LEWICE2D and GlennICE
Results for Ice Prediction Workshop

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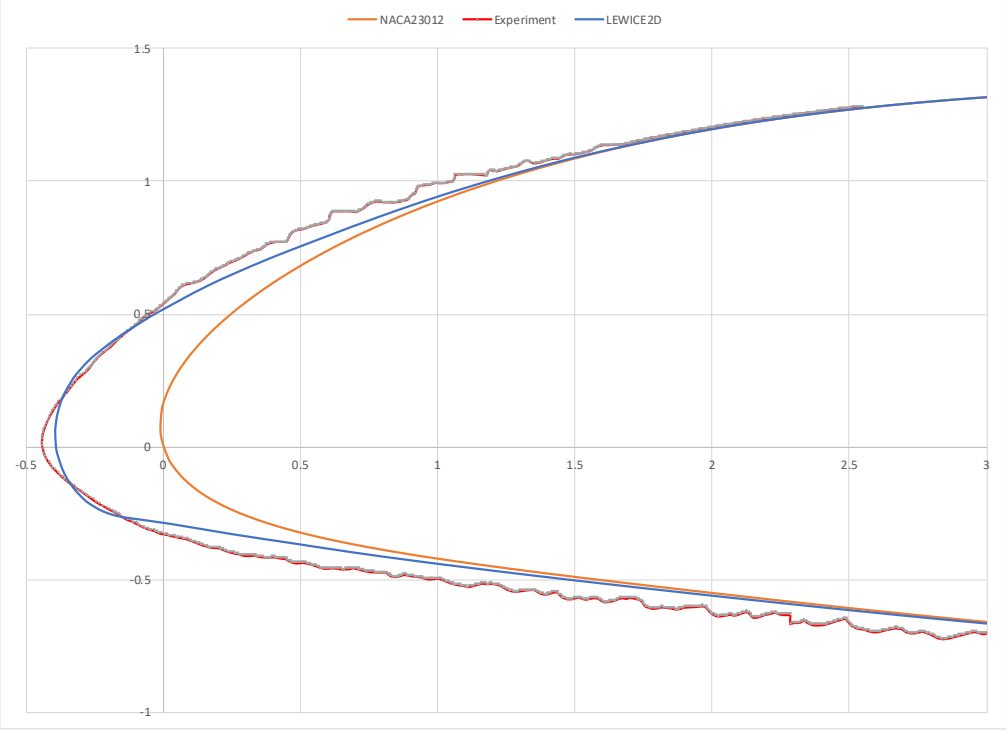
Simulation Process

- LEWICE2D
  - Use multi-time step potential flow for ice shapes
  - Use 2D slice from FUN3D for impingement cases
  - Ice Density=450 for swept wing cases
- GlennICE
  - Use grid supplied (no grid independence study)
  - Residuals converged to 10^{-10}
  - Ice Density=450 for swept wing cases
  - Transition = 1% with turbulent_htc_augmentation = 6

2D Ice Shapes

- Four conditions
  - Two 18” NACA23012 (two different temperatures)
  - Two 72” NACA23012 (monomodal and bimodal)
  - No AOA correction (2° AOA)
- LEWICE2D Process
  - Multi-time step cases with 2D potential flow
- GlennICE Process
  - Preset transition at 1% chord, turbulent_htc_augmentation=6

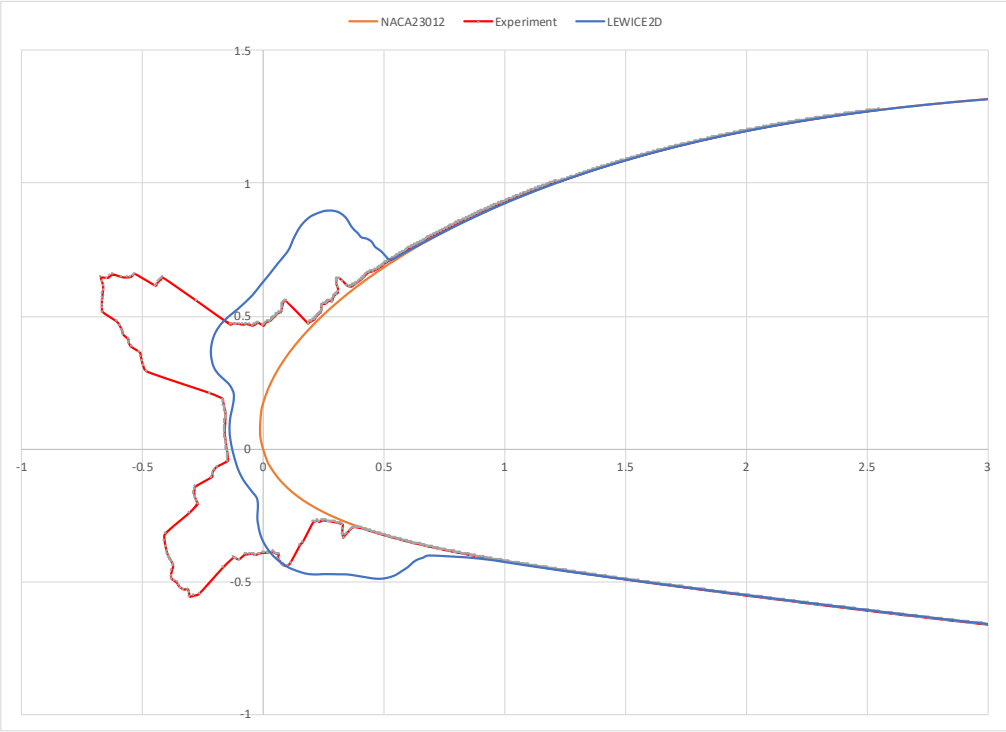
LEWICE2D Case 241



Time = 300 s
V=103 m/s
AOA=2°
T=250.15 K
LWC=0.42 g/m^3
MVD=30 (7 bin dist)

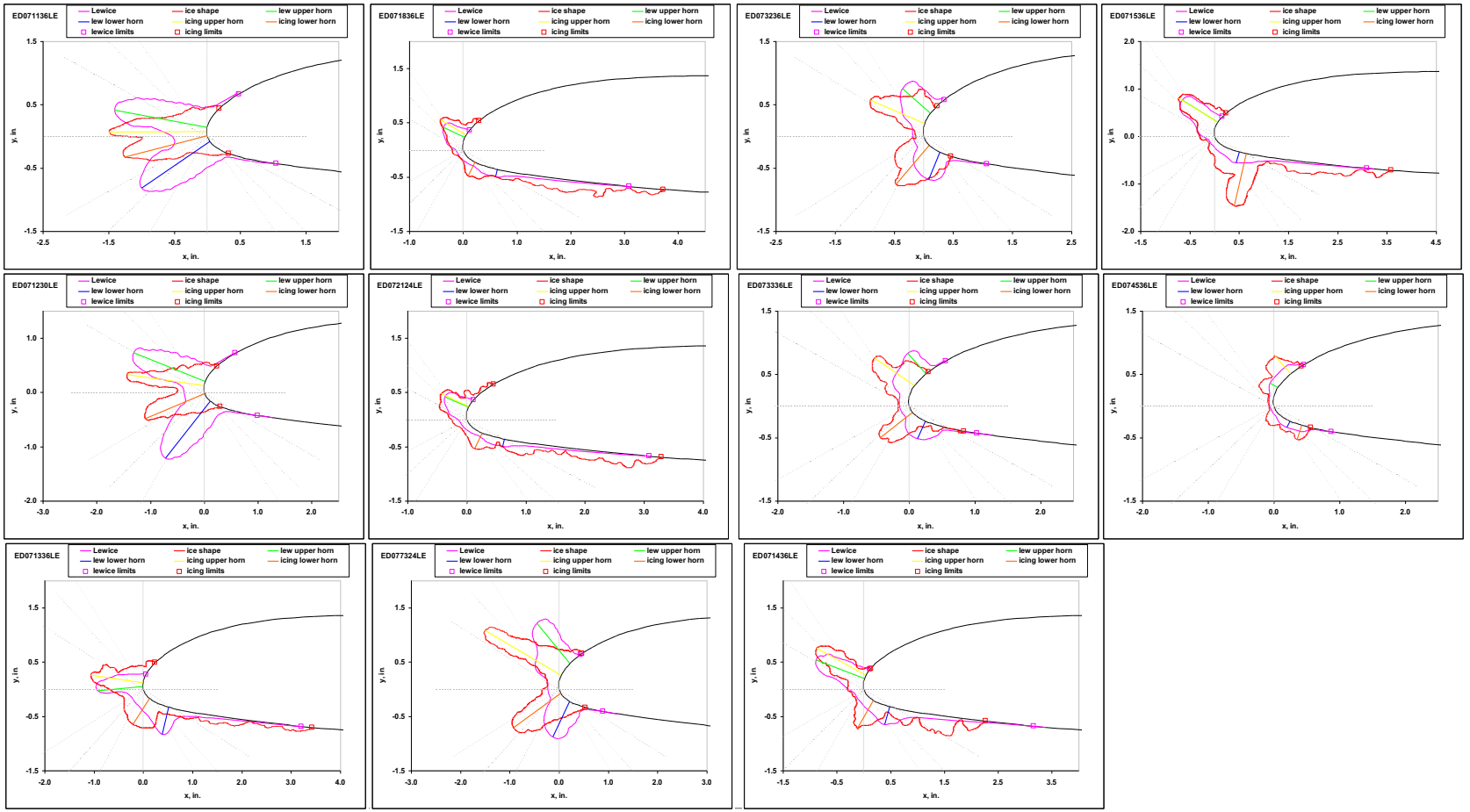
GlennICE Case 241

LEWICE2D Case 242

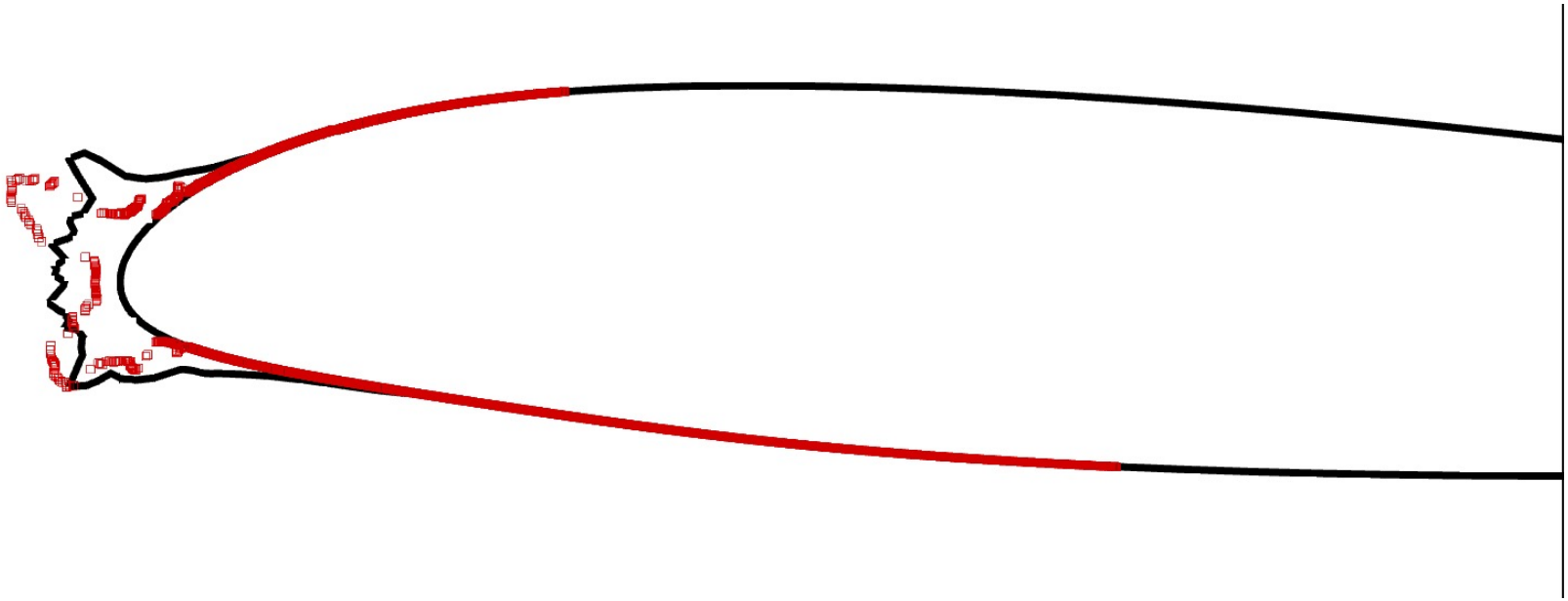


Time = 300 s
V=103 m/s
AOA=2°
T=266 K
LWC=0.81 g/m^3
MVD=15 (7 bin dist)

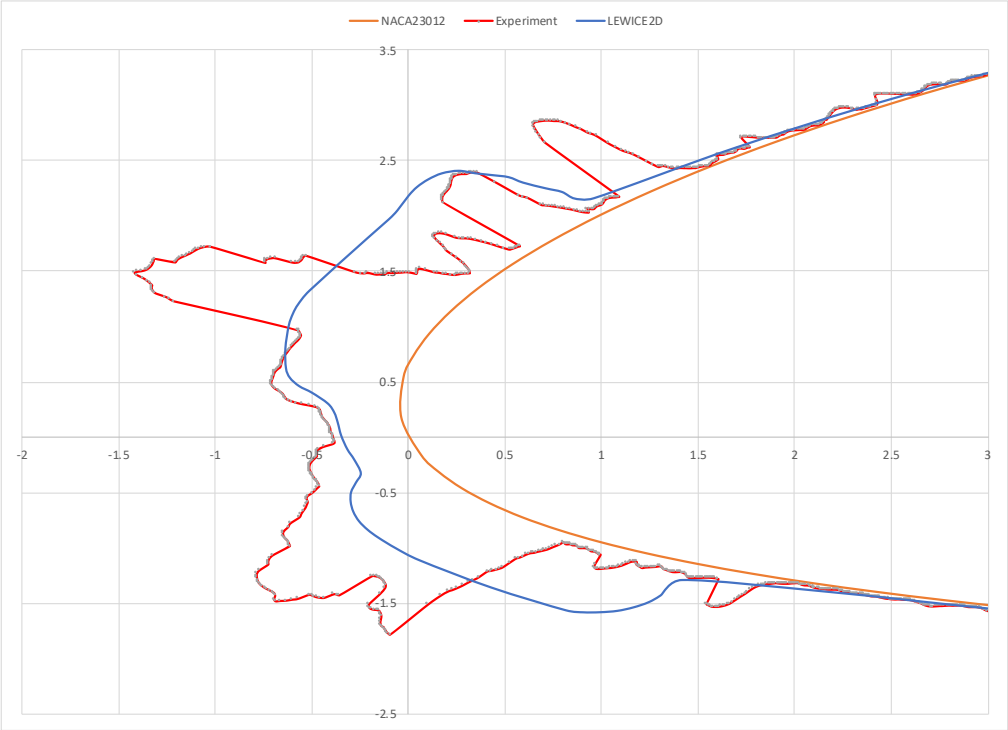
Other LEWICE2D Predictions on 18” NACA23012



GlennICE Case 242

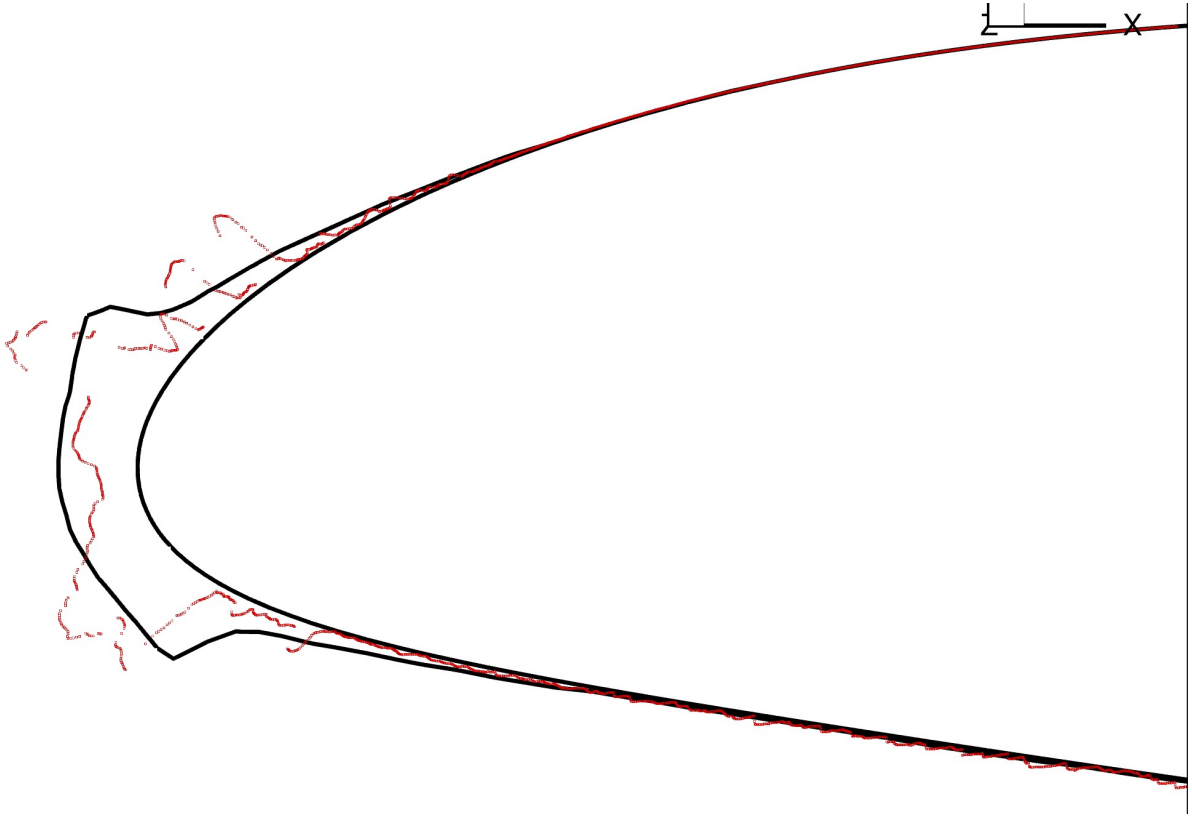


LEWICE 2D Case 251

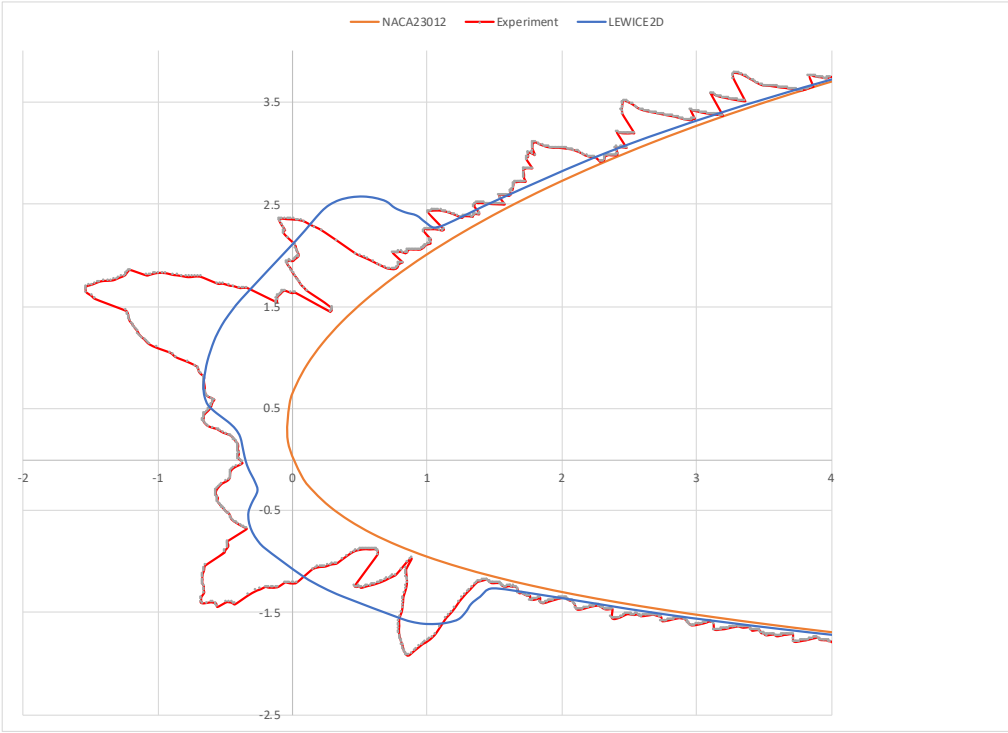


Time = 398 s
V=103 m/s
AOA=2˚
T=260.7 K
LWC=1.64 g/m^3
MVD=21.5 (7 bin dist)

GlennICE Case 251

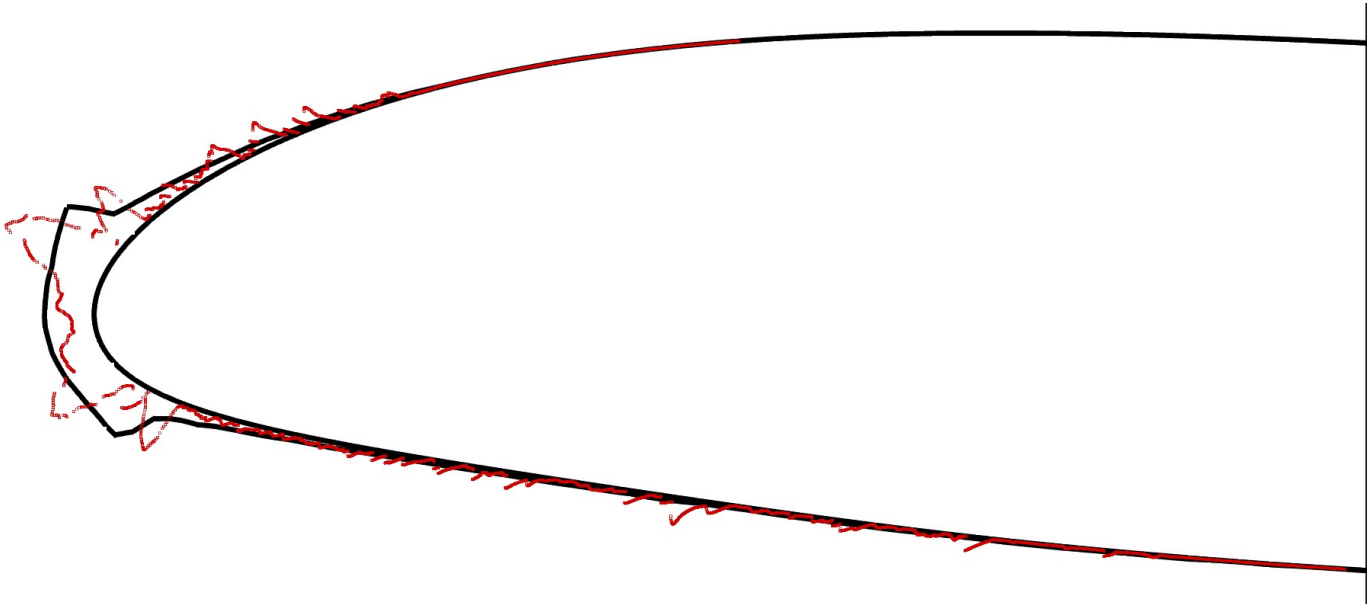


LEWICE2D Case 252



Time = 398 s
V=103 m/s
AOA=2°
T=260.7 K
LWC=1.64 g/m^3
MVD=21.5 (BiModal dist)

GlennICE Case 252



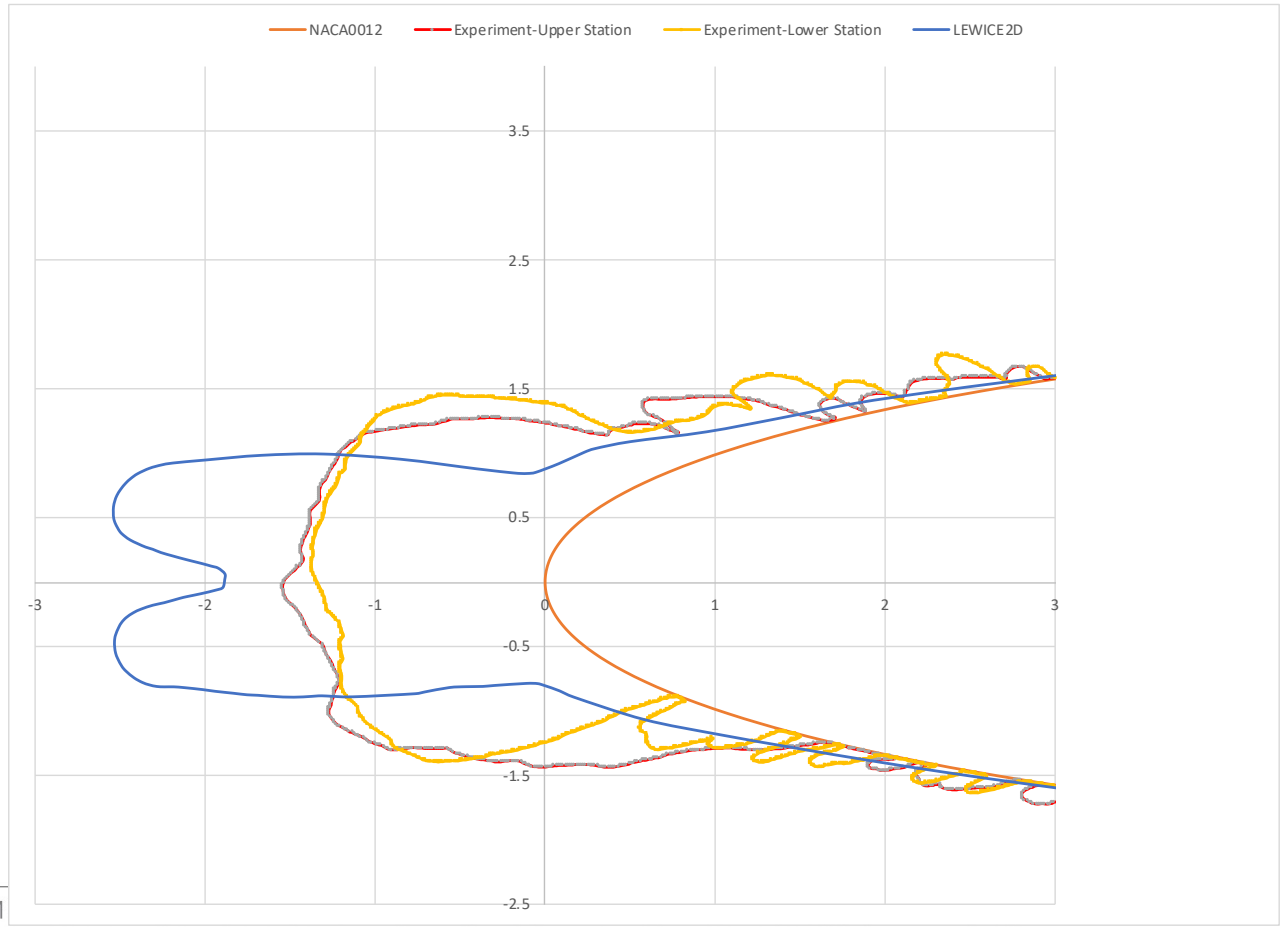
3D Ice Shapes

- Six Cases
  - Four 30-deg sweep NACA0012
    - Two different velocities
    - For each velocity, two different temperatures
  - Two 45-deg NACA0012
    - Two different temperatures
- LEWICE2D Process
  - Adjust velocity ($V_{2D}=V_{3D}*\cos\phi$)
  - Adjust T_{static} (keep T_{total} same)
- GlennICE Process
  - Preset transition at 1% chord, turbulent_htc_augmentation=6

3D Sweep Correction (LEWICE)

- Use coordinates normal to LE (NACA0012)
- Use $V_{2D} = V_{3D} * \cos(\phi)$
- Match T_{tot} (T_{static} adjusted)
- No AOA correction (0° AOA)
- Multi-time step cases with 2D potential flow
- Ice density = 450

LEWICE2D Case 361

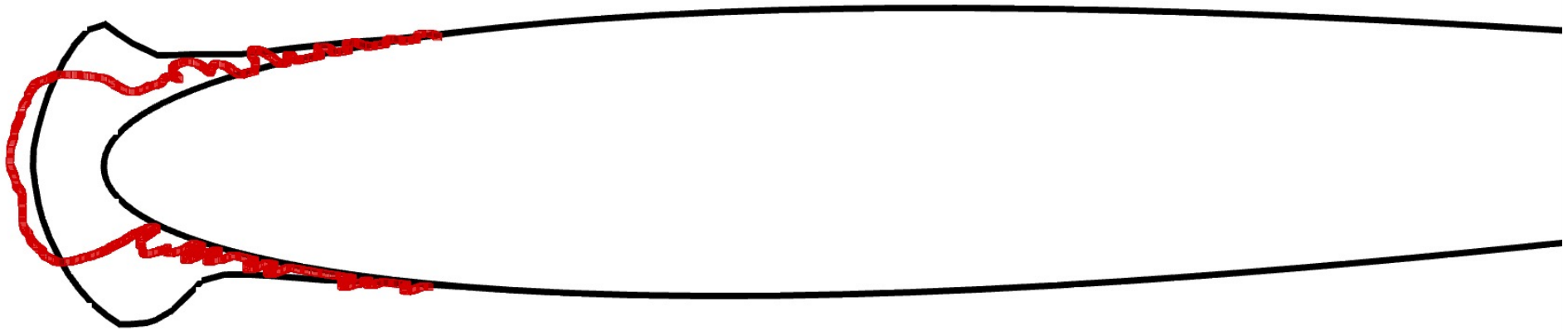


Time = 1200 s
V=89.2 m/s (103m/s orig)
AOA=0°
T=258.6 K (257K orig)
LWC=0.5 g/m^3
MVD=34.7 (7 bin dist)
Ice density = 450 kg/m^3

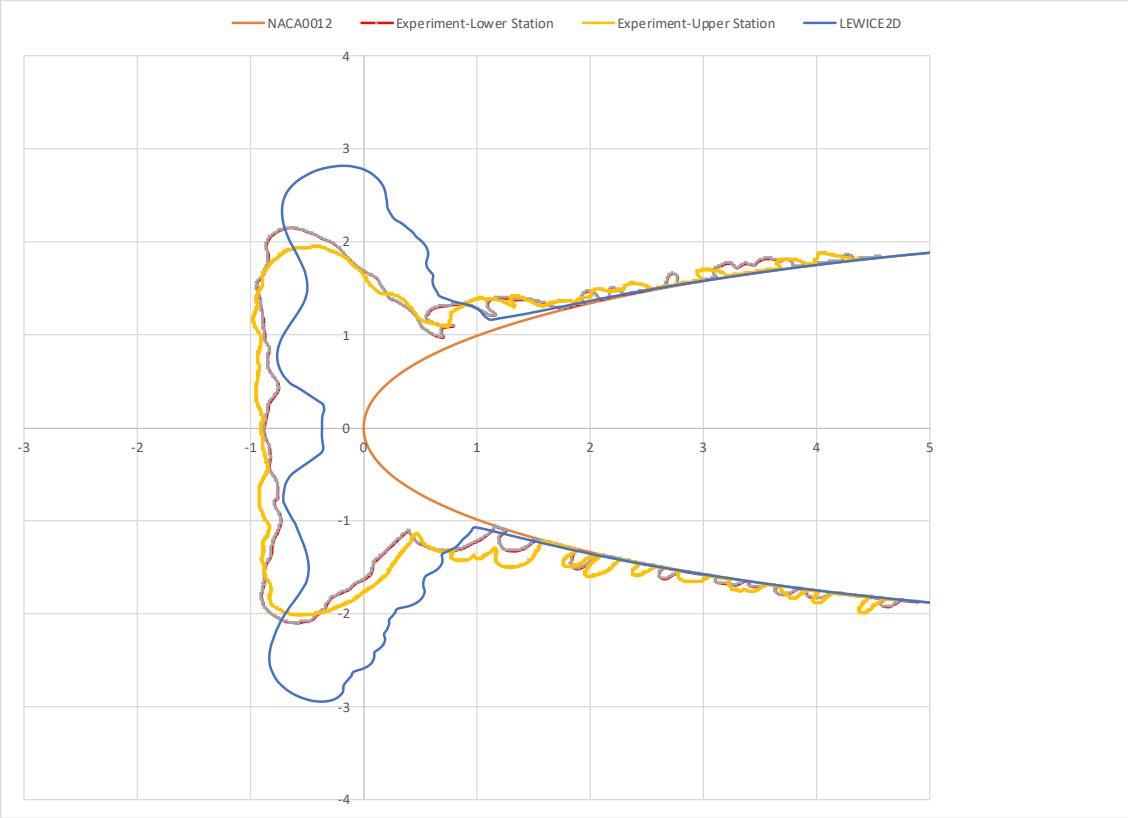
AM

AIAA
SHAPING THE FUTURE OF AEROSPACE

GlennICE Case 361

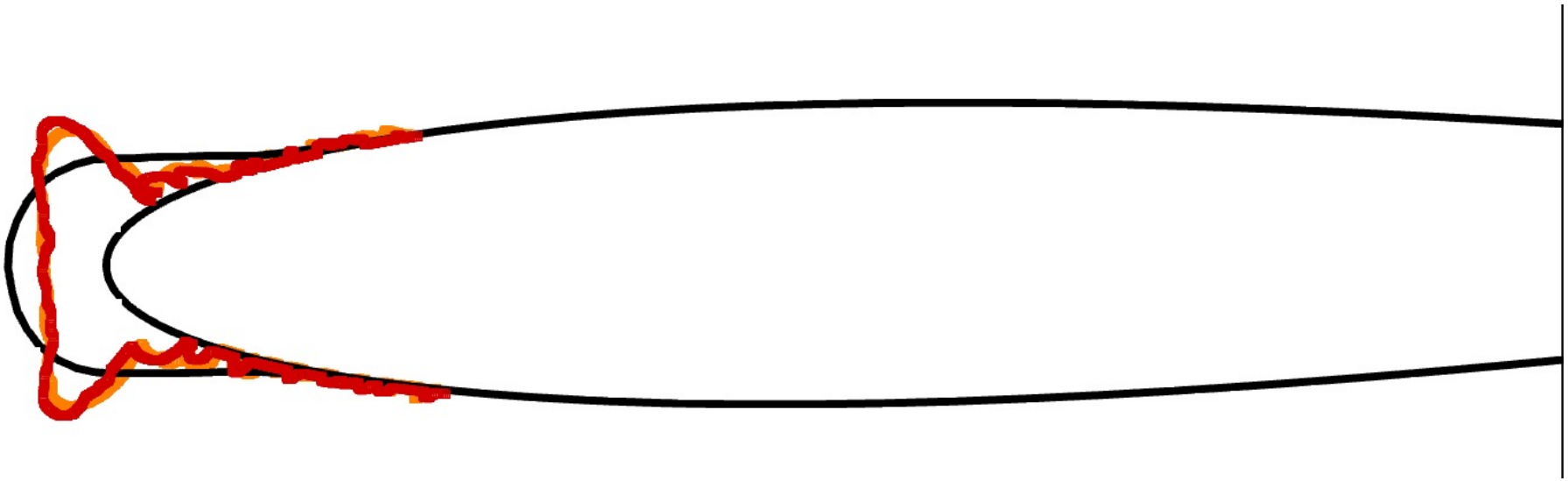


LEWICE2D Case 362

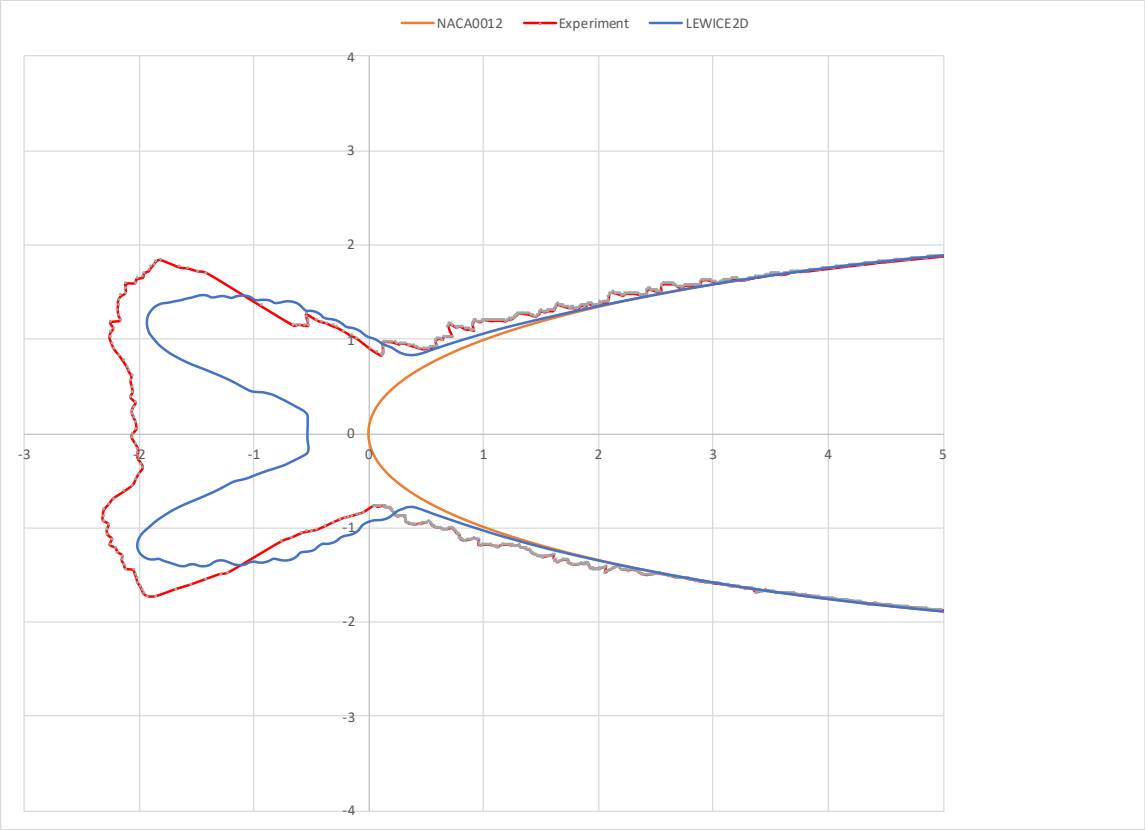


Time = 1200 s
V=89.2 m/s (103m/s orig)
AOA=0°
T=267.8 K (266K orig)
LWC=0.5 g/m^3
MVD=34.7 (7 bin dist)
Ice density = 450 kg/m^3

GlennICE Case 362

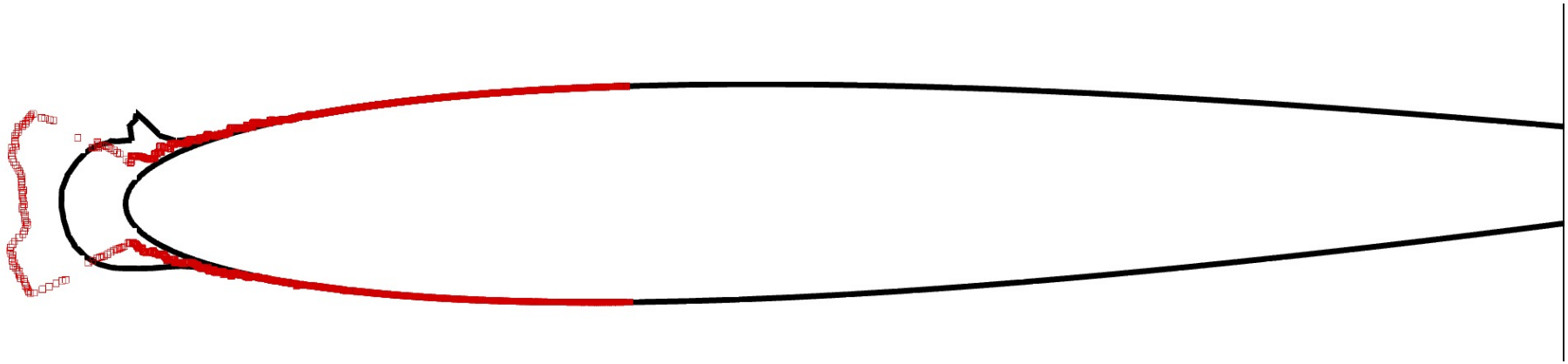


LEWICE2D Case 363

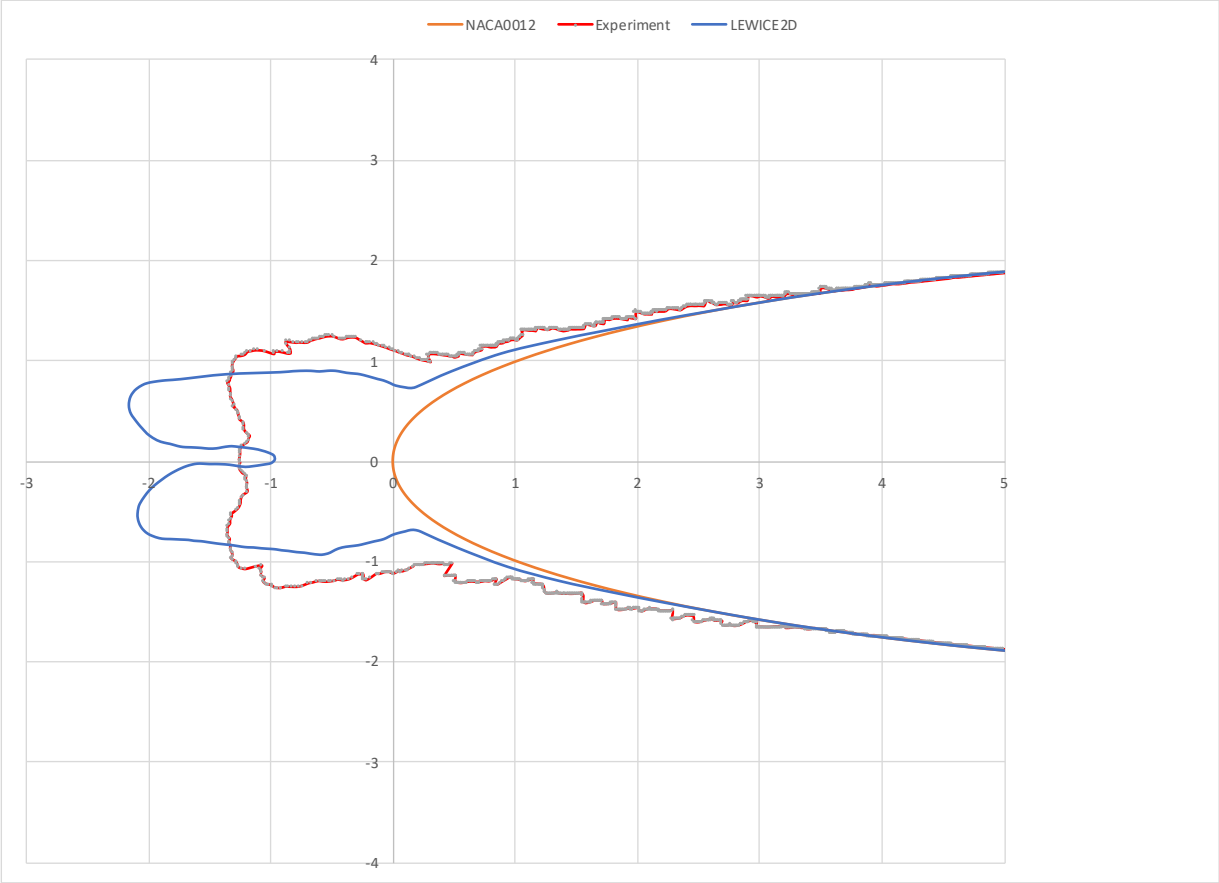


Time = 1062 s
V=99.6 m/s (115 m/s orig)
AOA=0˚
T=264.8 K (263K orig)
LWC=0.5 g/m^3
MVD=20.5 (7 bin dist)
Ice density = 450 kg/m^3

GlennICE Case 363

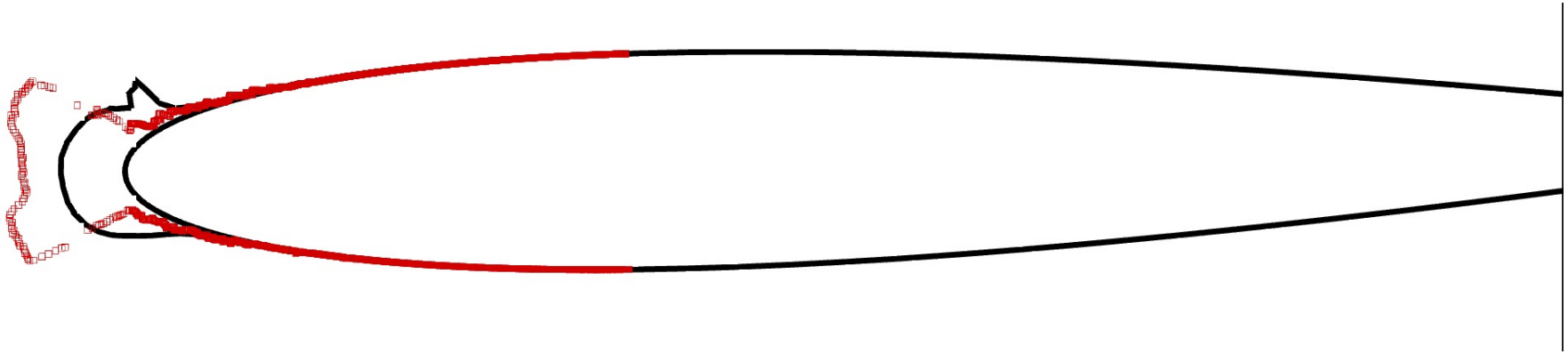


LEWICE2D Case 364

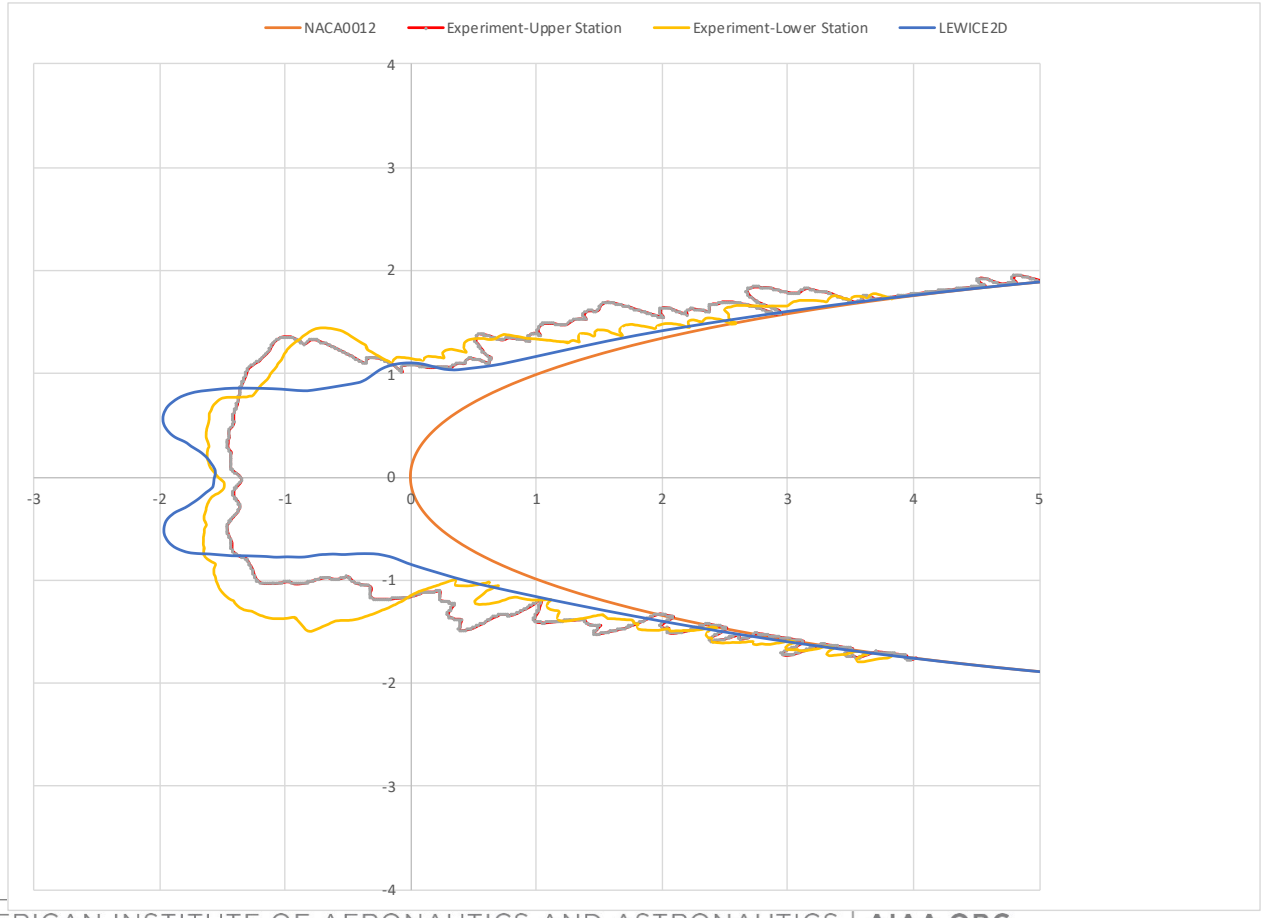


Time = 1062 s
V=99.6 m/s (115 m/s orig)
AOA=0˚
T=261.5 K (259.7K orig)
LWC=0.5 g/m^3
MVD=20.5 (7 bin dist)
Ice density = 450 kg/m^3

GlennICE Case 364

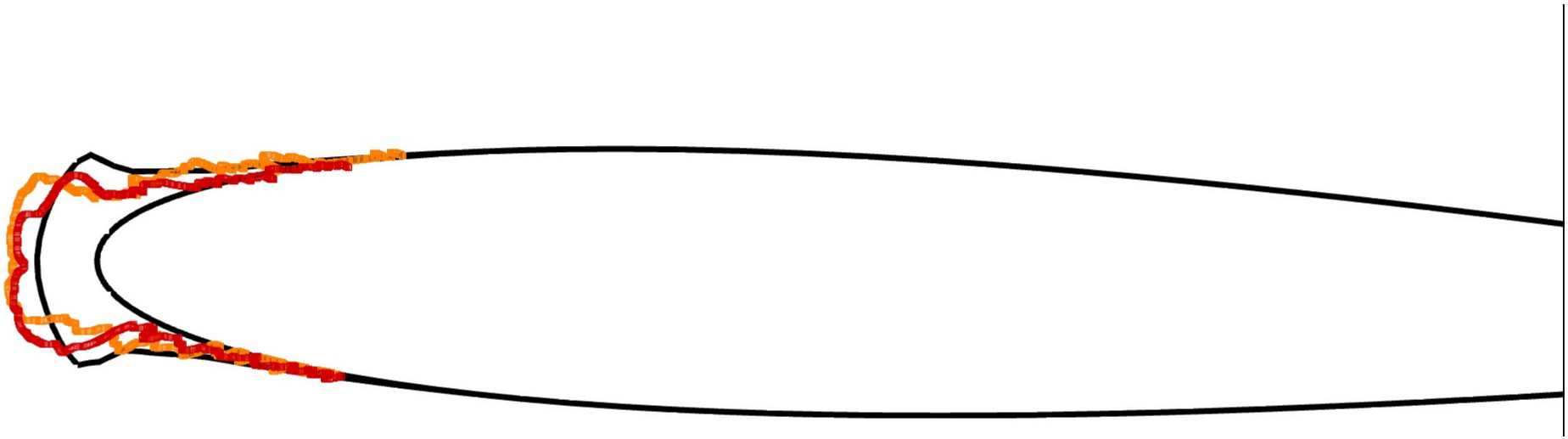


LEWICE2D Case 371

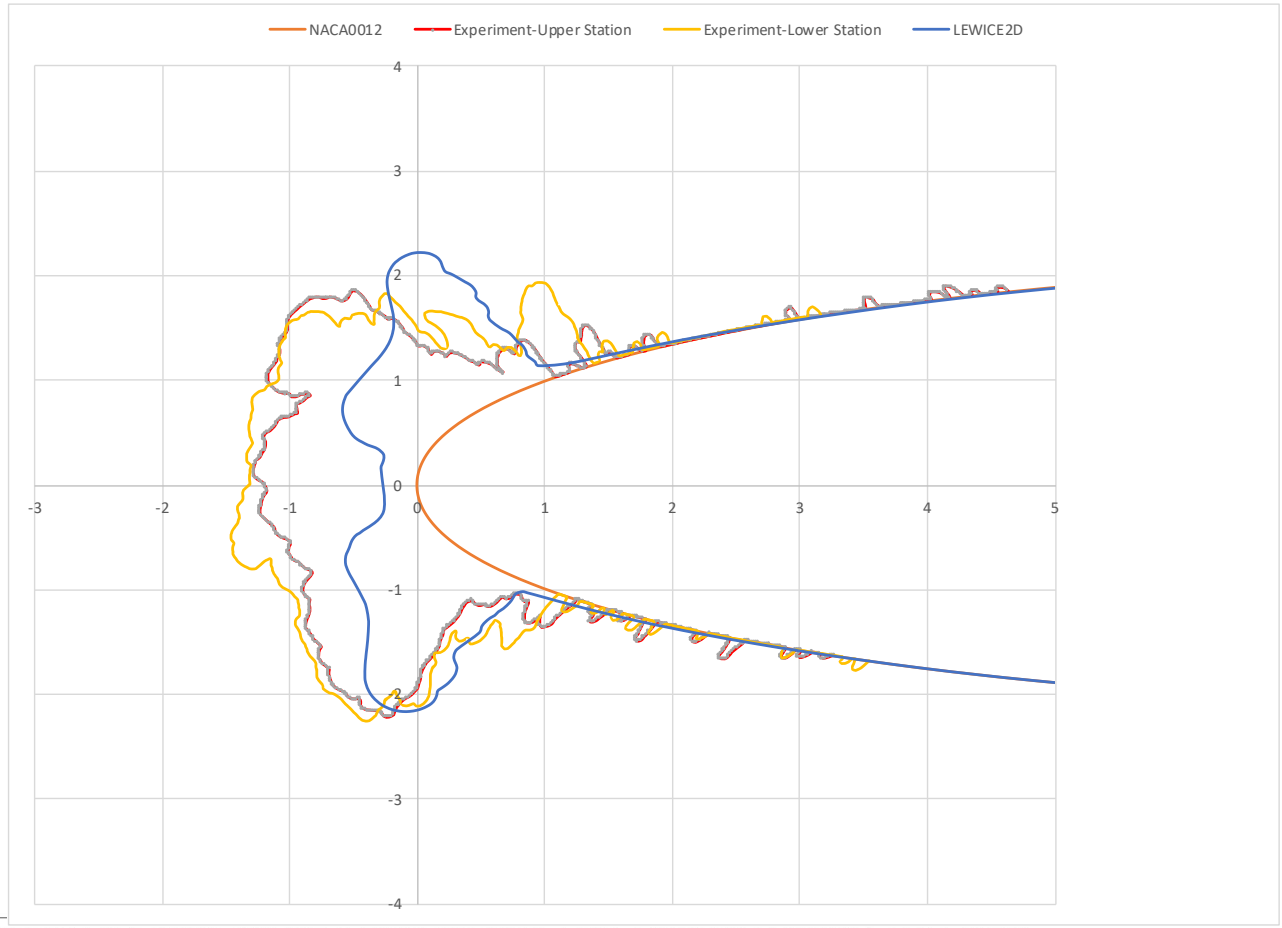


Time = 1200 s
V=72.3 m/s (103m/s orig)
AOA=0°
T=261.5 K (257K orig)
LWC=0.5 g/m^3
MVD=32 (7 bin dist)
Ice density = 450 kg/m^3

GlennICE Case 371



LEWICE2D Case 372



Time = 1200 s
V=72.3 m/s (103m/s orig)
AOA=0°
T=269.1 K (266K orig)
LWC=0.5 g/m^3
MVD=32 (7 bin dist)
Ice density = 450 kg/m^3

GlennICE Case 372

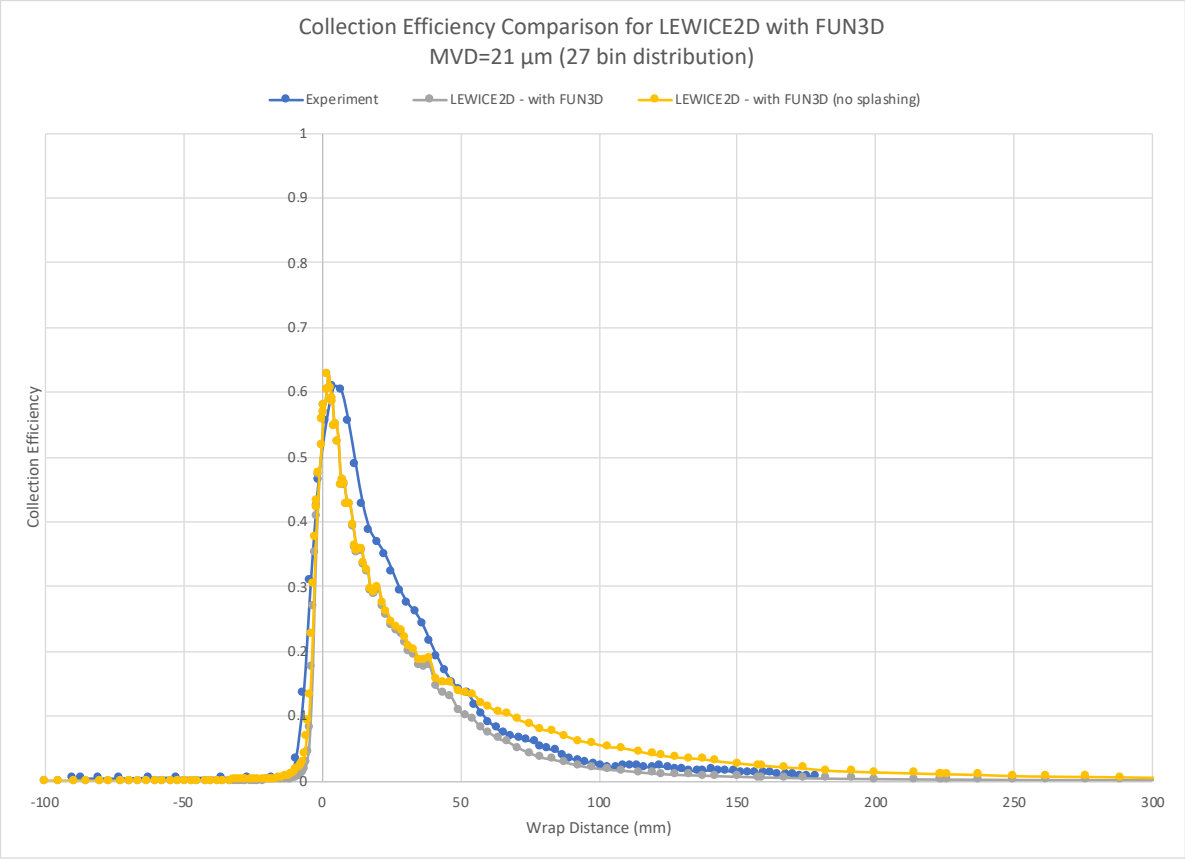
Impingement on NACA64A008 Wing

- Two cases
  - 21 micron and 92 micron
  - 27 bin distributions
  - AOA=6°
- LEWICE2D Process
  - Collection efficiency is horizontal, not normal to LE
  - Horizontal slice used
  - No adjustment to velocity
  - Read 2D slice from 3D flow into LEWICE2D
  - Adjustment needed for beta
  - $\beta_{3D} = \beta_{2D} \frac{\sqrt{\Delta x^2 + \Delta y^2}}{\sqrt{\Delta x^2 + \frac{\Delta y^2}{cos^2 \phi}}}$

Process for Using FUN3D in LEWICE2D

- Load solution into Tecplot
- Take 2D slice at Z-location of data
  - Based on case orientation, sometimes the slice is a Y-location
- Add 2D Cartesian zone (5000x2000)
- Interpolate flow variables to cartesian grid
- Export 2D geometry, grid and flow variables
- Run cases in LEWICE2D

LEWICE2D Swept Tail Collection Efficiency MVD = 21



Time = N/A
V=78.7 m/s
AOA=6°
T=291.2 K
LWC=N/A
MVD=21 (27 bin dist)

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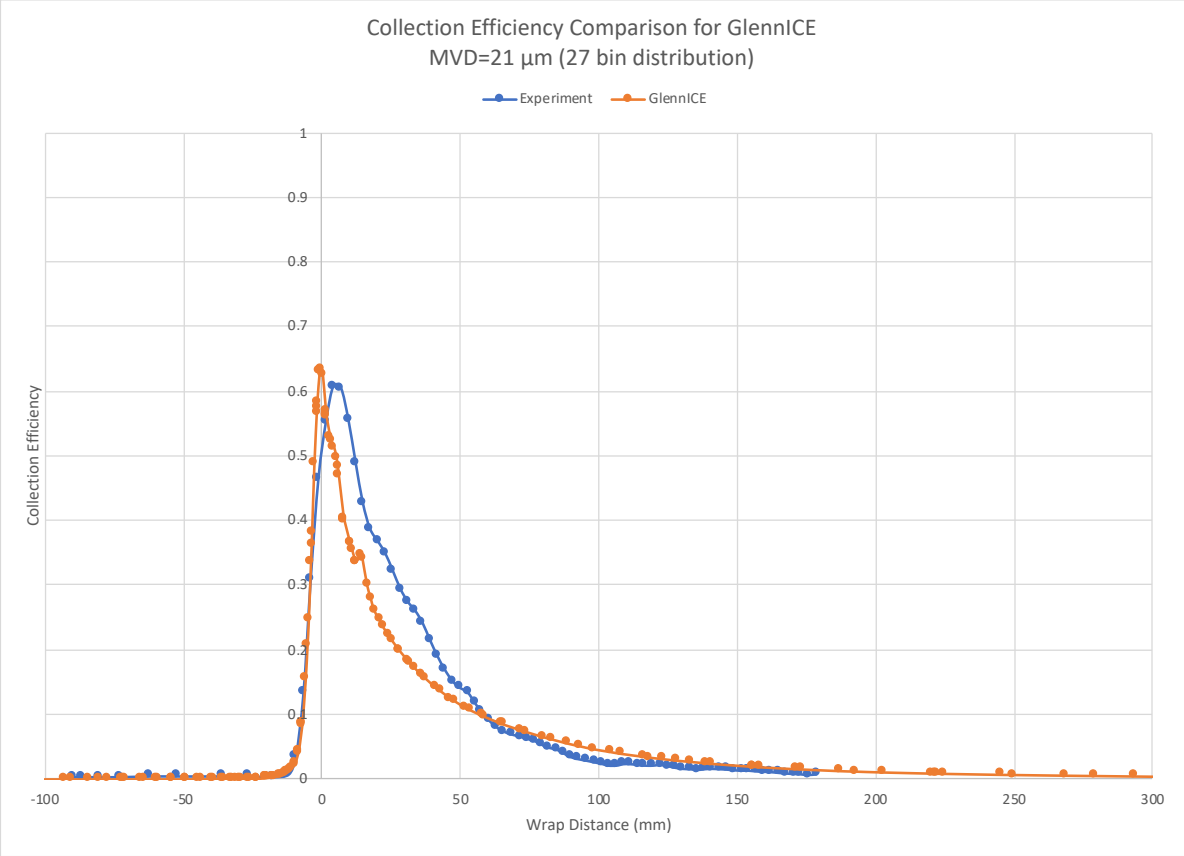
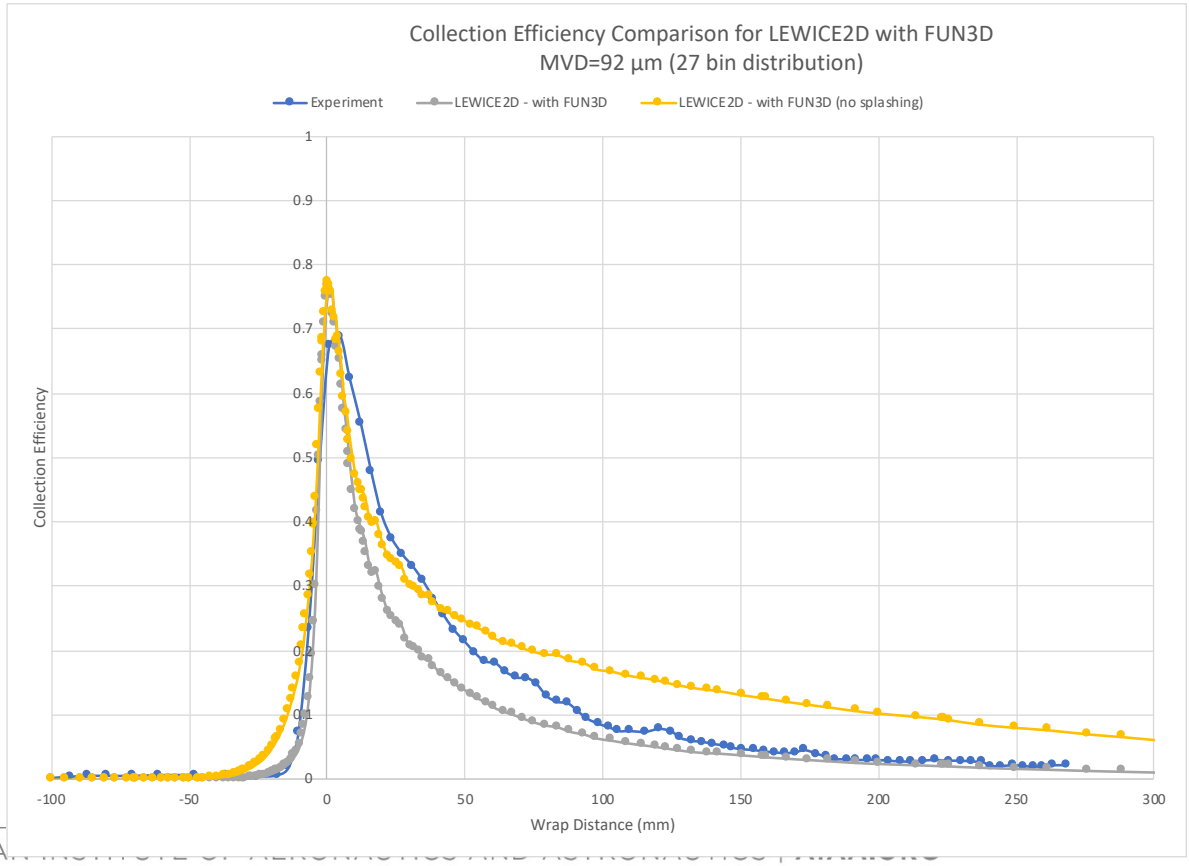
GlennICE Swept Tail MVD=21



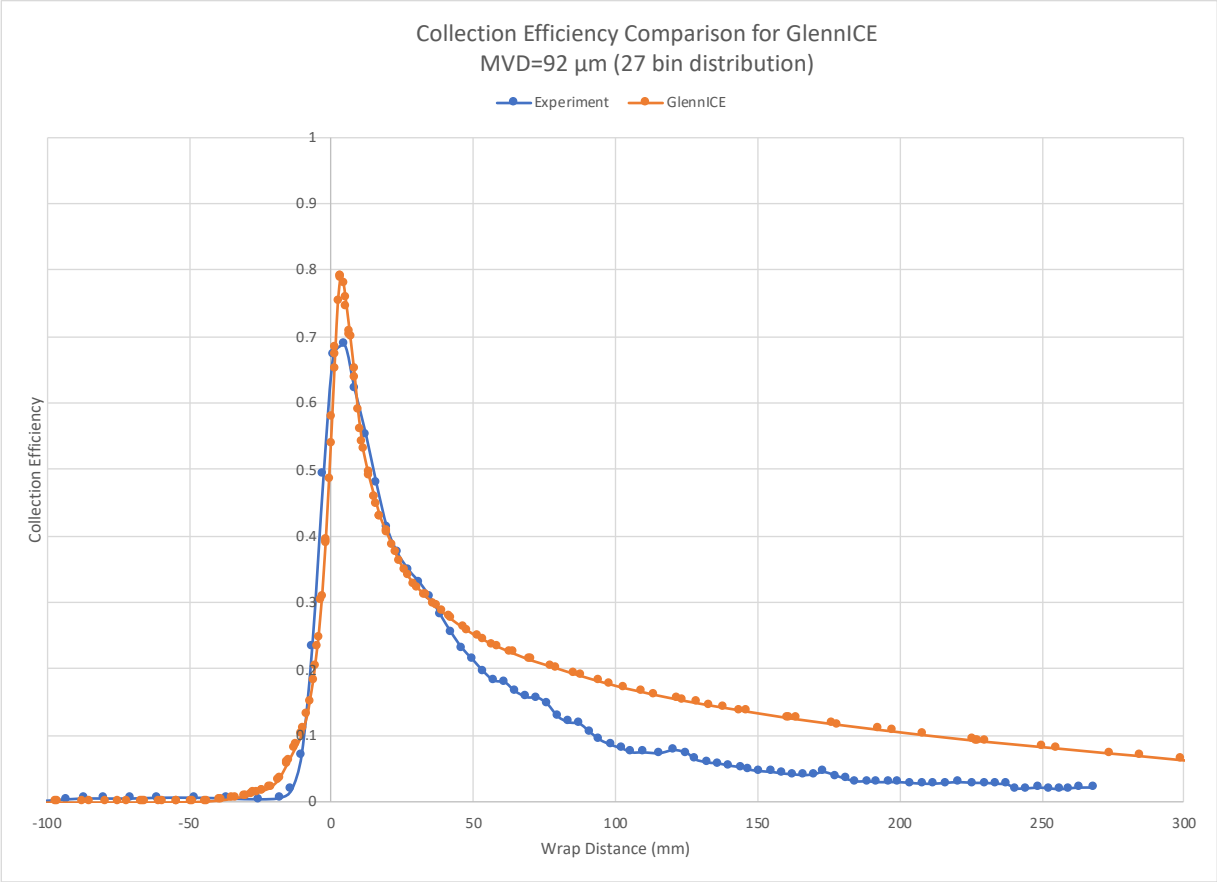
LEWIICE2D Swept Tail Collection Efficiency MVD = 92



Time = N/A
V=78.7 m/s
AOA=6°
T=291.2 K
LWC=N/A
MVD=92 (27 bin dist)

SHAPING THE FUTURE OF AEROSPACE

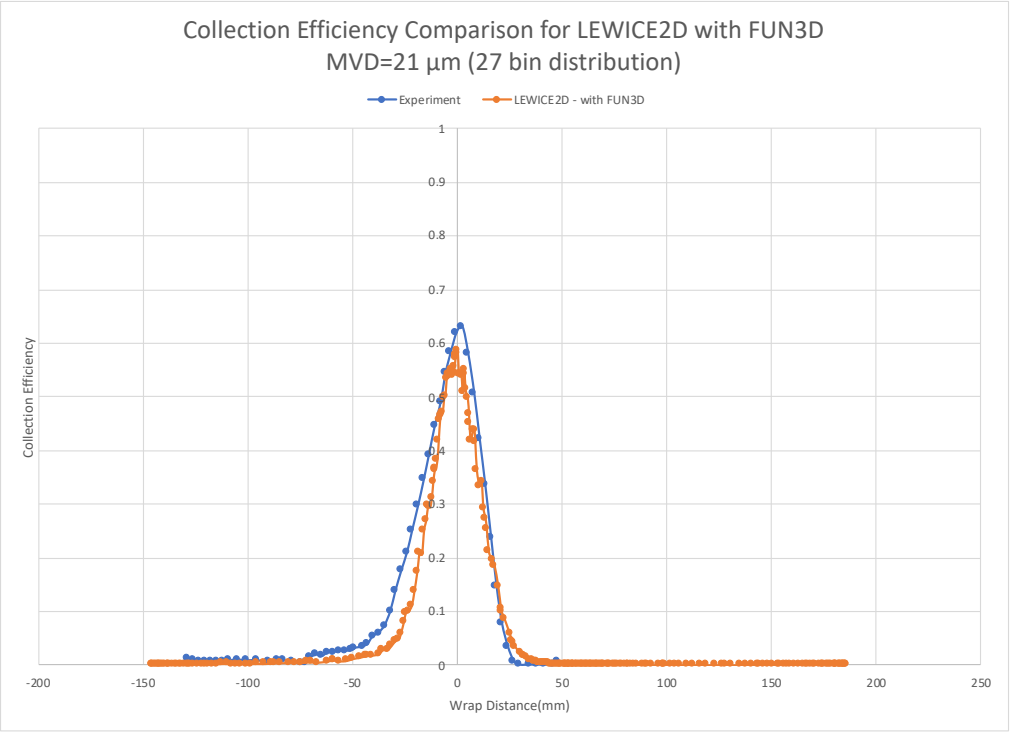
GlennICE Swept Tail MVD=92



Impingement on Multi-Element Airfoil

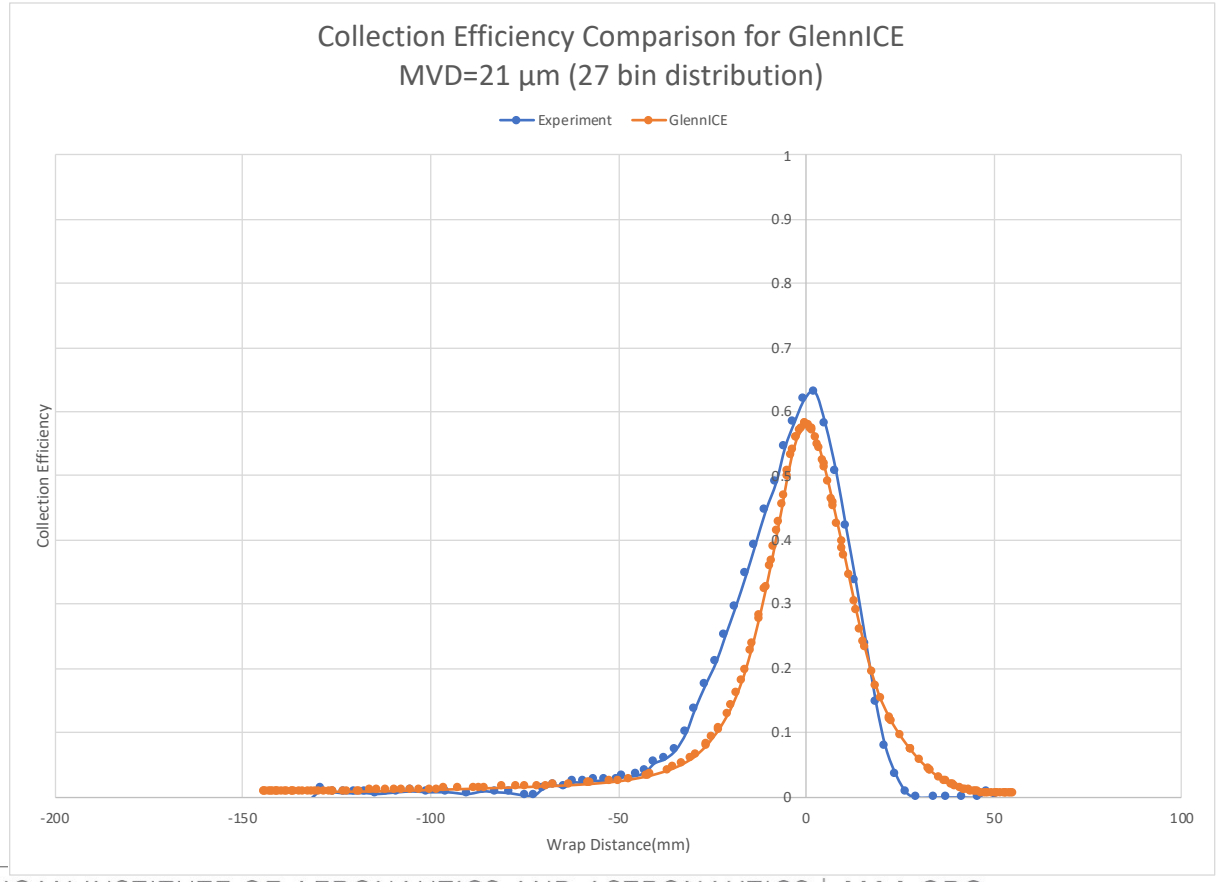
- Two cases
  - 21 micron and 92 micron
  - 27 bin distributions
  - AOA=4°
- LEWICE2D Process
  - Read 2D slice from 3D flow into LEWICE2D

LEWICE2D Multi-Element Airfoil (Slat) MVD = 21



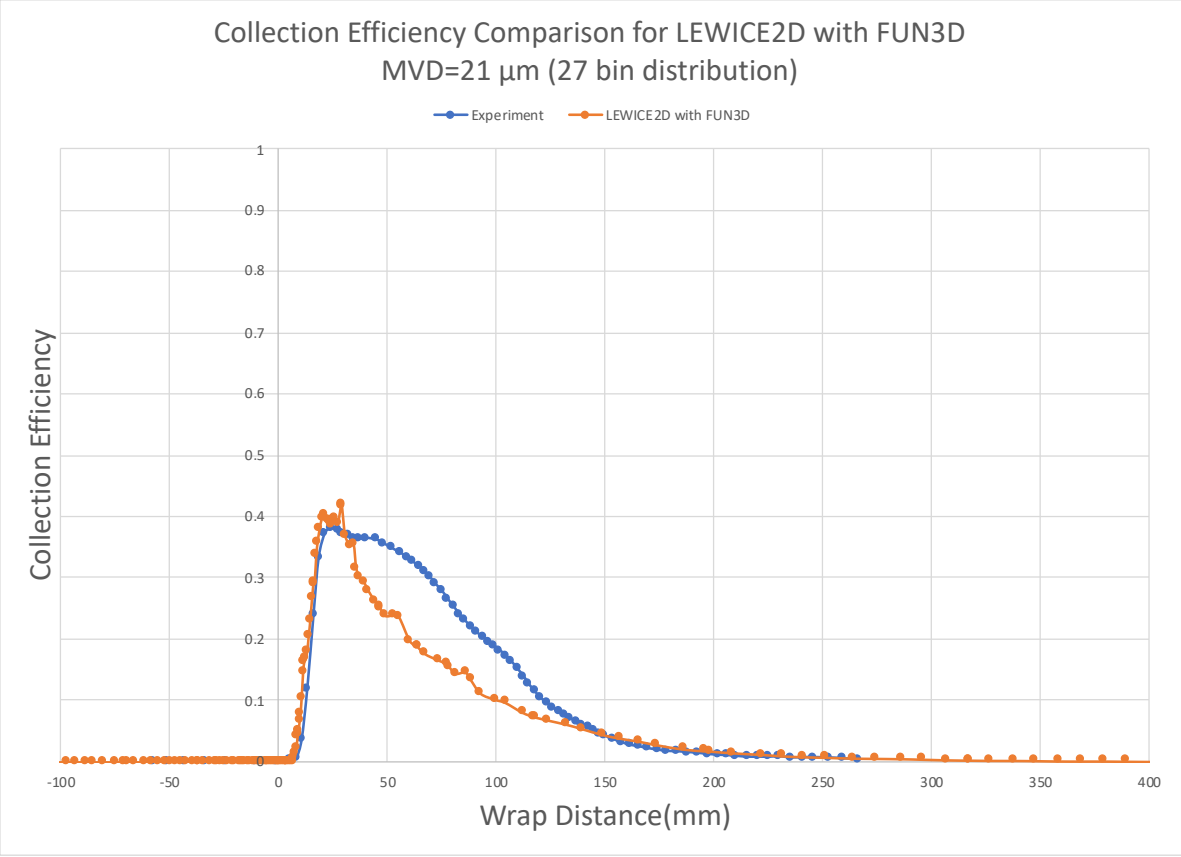
Time = N/A
V=78.7 m/s
AOA=4°
T=291.2 K
LWC=N/A
MVD=21 (27 bin dist)

GlennICE Multi-Element Airfoil (Slat) MVD = 21



Time = N/A
V=78.7 m/s
AOA=4°
T=291.2 K
LWC=N/A
MVD=21 (27 bin dist)

LEWICE2D Multi-Element Airfoil (Main) MVD = 21



Time = N/A
V=78.7 m/s
AOA=4°
T=291.2 K
LWC=N/A
MVD=21 (27 bin dist)

AMERICA

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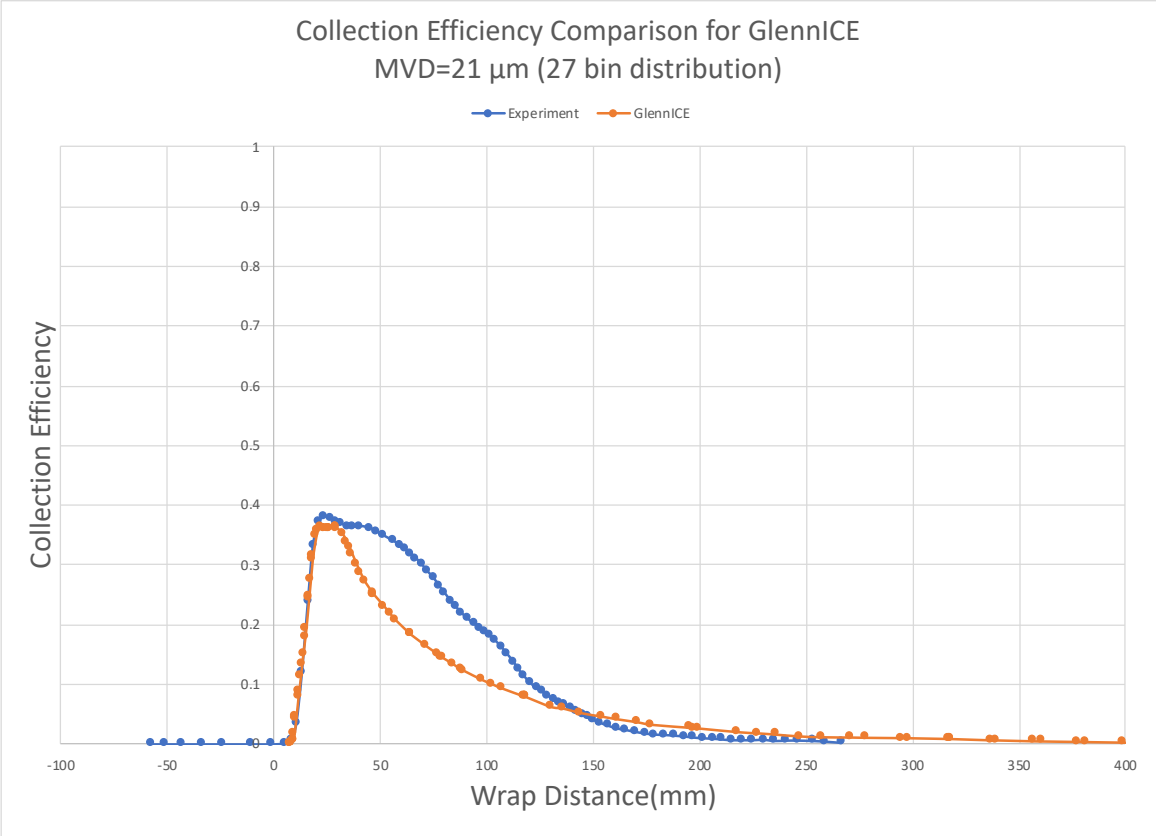
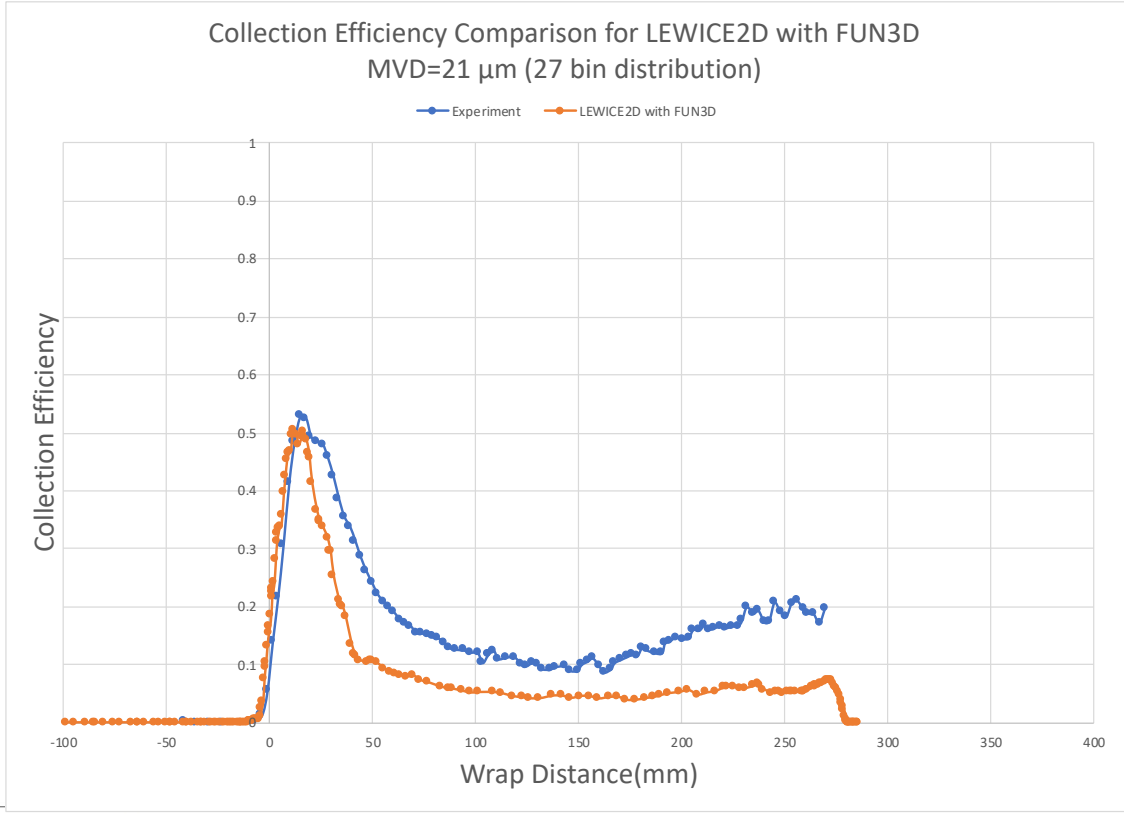
SHAPING THE FUTURE OF AEROSPACE

GlennICE Multi-Element Airfoil (Main) MVD = 21



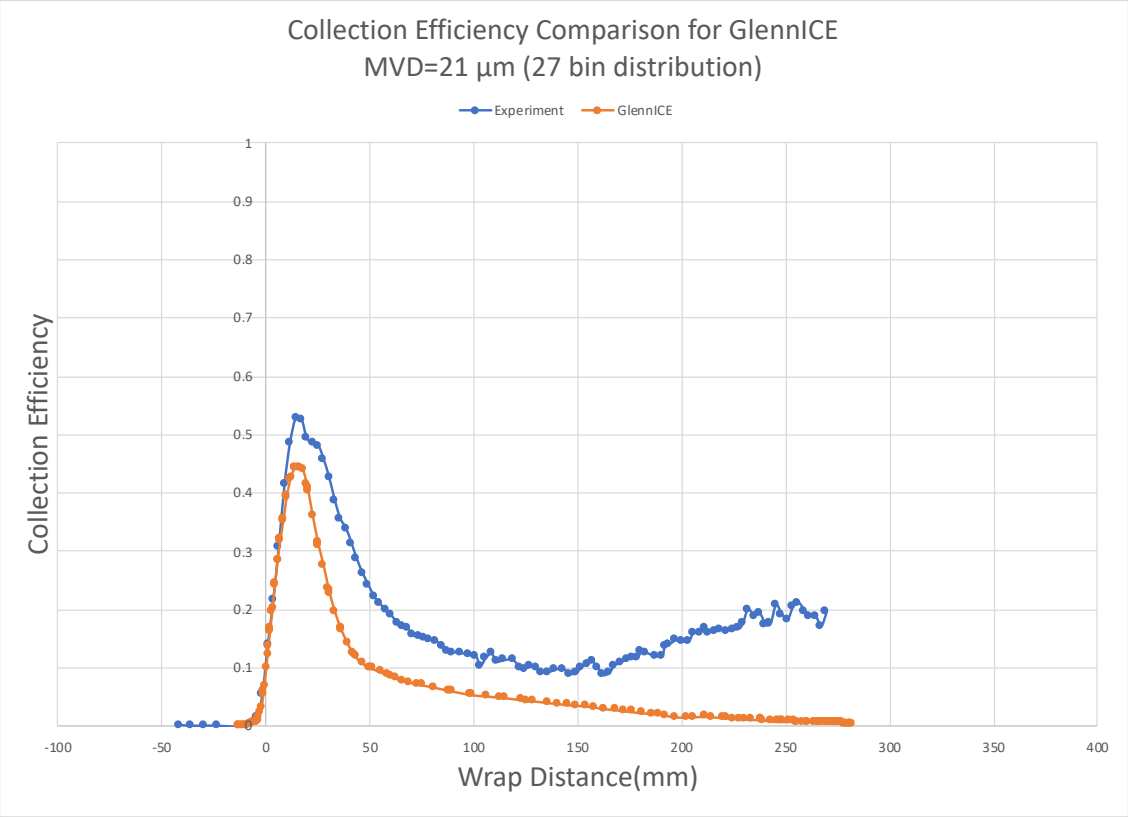
Time = N/A
V=78.7 m/s
AOA=4°
T=291.2 K
LWC=N/A
MVD=21 (27 bin dist)

LEWICE2D Multi-Element Airfoil (Flap) MVD = 21



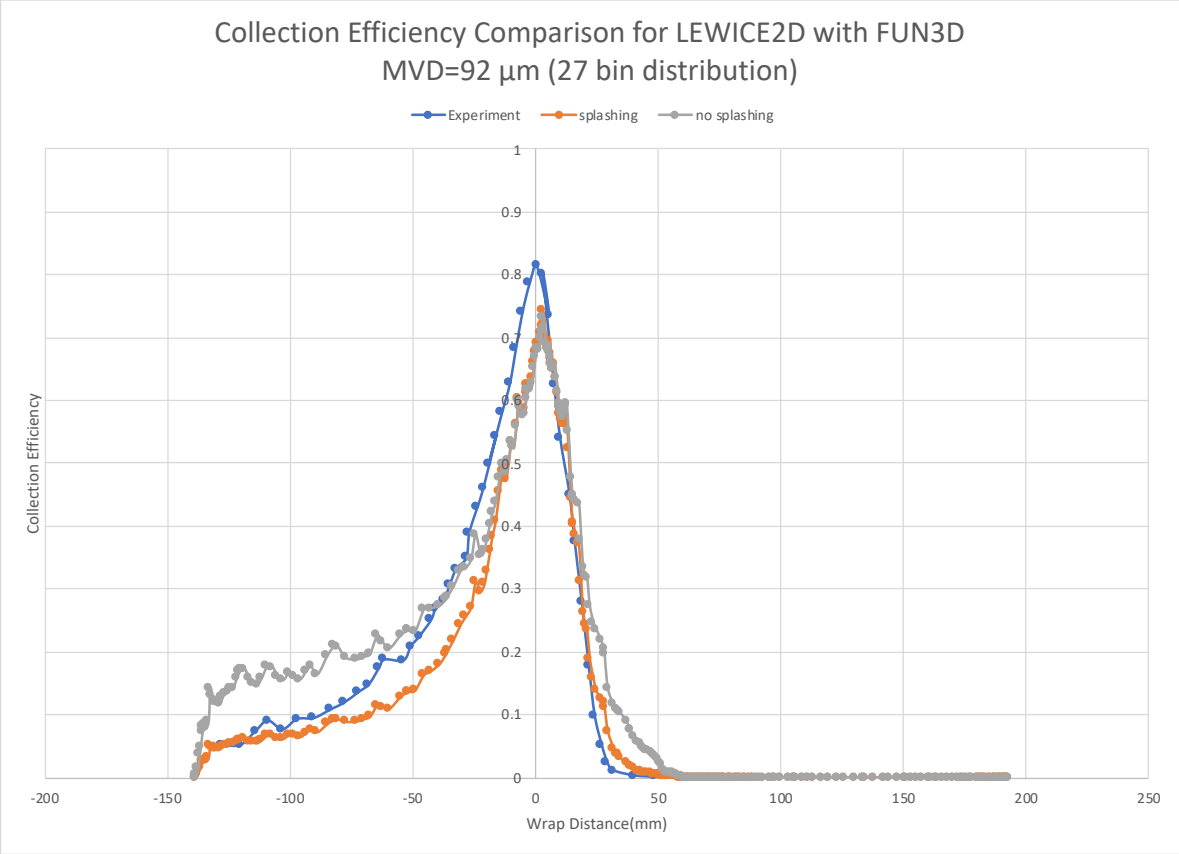
Time = N/A
V=78.7 m/s
AOA=4°
T=291.2 K
LWC=N/A
MVD=21 (27 bin dist)

GlennICE Multi-Element Airfoil (Flap) MVD = 21



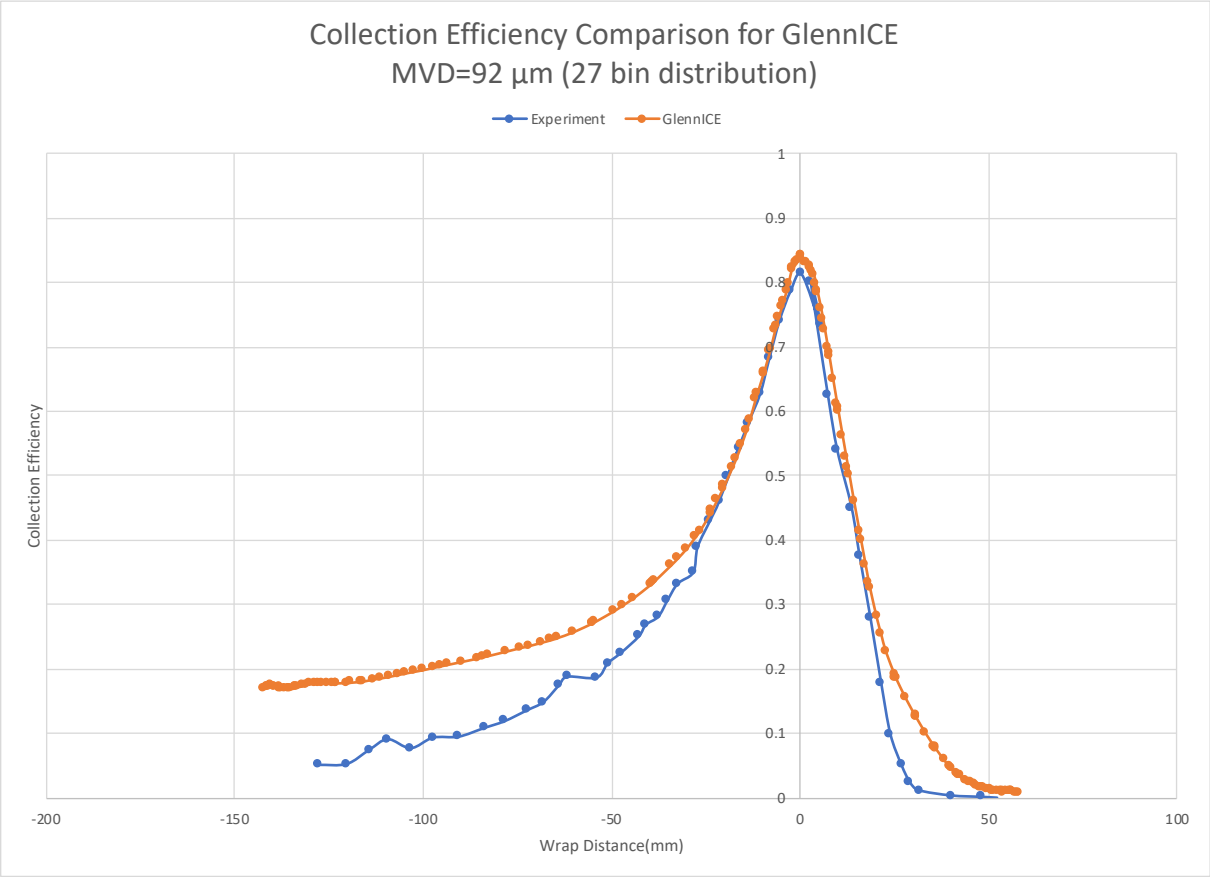
Time = N/A
V=78.7 m/s
AOA=4°
T=291.2 K
LWC=N/A
MVD=21 (27 bin dist)

LEWICE2D Multi-Element Airfoil (Slat) MVD = 92



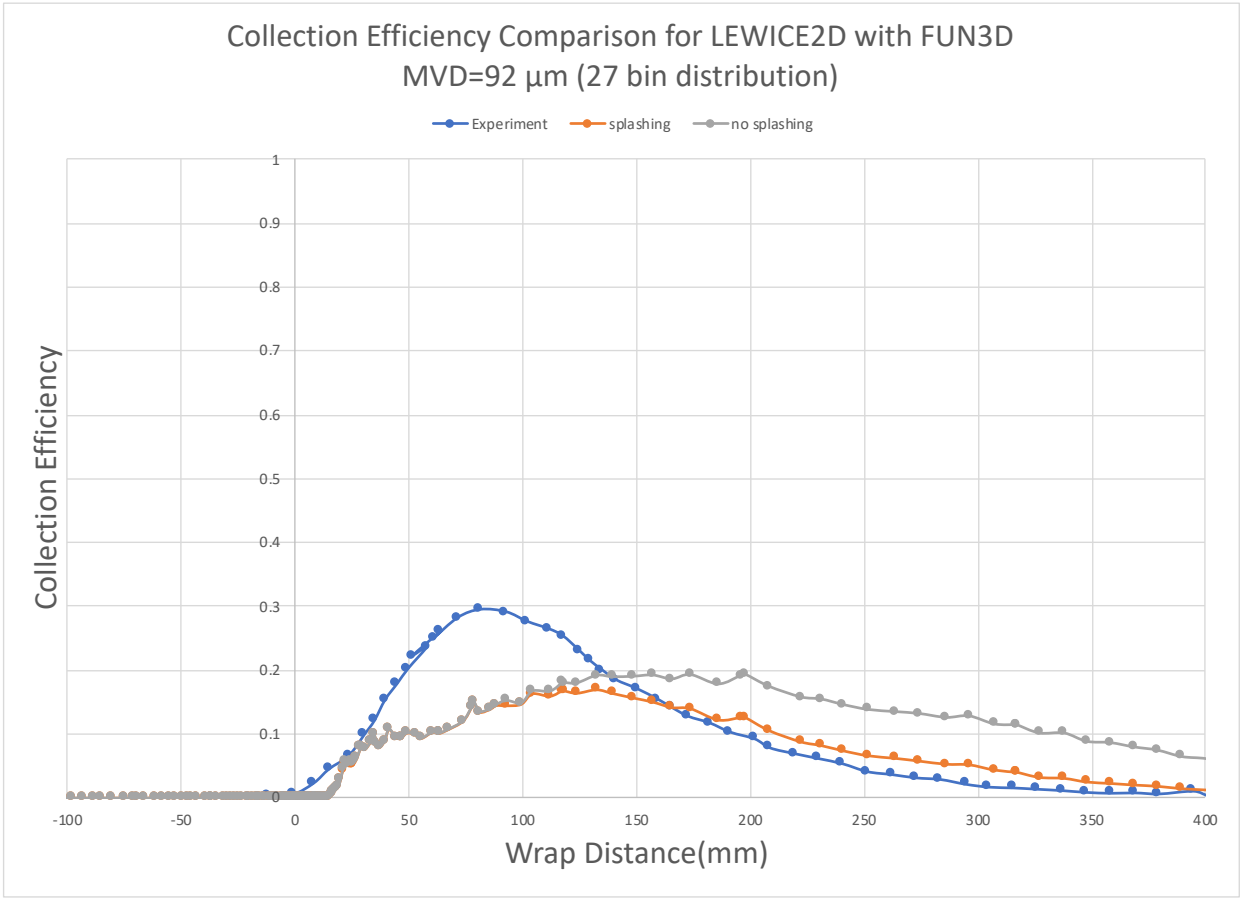
Time = N/A
V=78.7 m/s
AOA=4°
T=291.2 K
LWC=N/A
MVD=21 (27 bin dist)

GlennICE Multi-Element Airfoil (Slat) MVD = 92



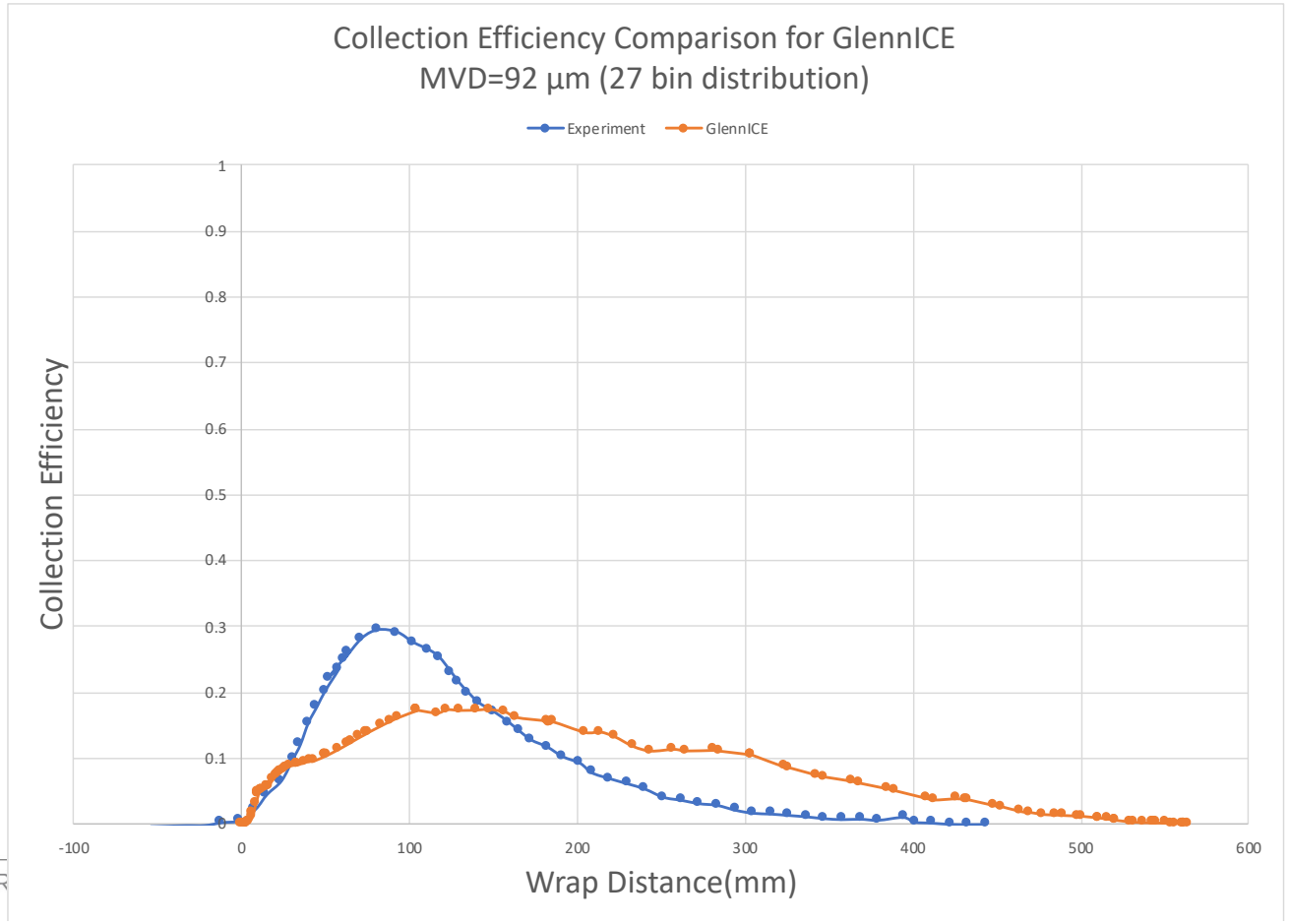
Time = N/A
V=78.7 m/s
AOA=4°
T=291.2 K
LWC=N/A
MVD=21 (27 bin dist)

LEWICE2D Multi-Element Airfoil (Main) MVD = 92



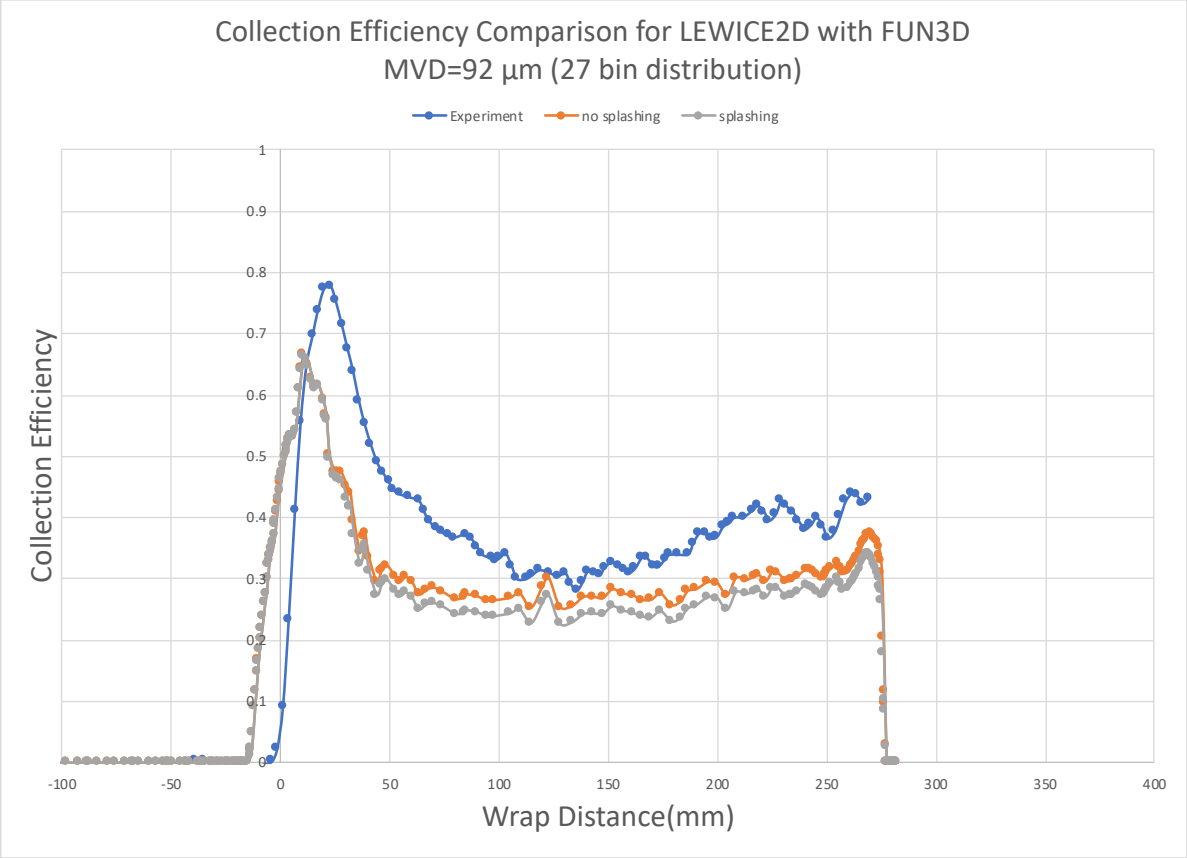
Time = N/A
V=78.7 m/s
AOA=4°
T=291.2 K
LWC=N/A
MVD=21 (27 bin dist)

GlennICE Multi-Element Airfoil (Main) MVD = 92



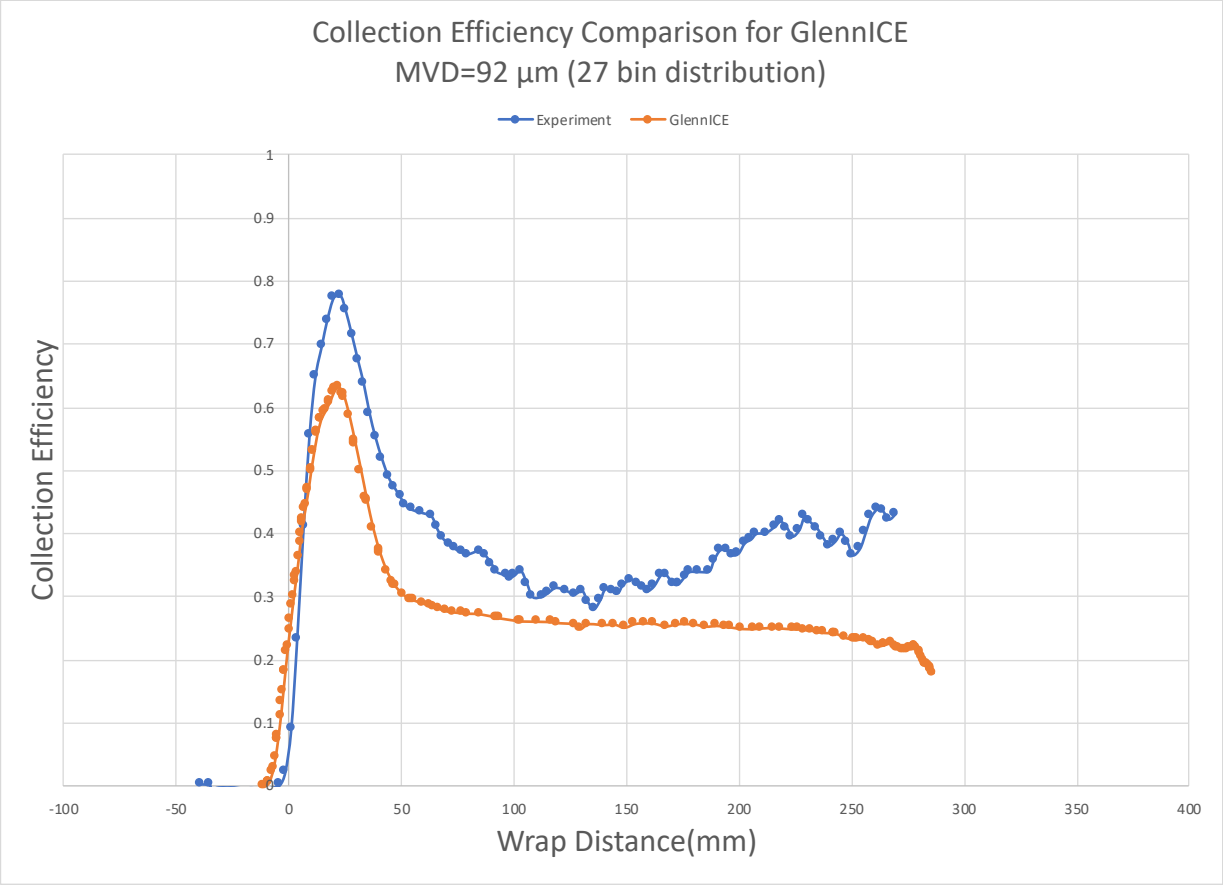
Time = N/A
V=78.7 m/s
AOA=4°
T=291.2 K
LWC=N/A
MVD=21 (27 bin dist)

LEWICE2D Multi-Element Airfoil (Flap) MVD = 92



Time = N/A
V=78.7 m/s
AOA=4°
T=291.2 K
LWC=N/A
MVD=21 (27 bin dist)

GlennICE Multi-Element Airfoil (Flap) MVD = 92

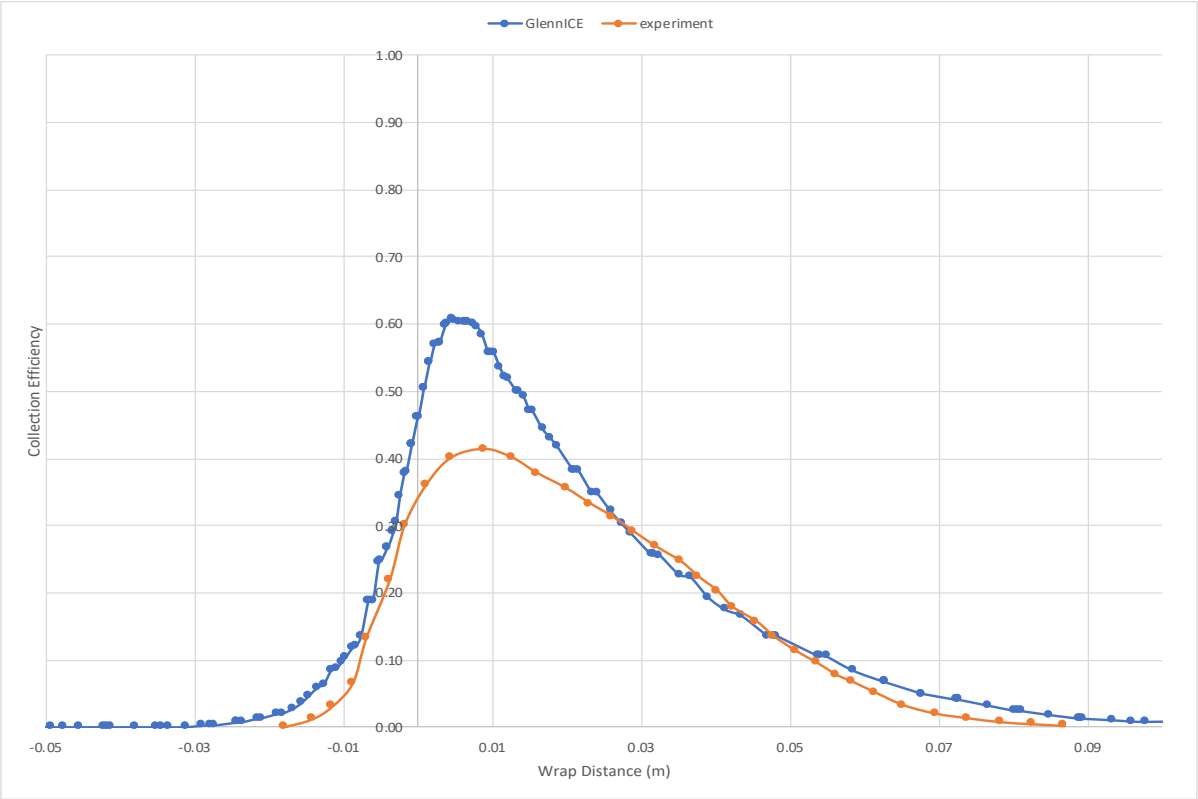


Time = N/A
V=78.7 m/s
AOA=4°
T=291.2 K
LWC=N/A
MVD=21 (27 bin dist)

Impingement on Axi-symmetric Inlet

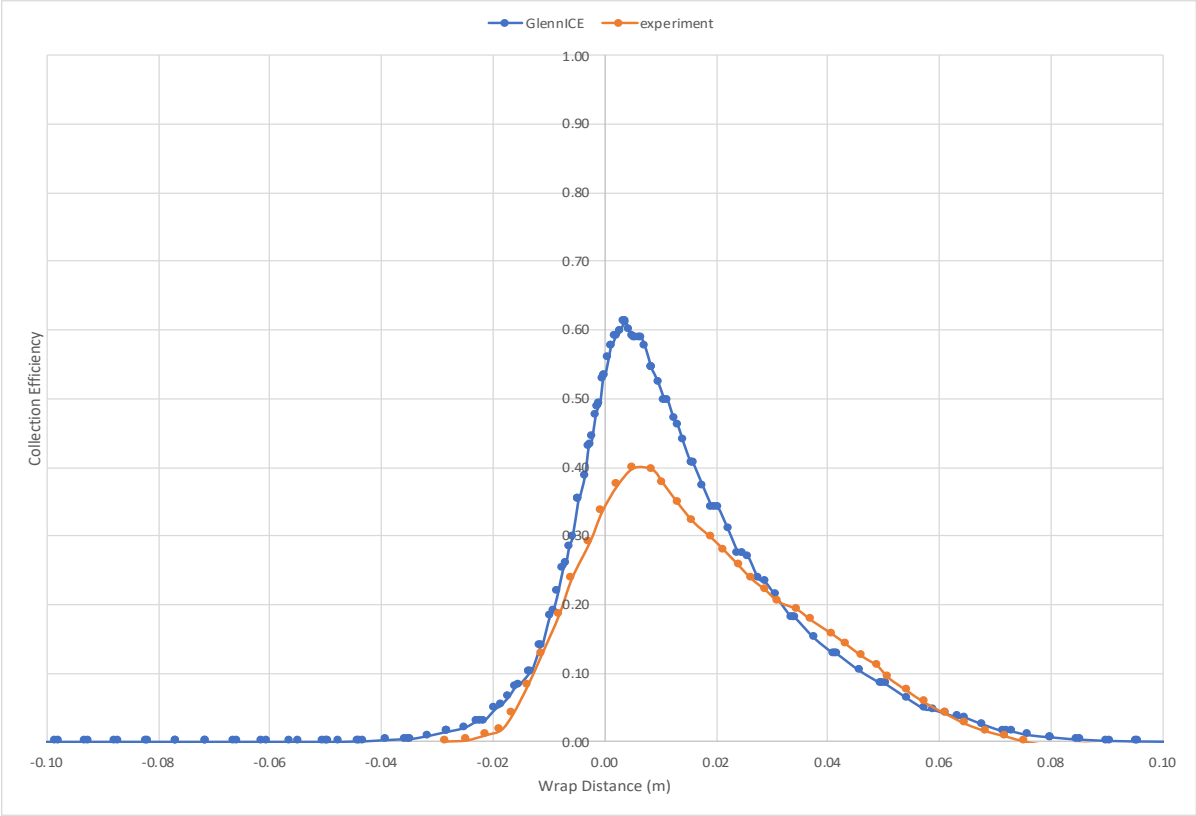
- Two cases
  - Two mass flows through inlet
  - AOA=15°, so results are not symmetric
- LEWICE2D not performed
- GlennICE 7-Bin Results presented

GlennICE Case 131 Theta=0°



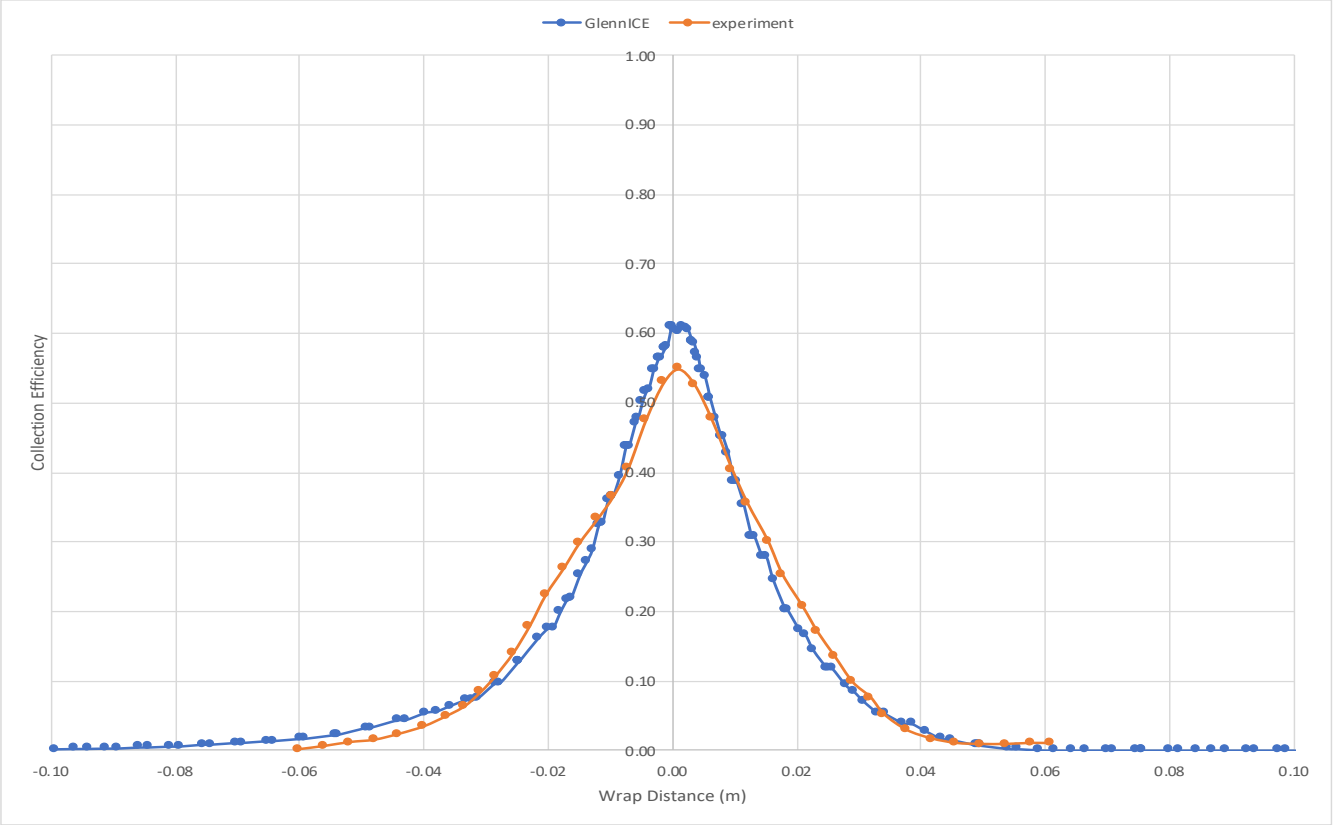
Time = N/A
V=78.7 m/s
AOA=4°
T=283.2 K
Mass Flow = 7.8 kg/s
MVD=21 (7 bin dist)

GlennICE Case 131 Theta=45°



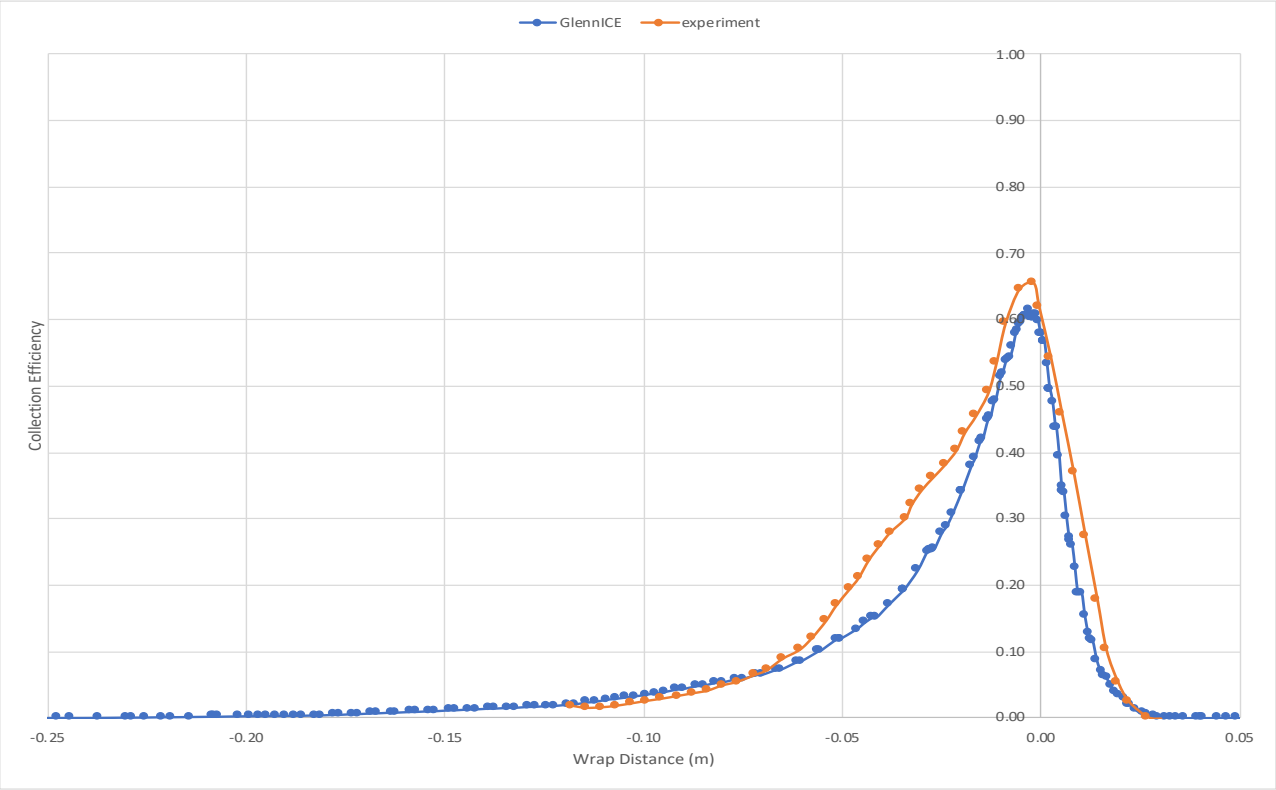
Time = N/A
V=78.7 m/s
AOA=4°
T=283.2 K
Mass Flow = 7.8 kg/s
MVD=21 (7 bin dist)

GlennICE Case 131 Theta=90°



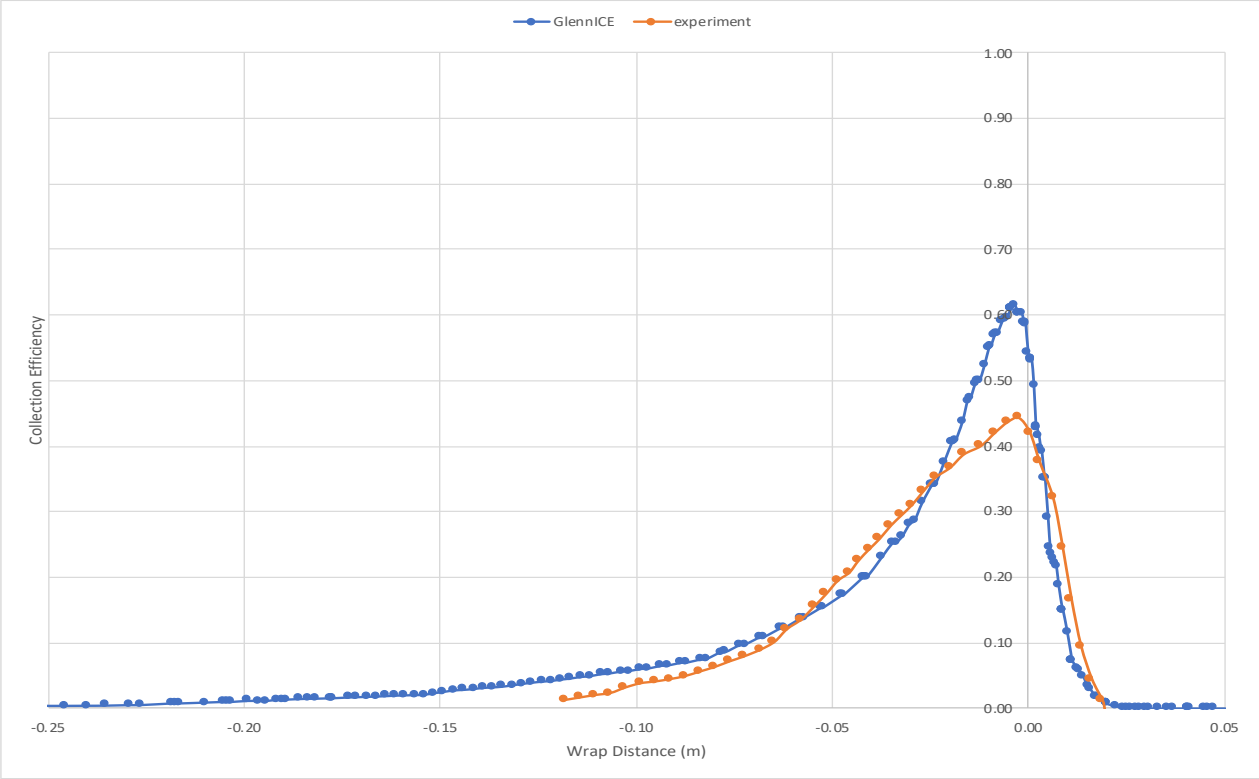
Time = N/A
V=78.7 m/s
AOA=4°
T=283.2 K
Mass Flow = 7.8 kg/s
MVD=21 (7 bin dist)

GlennICE Case 131 Theta=135°



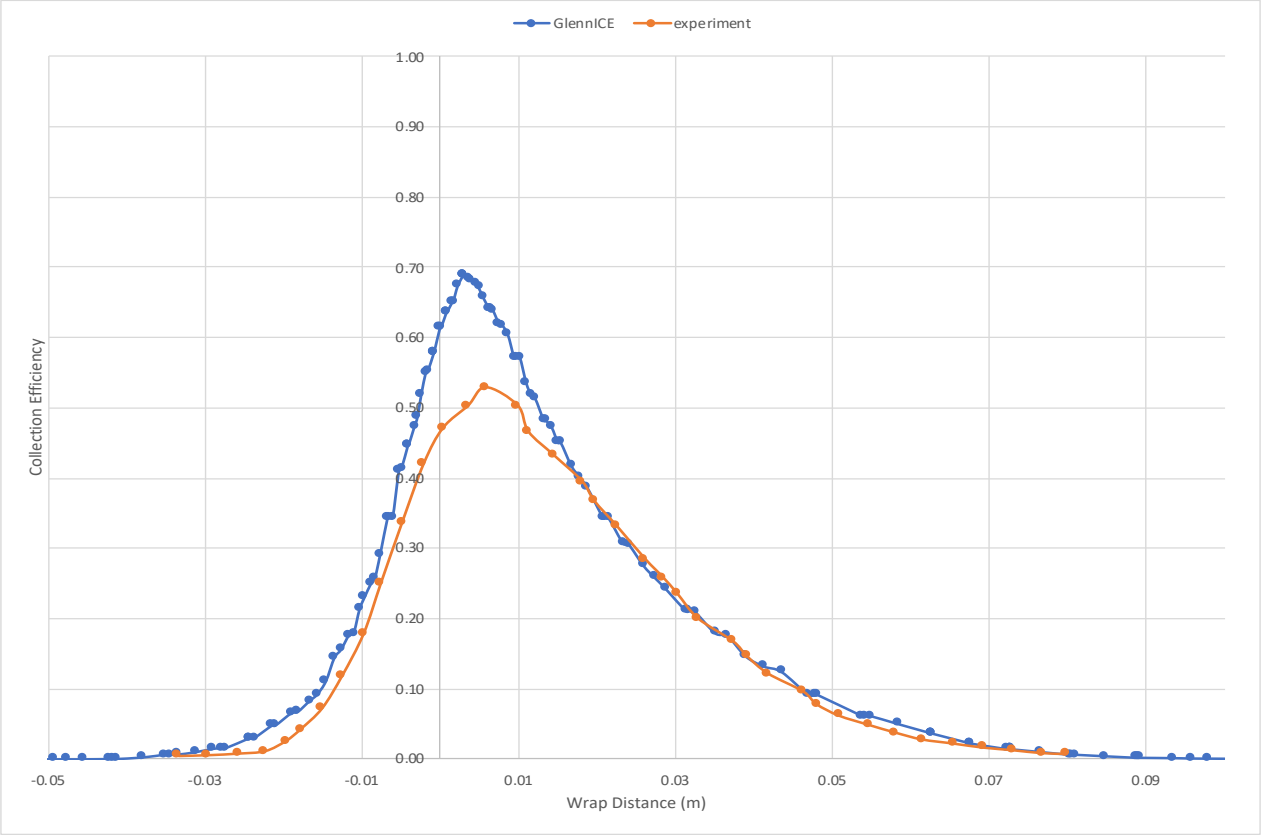
Time = N/A
V=78.7 m/s
AOA=4°
T=283.2 K
Mass Flow = 7.8 kg/s
MVD=21 (7 bin dist)

GlennICE Case 131 Theta=180°



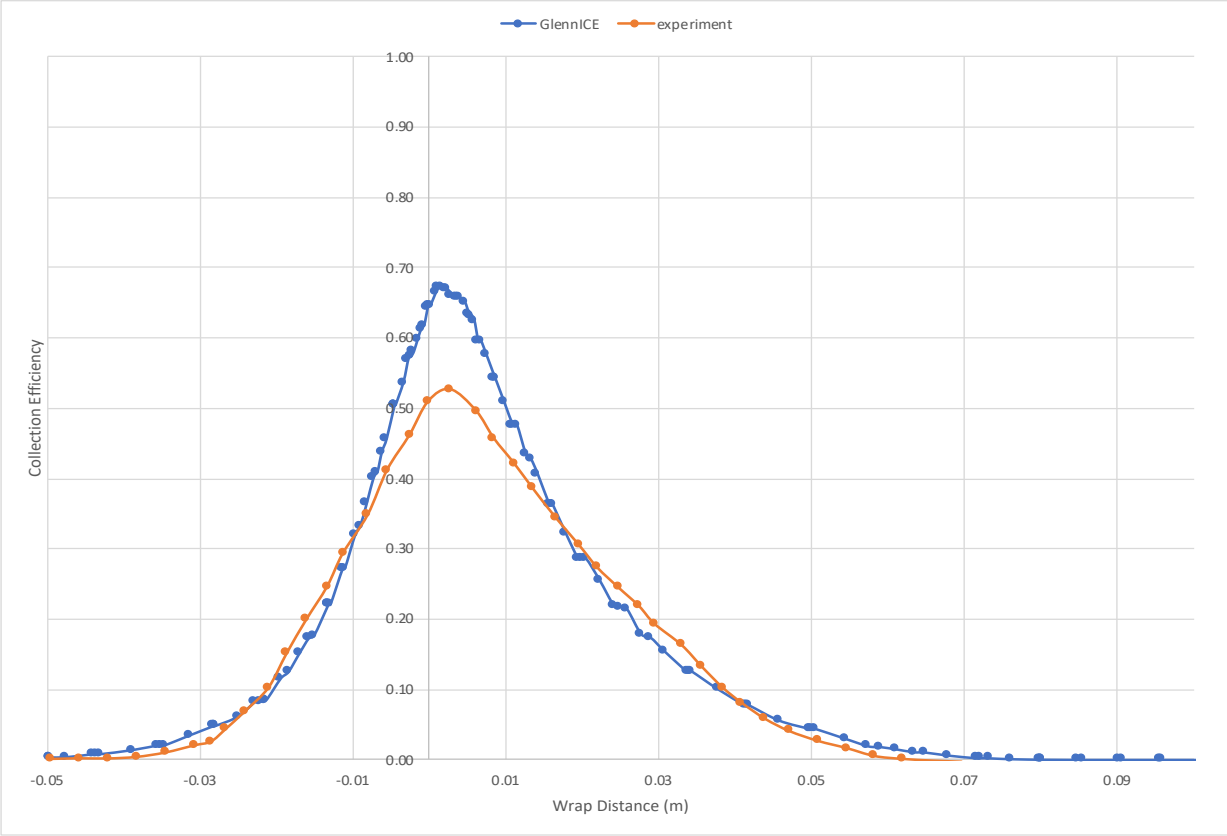
Time = N/A
V=78.7 m/s
AOA=4°
T=283.2 K
Mass Flow = 7.8 kg/s
MVD=21 (7 bin dist)

GlennICE Case 132 Theta=0°



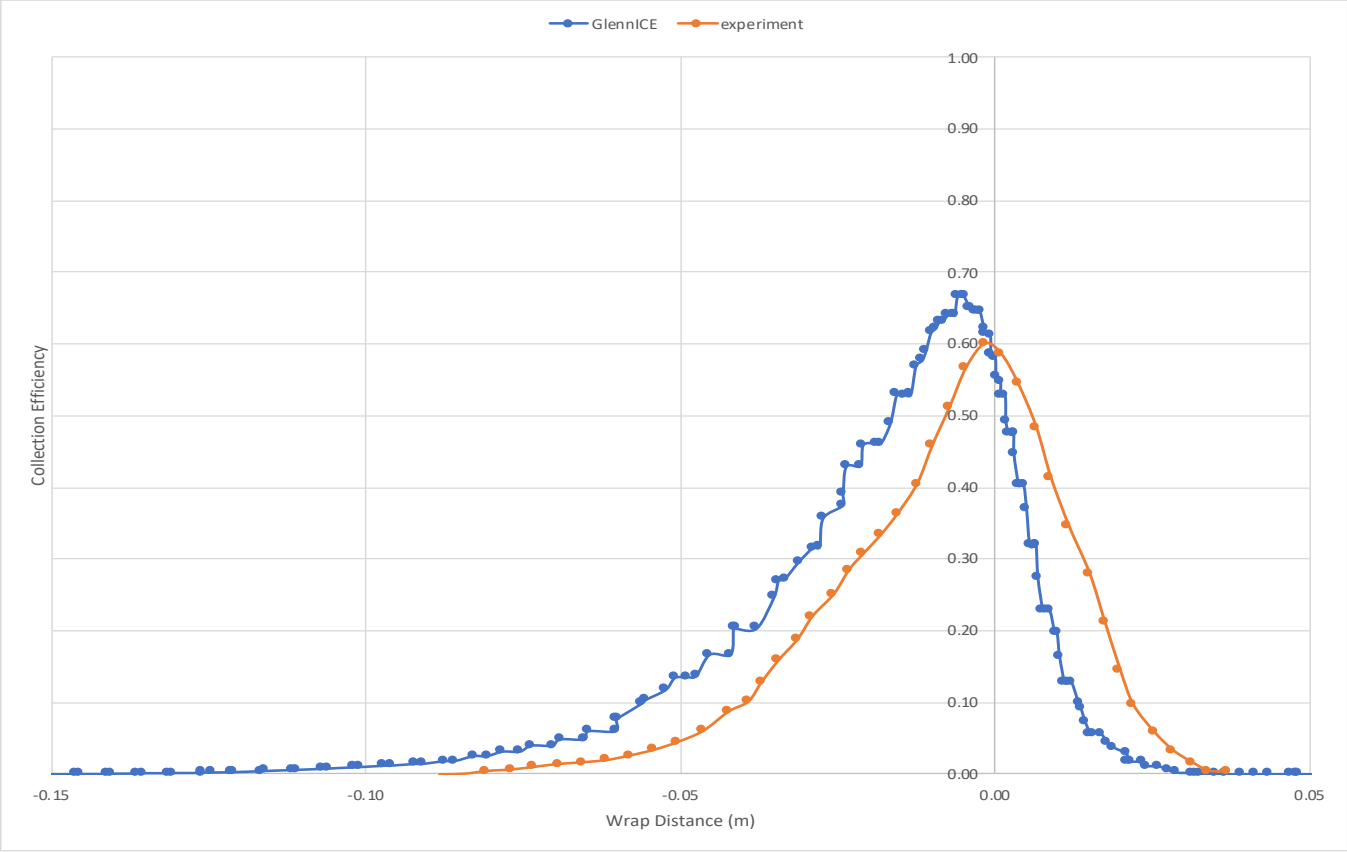
Time = N/A
V=78.7 m/s
AOA=4°
T=283.2 K
Mass Flow = 10.4 kg/s
MVD=21 (7 bin dist)

GlennICE Case 132 Theta=45°



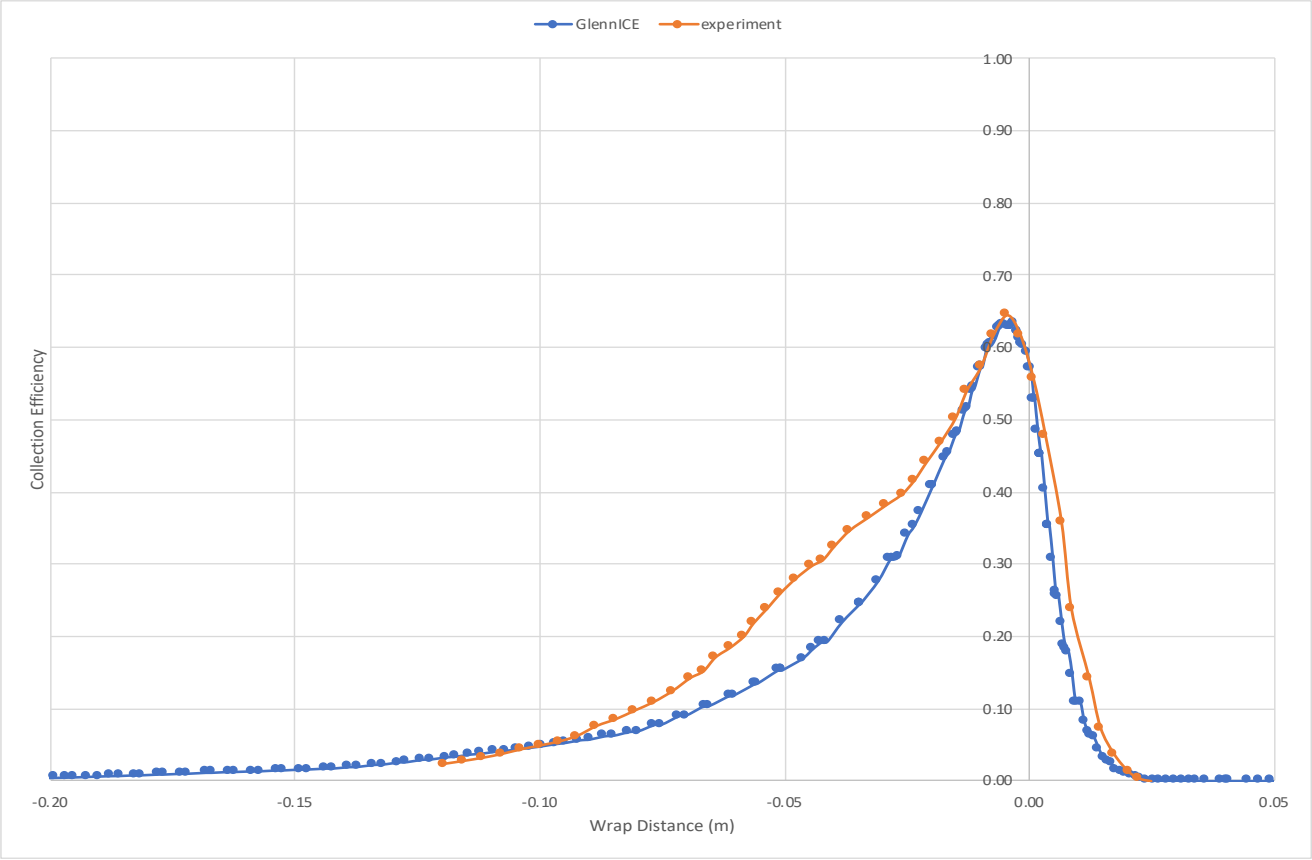
Time = N/A
V=78.7 m/s
AOA=4°
T=283.2 K
Mass Flow = 10.4 kg/s
MVD=21 (7 bin dist)

GlennICE Case 132 Theta=90°



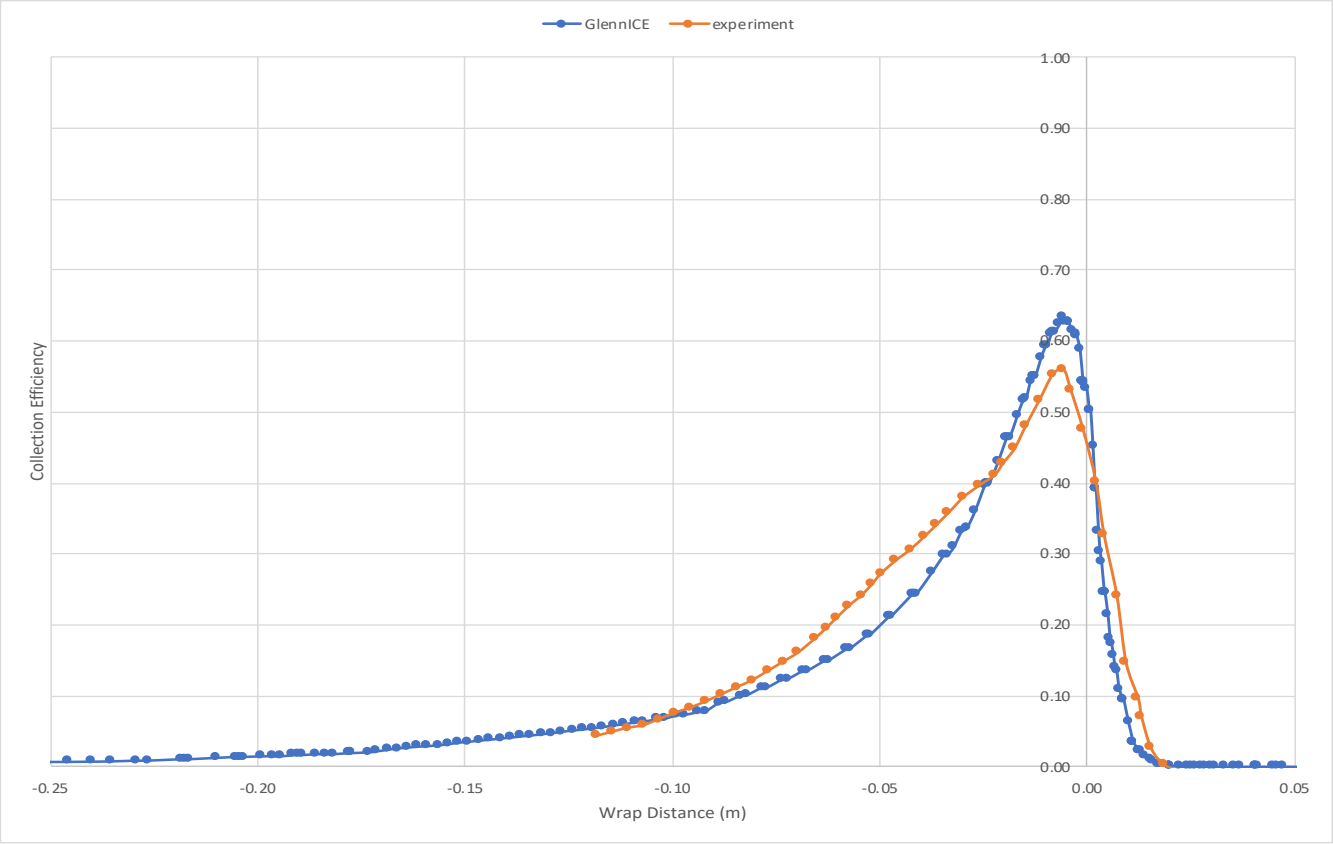
Time = N/A
V=78.7 m/s
AOA=4°
T=283.2 K
Mass Flow = 10.4 kg/s
MVD=21 (7 bin dist)

GlennICE Case 132 Theta=135°



Time = N/A
V=78.7 m/s
AOA=4°
T=283.2 K
Mass Flow = 10.4 kg/s
MVD=21 (7 bin dist)

GlennICE Case 132 Theta=180°



Time = N/A
V=78.7 m/s
AOA=4°
T=283.2 K
Mass Flow = 10.4 kg/s
MVD=21 (7 bin dist)

Conclusions – LEWICE Results

- LEWICE underpredicted heat transfer coefficient on NACA23012 airfoil
- Constant Ice Density leads to inconsistent results for swept wing cases
- Splashing model is tuned to potential flow, not Naviér-Stokes flows
- Use of cartesian grid lead to noise in collection efficiency prediction

Conclusions - GlennICE

- Use of constant heat transfer enhancement and constant ice density led to inconsistent results
- Used the grids supplied
  - Lack of time to perform grid sensitivity study for multi-element airfoil and inlet could cause discrepancy in results