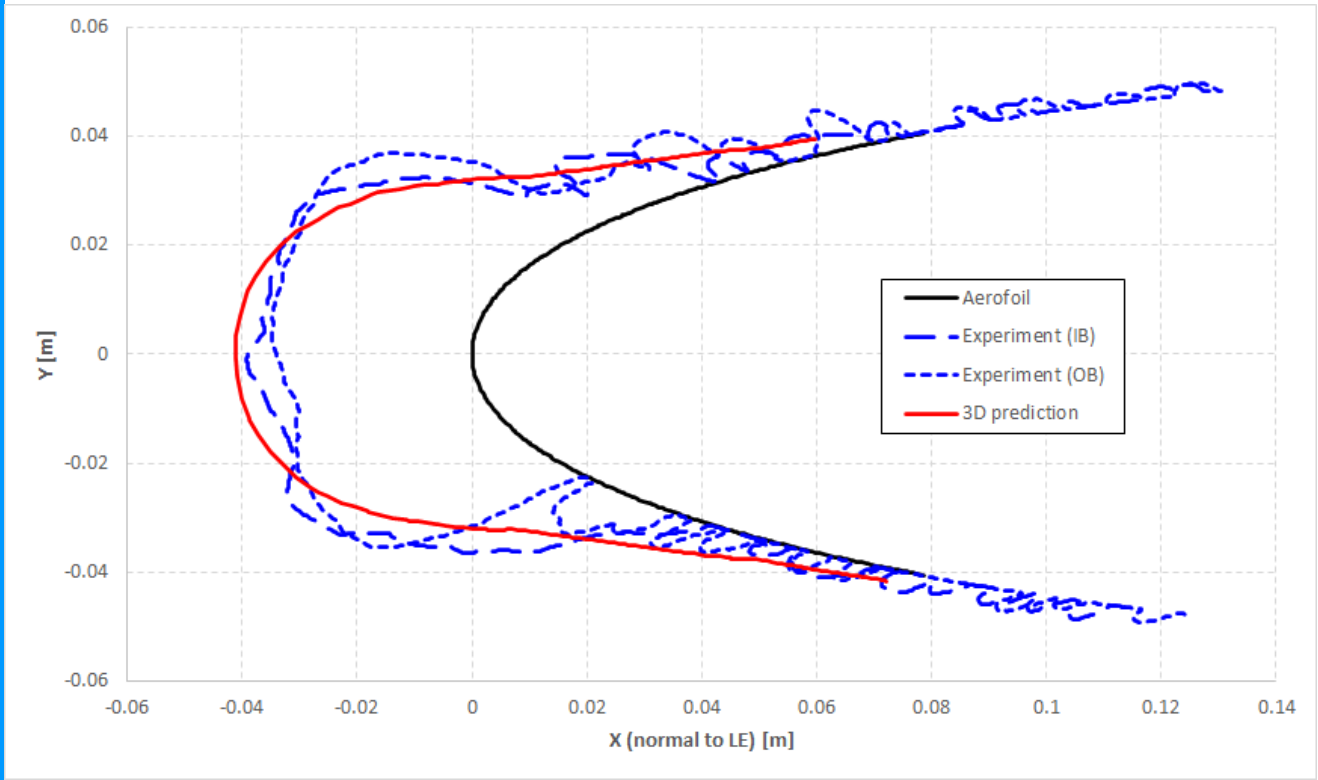
Case 361 and 362

- 30-degree swept NACA0012, $\alpha = 0°$
  - Case 361 is SAT = -16.15C
  - Case 362 is SAT = -7.15C
- Both cases are MVD = 34.7microns, 0.5g/m^3
- Modelled within IRT, including walls (3D)
- 11.80 million cells

Case 361

- Ice shape



Ice mass = 2.23kg/m

Experiment = 1.9kg/m

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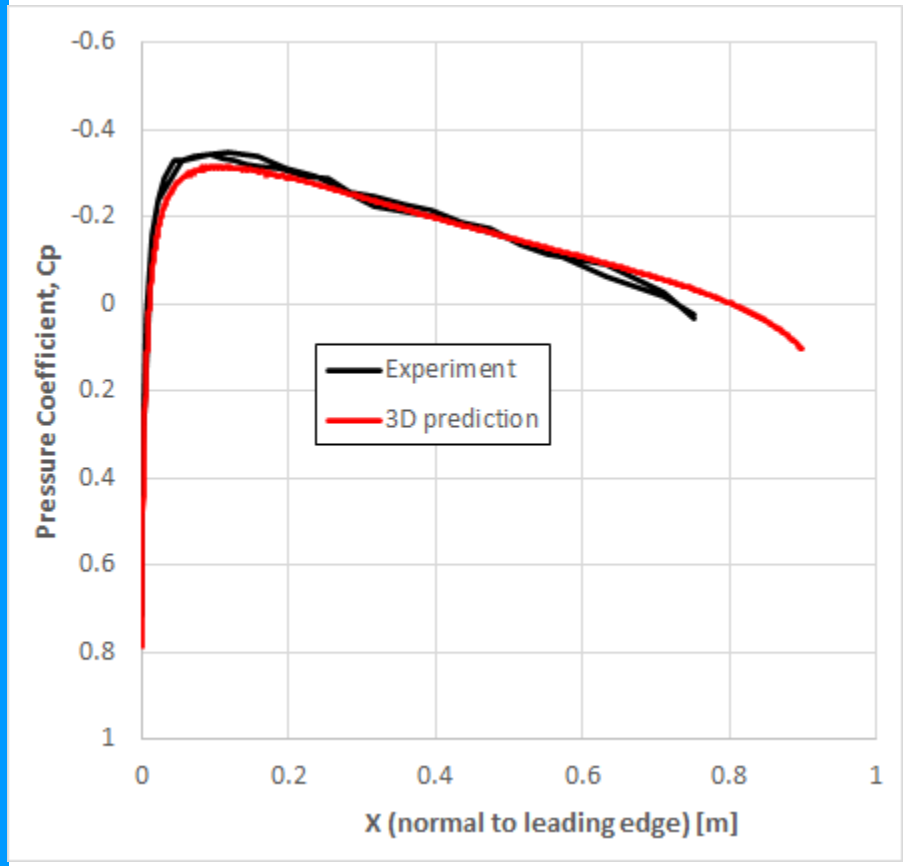
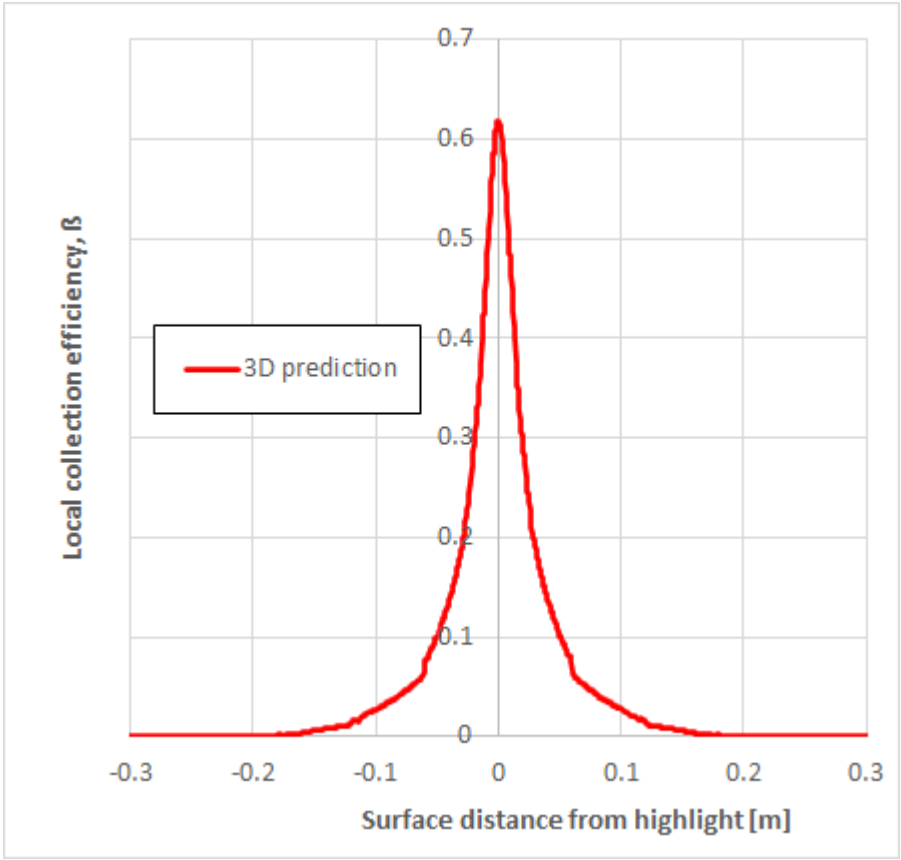
Case 361 (cont.)





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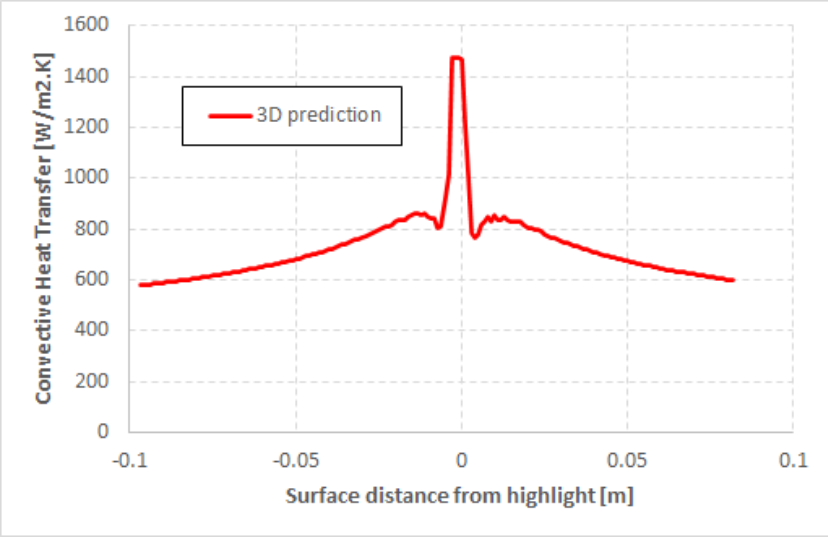
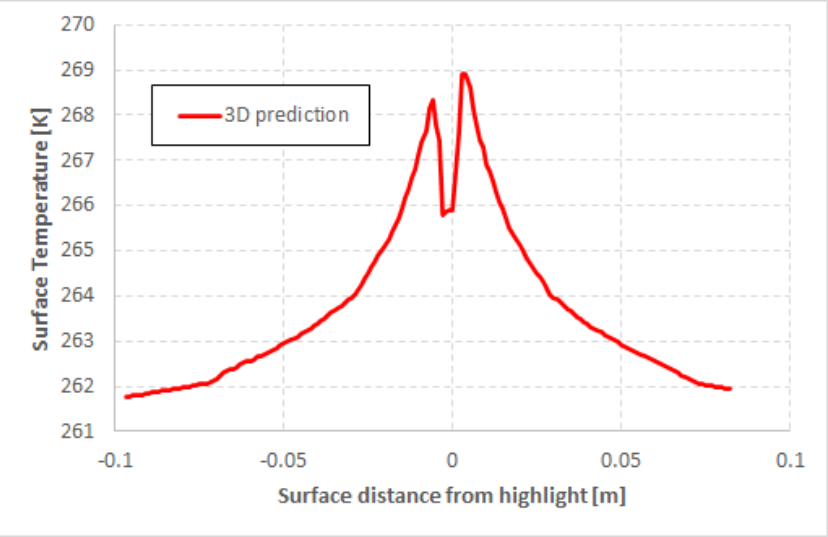
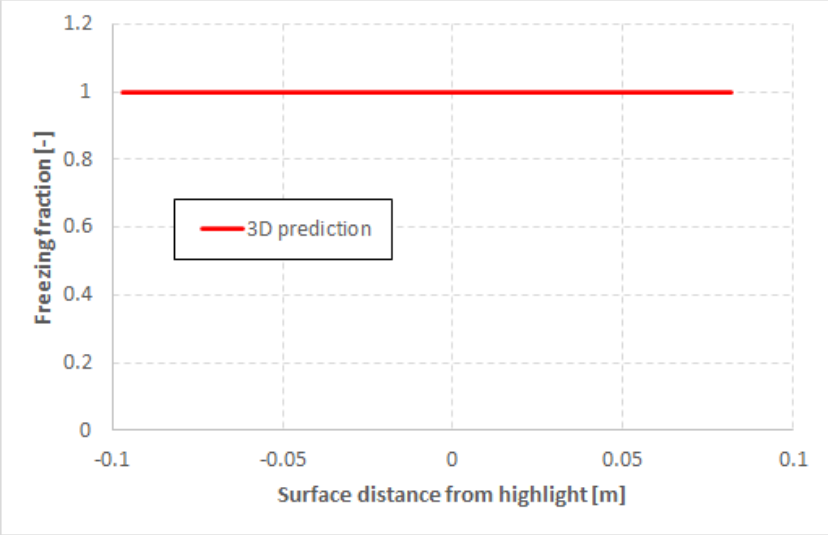
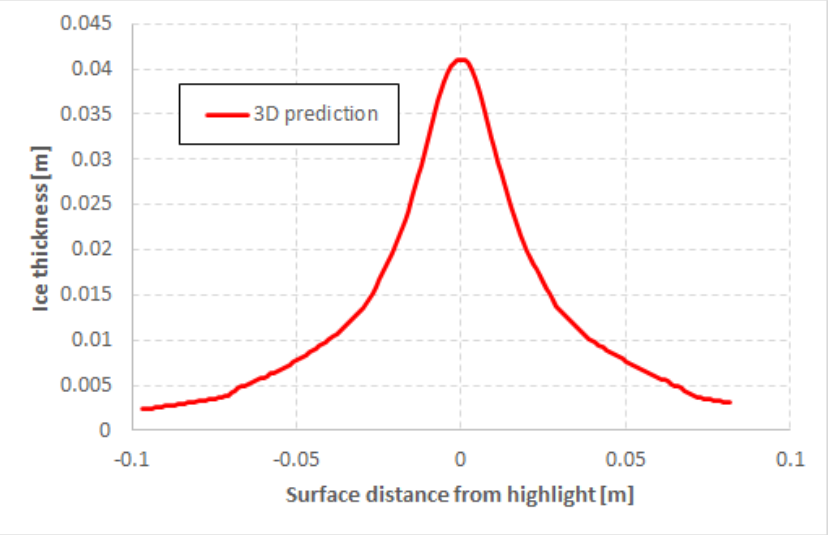
Case 361 (cont.)









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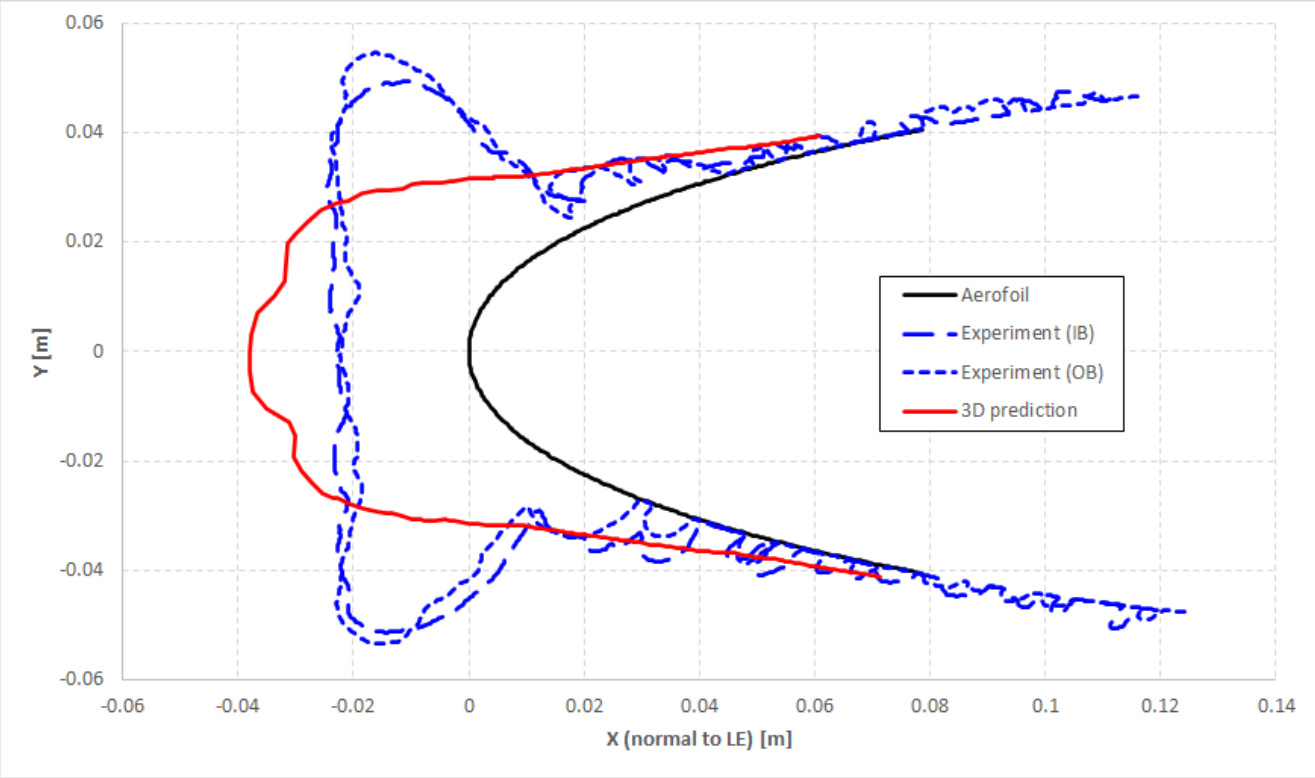
Case 362

- Ice shape



Ice mass = 2.13kg/m

Experiment = 1.62kg/m

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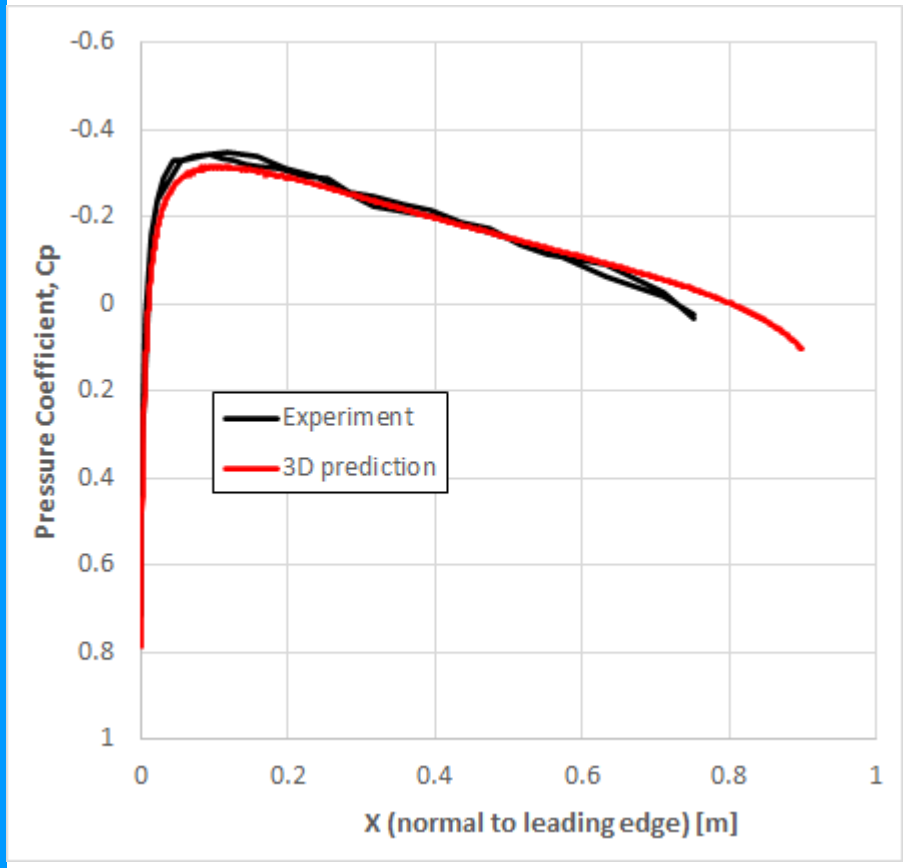
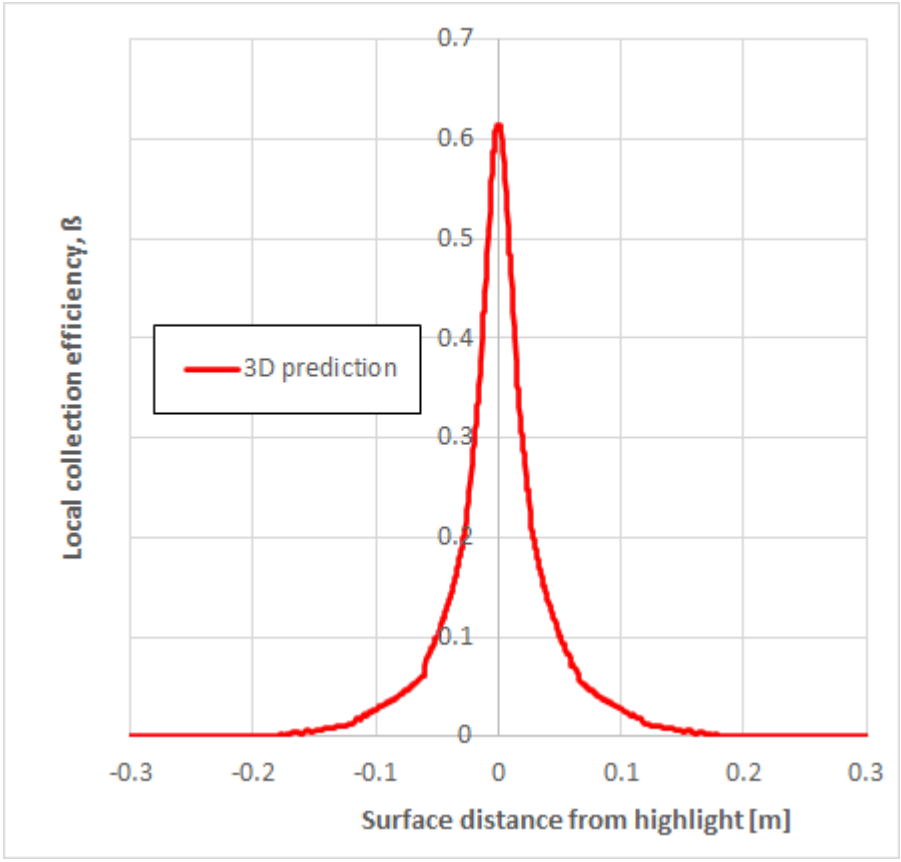
Case 362 (cont.)





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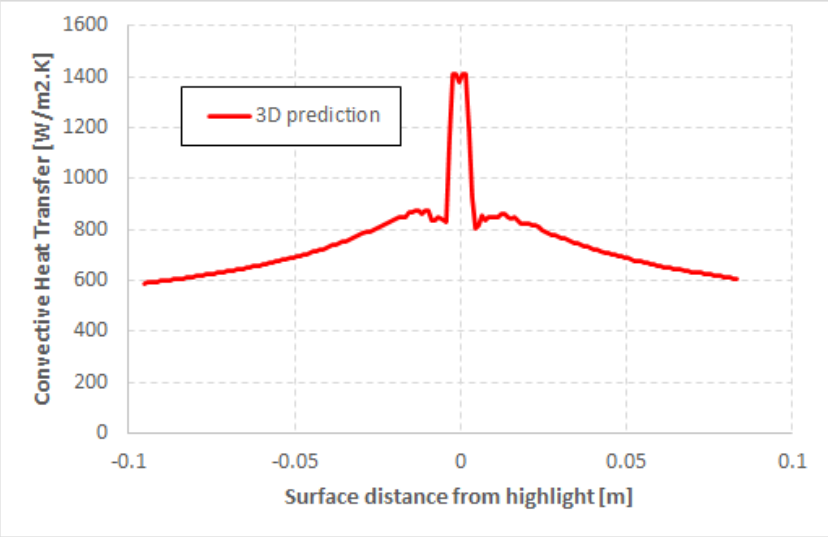
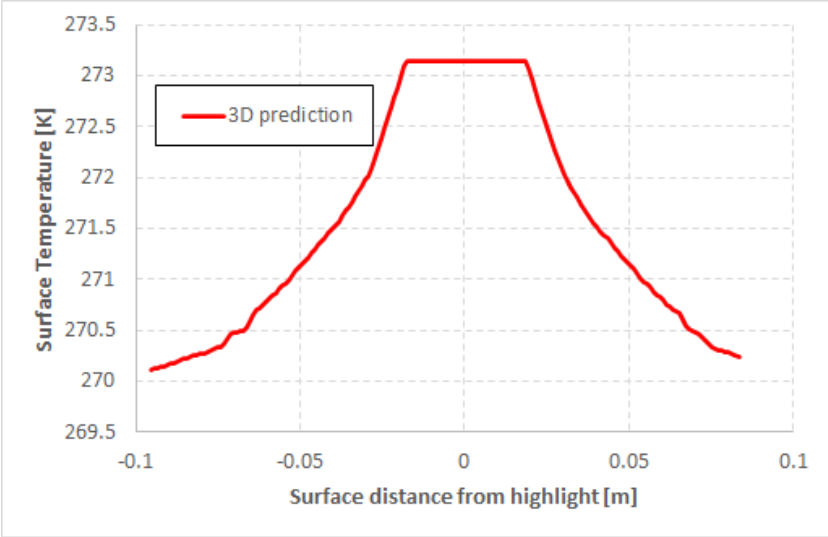
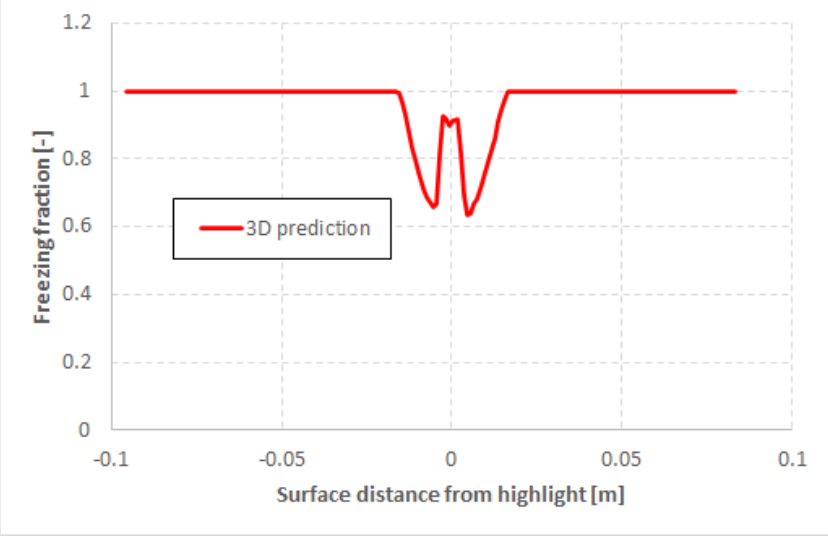
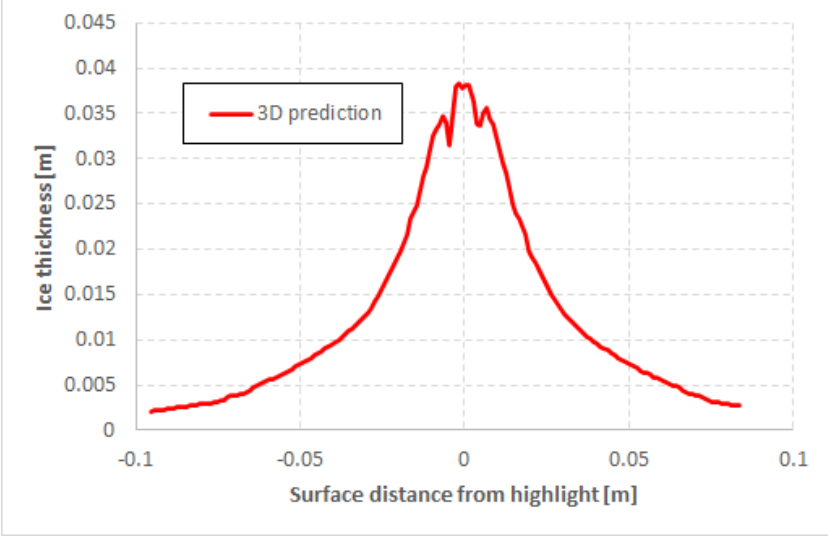
Case 362 (cont.)









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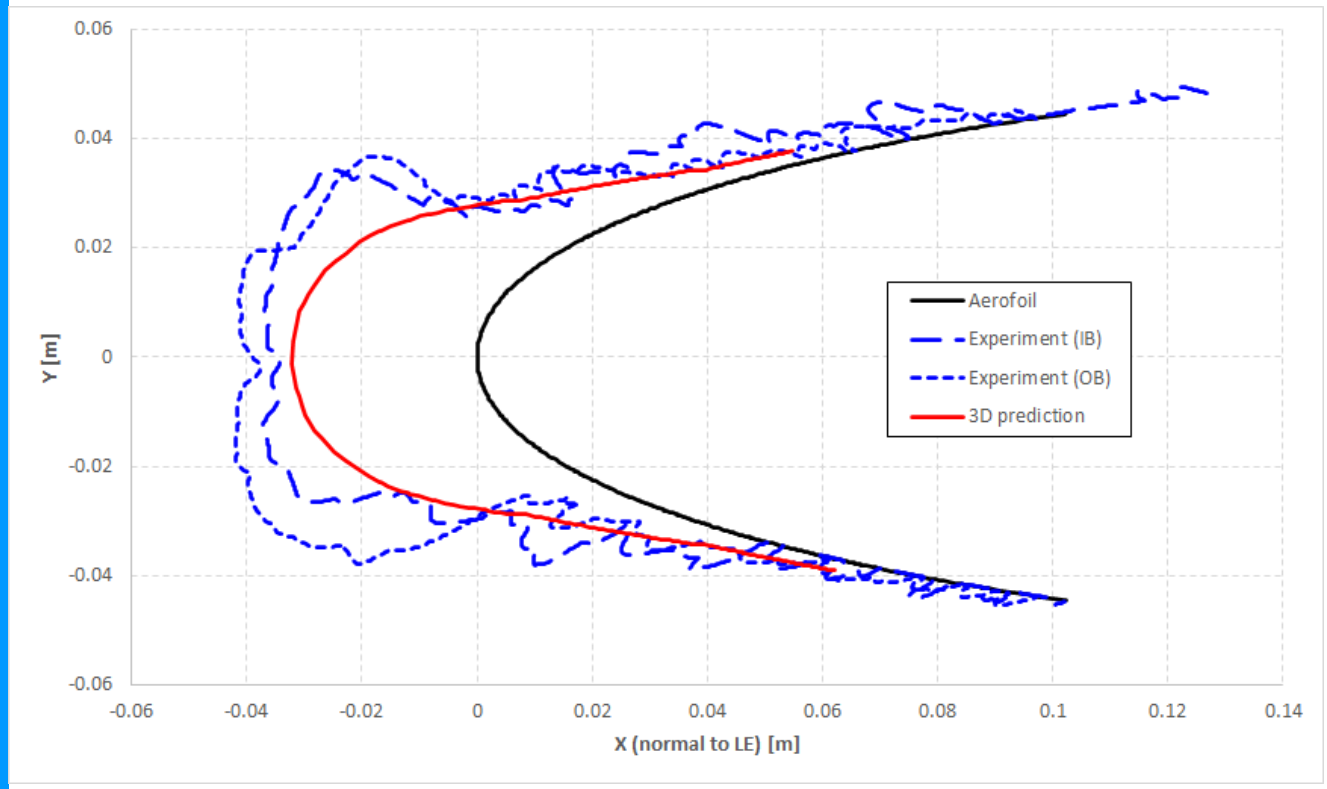
Case 371 and 372

- 45-degree swept NACA0012, $\alpha = 0°$
  - Case 371 is SAT = -16.15C
  - Case 372 is SAT = -7.15C
- Both cases are MVD = 32microns, 0.5g/m^3
- Modelled within IRT, including walls (3D)
- 11.78 million cells

Case 371

- Ice shape



Ice mass = 2.04kg/m

Experiment = 1.58kg/m

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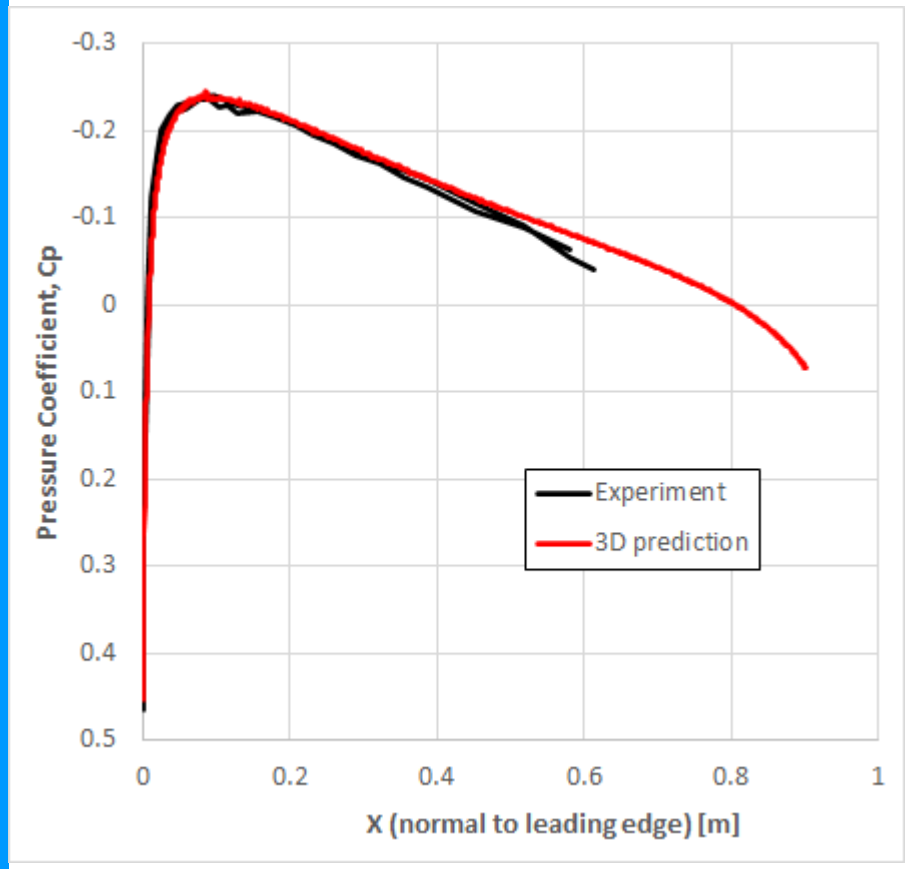
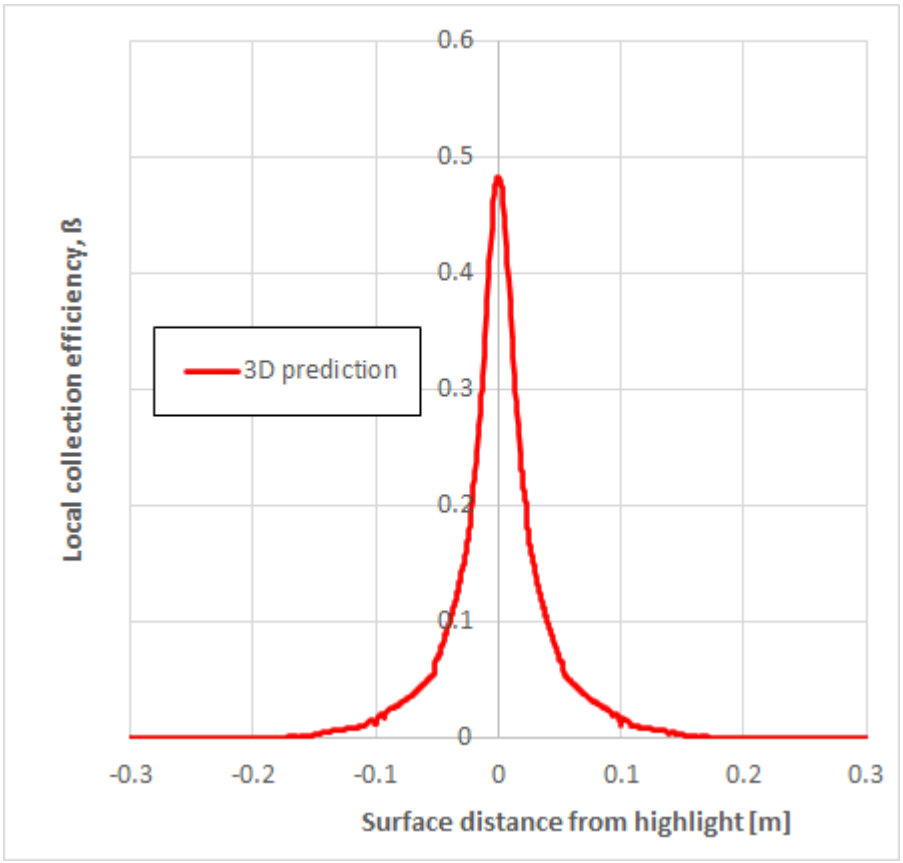
Case 371 (cont.)





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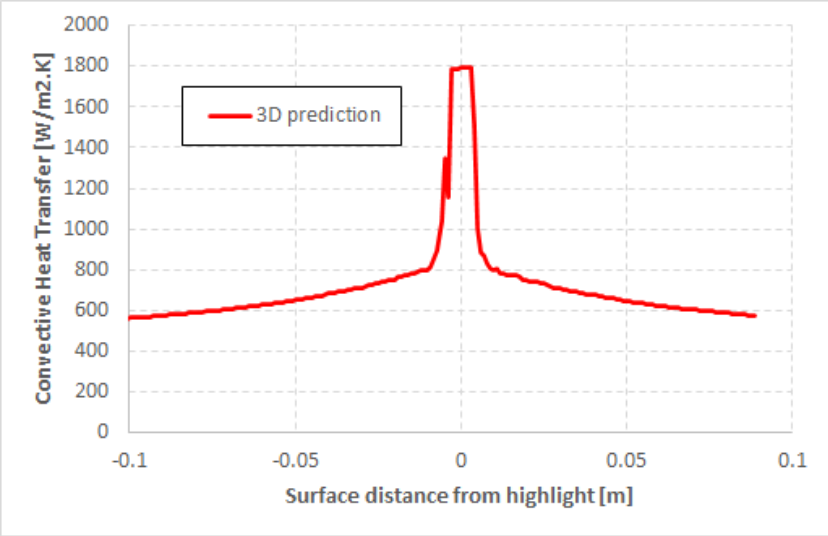
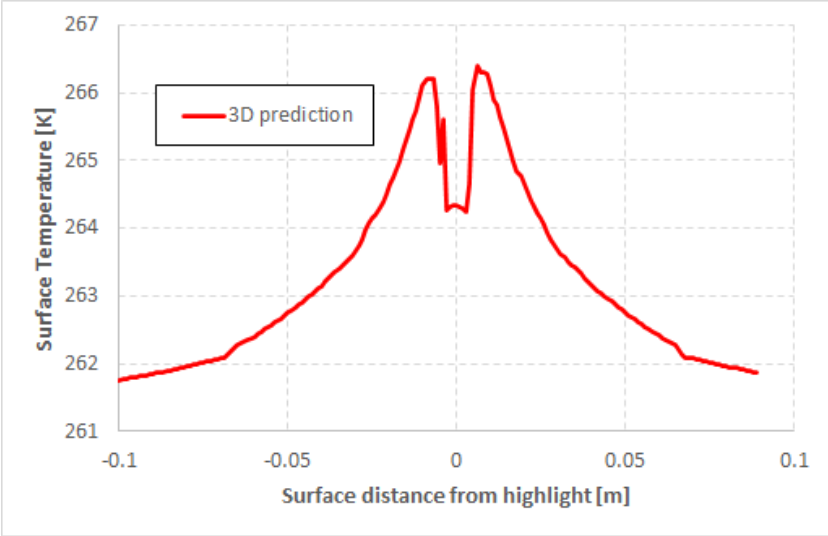
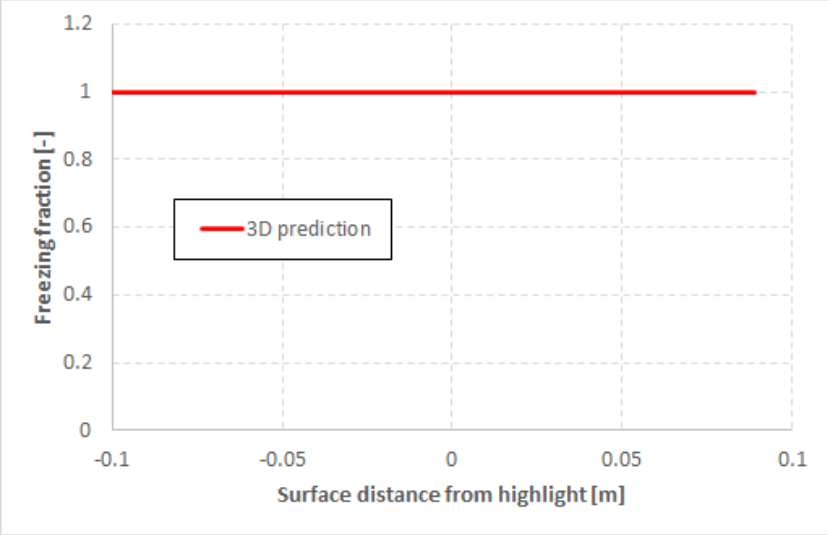
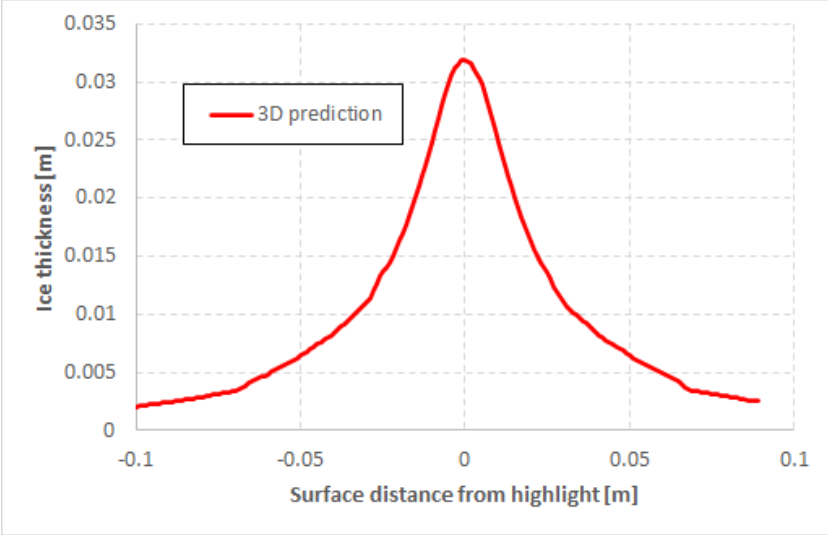
Case 371 (cont.)









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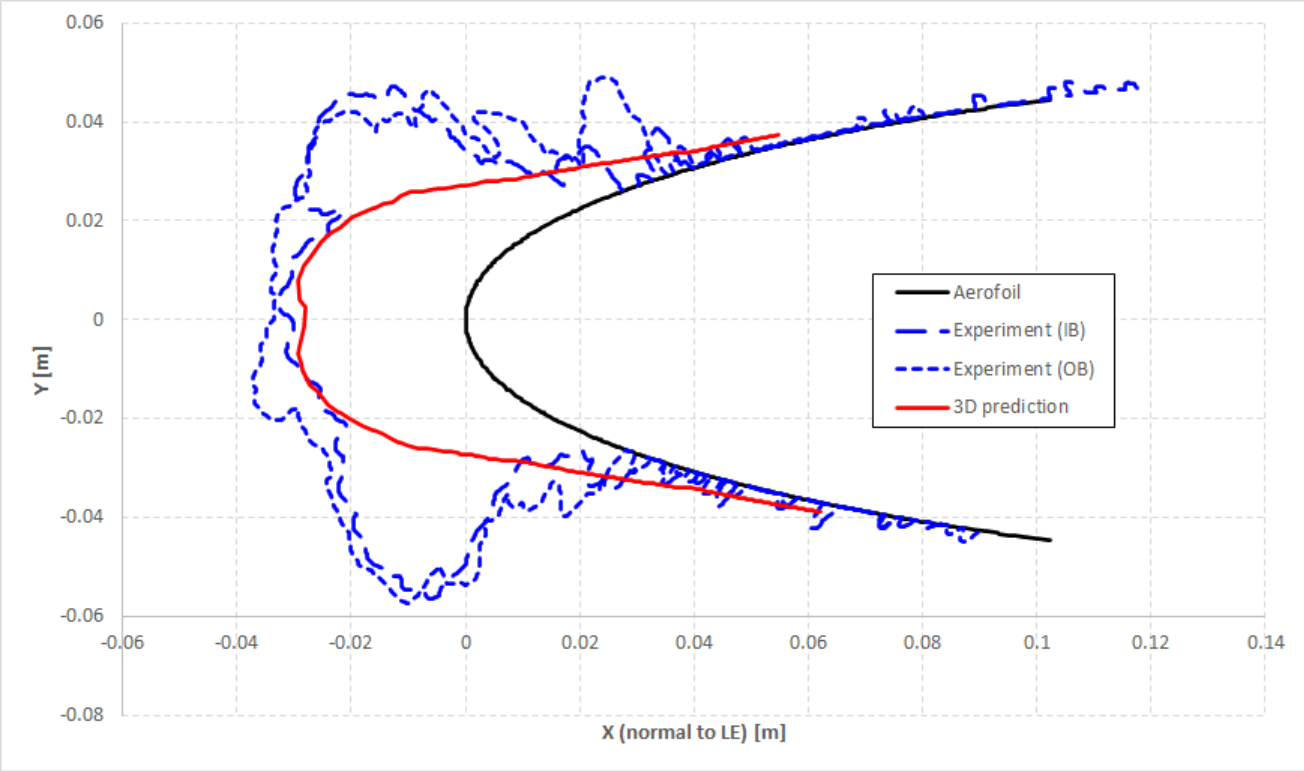
Case 372

- Ice shape



Ice mass = 1.93kg/m

Experiment = 1.60kg/m

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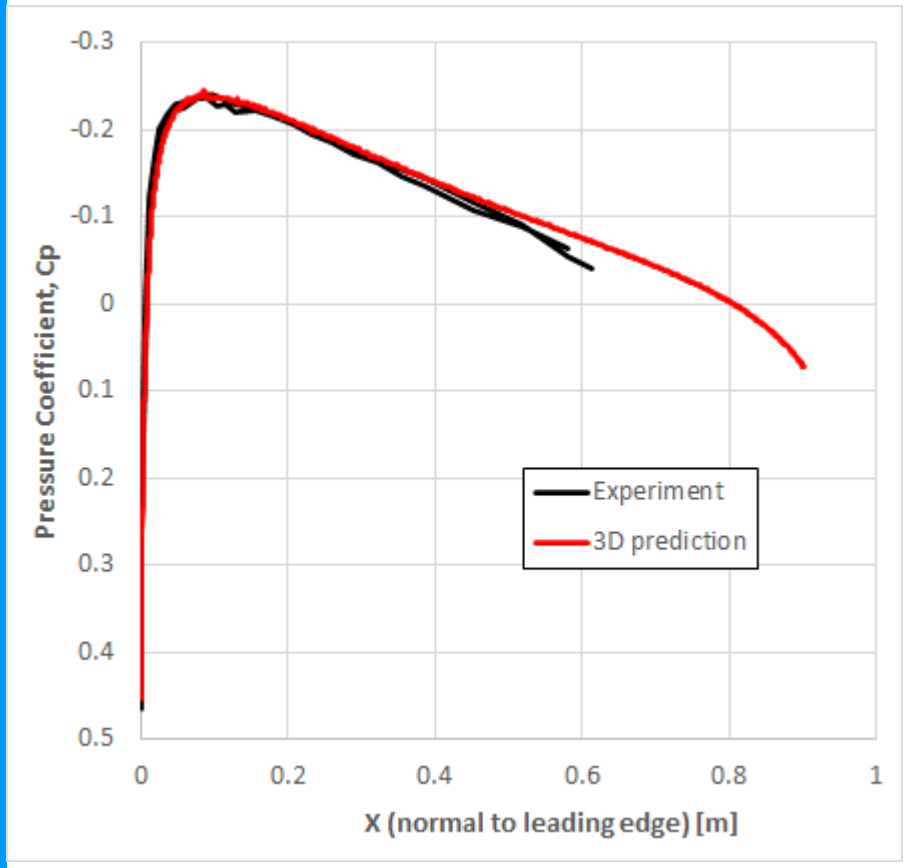
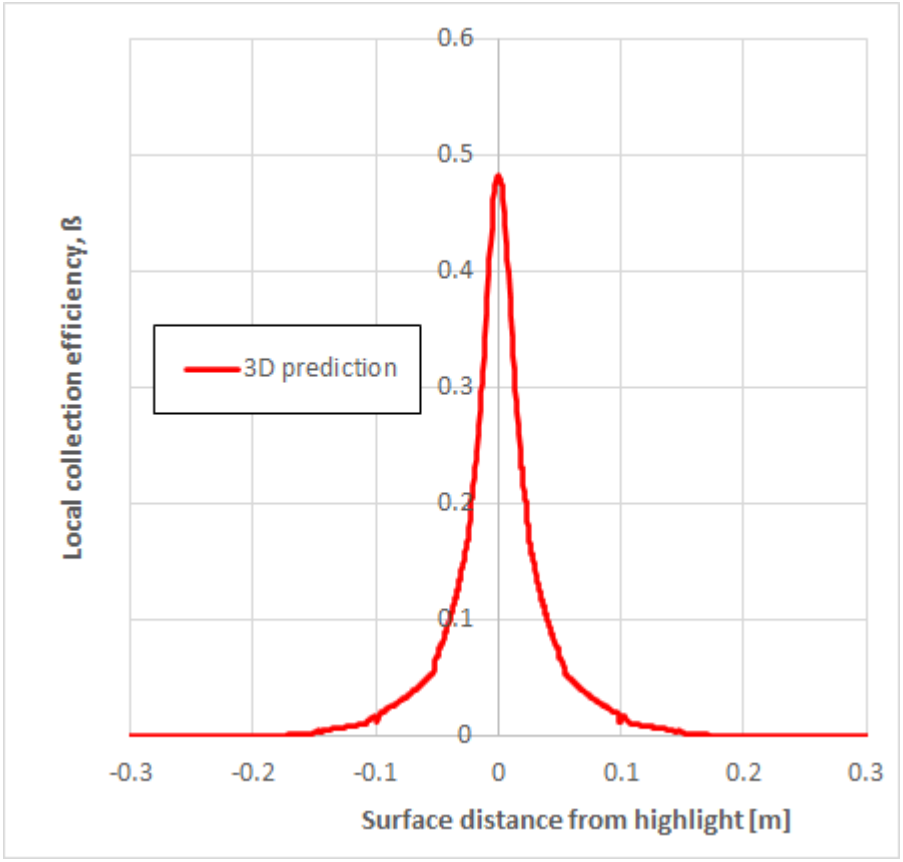
Case 372 (cont.)





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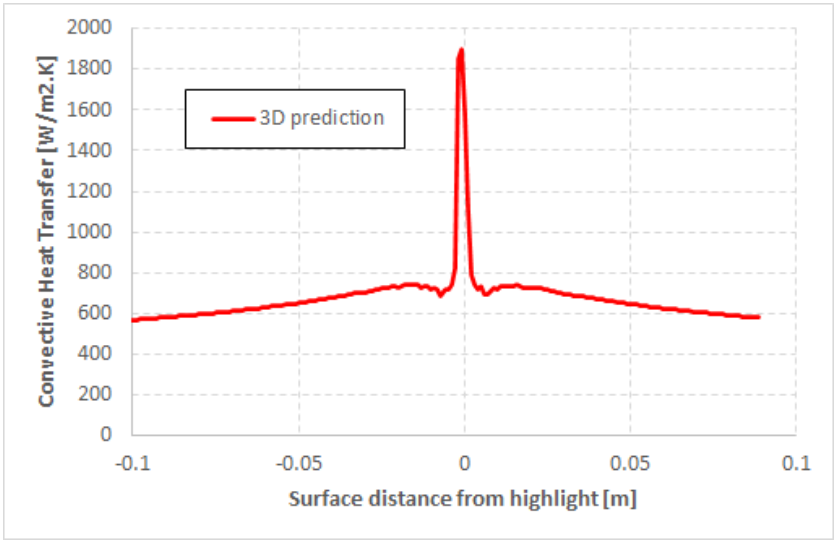
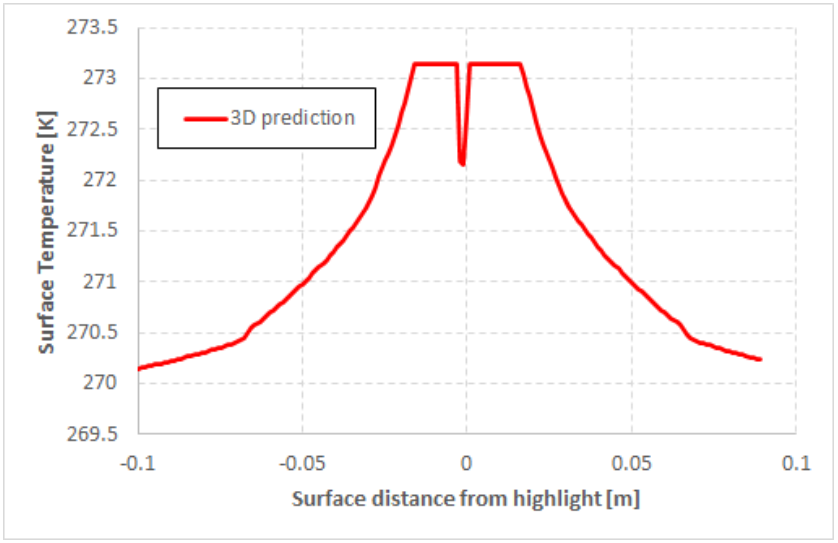
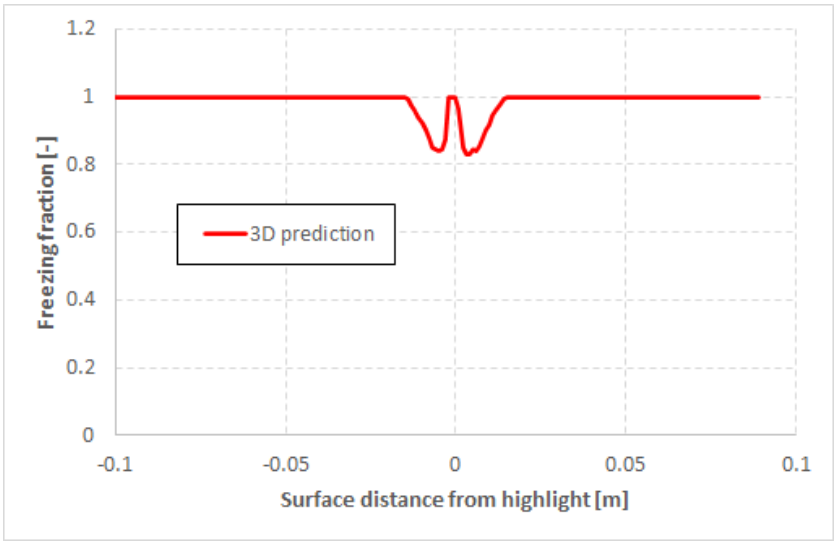
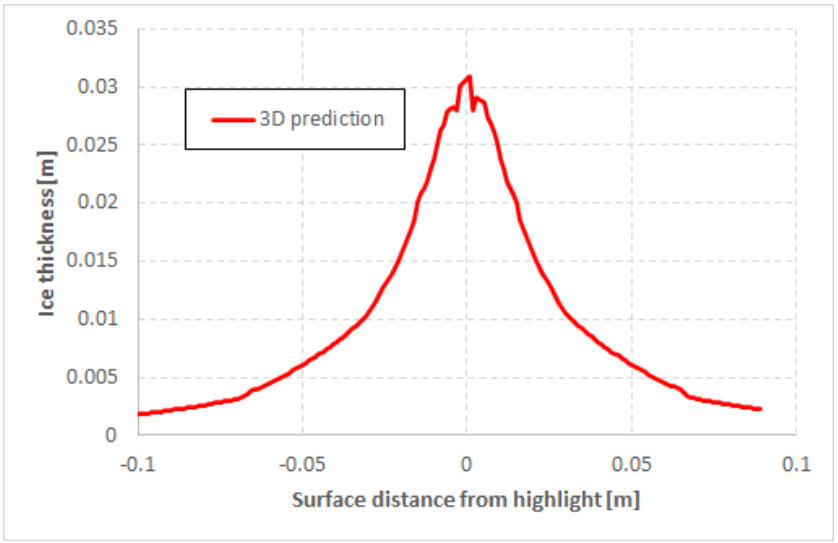
Case 372 (cont.)









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