

3rd Ice Prediction Workshop Results: ONERA M6 Wing

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Presented 22 September 2026

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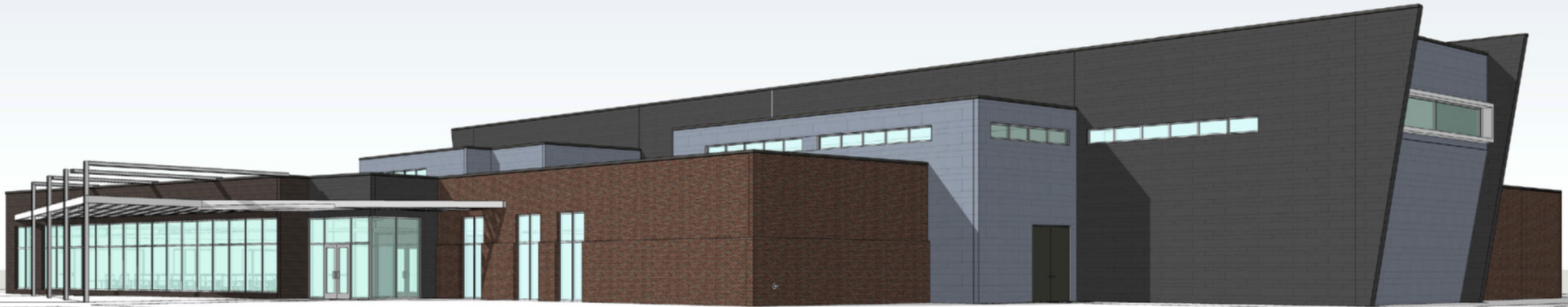
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3rd Ice Prediction Workshop Results: ONERA M6 Wing

Advanced Virtual Engineering and Testing Laboratories

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3rd IPW AIAA Workshop | September 22, 2026

NIAR Advanced Virtual Engineering and Testing Laboratories

- **NIAR Virtual Engineering Laboratory Evolution:** 1992 Computational Mechanics(M+S) – Virtual Engineering 2005 (MBE-MBSE) – Advanced Virtual Engineering and Testing 2010 (MBE, MBSE, DE and Digital Twin)
- **Since 2005 the AVET Laboratory has completed over 420 Virtual Engineering Projects:**
 - **World Class Research Program:** AVET Clients and Research Partners in 20 Countries
 - **Industry Applications:** Aerospace (Commercial, Military, and Space), Automotive, and Mass Transit
 - **Federal Government Agencies:** FAA, NASA, DoD (Air Force, ARMY, ONR), NSF, FTA, DOT
 - **Successfully completed CBA Projects** with FAA, EASA, and IAA
 - **R&D Methods Development and V&V:** From Conceptual Design to Certification by Analysis
- **Workforce Development:**
 - Over 400 Wichita State University engineering students have graduated from the Lab (U.G., M.S., and Ph.D.)
 - Organized Industry and Regulators workshops and training
 - Organized International Conferences (ASIDIC)
 - Hosted Research Scholars from other Universities and Research Centers: Italy, Japan, Germany, Mexico, France, and Spain
 - Licensed Simulation Methods to Aerospace OEMs
 - Participate in Committees: CMH 17, SAE SG28, SAE Seat Modeling...



Outline

3rd Ice Prediction Workshop Results: ONERA M6 Wing

- Numerical Methodology
- Multi-Shot Remeshing Technique
- Ice Accretion Results
- Conclusions and Future Work

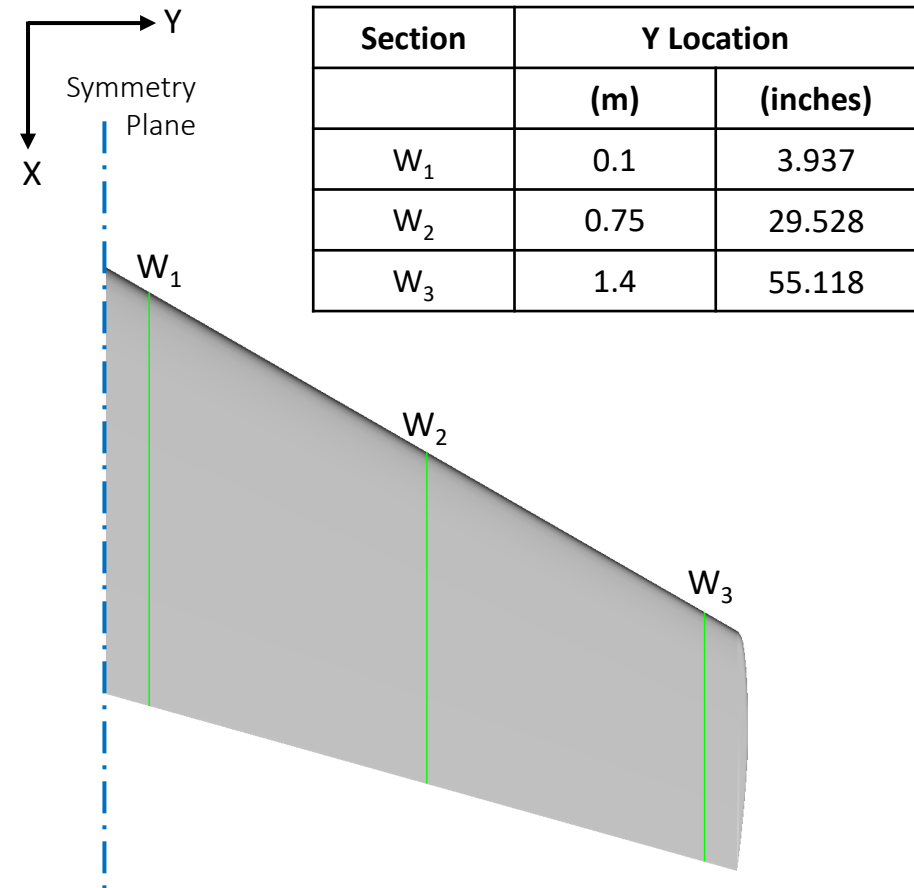
ONERA M6 Wing Geometry

3rd Ice Prediction Workshop Results: ONERA M6 Wing

Geometry Parameters:

- Root chord = 1.0 m
- Semi span = 1.476018 m
- Reference area = 1.1532 m²
- Aspect ratio = 3.778567
- Mean Aerodynamic Chord (MAC) = 0.801673 m

Moment Reference Center		
X (m)	Y (m)	Z (m)
0.25	0.0	0.0



Flight and Icing Conditions

3rd Ice Prediction Workshop Results: ONERA M6 Wing

Flight Conditions:

- Freestream Mach, $M_\infty = 0.40$
- Freestream Velocity, $U_\infty = 131.064$ m/s
- Angle of Attack, $\alpha = 2^\circ$
- Static Temperature, $T_{s,\infty} = 267.15$ K
- Total Temperature, $T_{0,\infty} = 275.7$ K
- Pressure, $P_\infty = 52377.824$ Pa
- Density, $\rho_\infty = 0.68301$ kg/m³
- Speed of Sound, $a_\infty = 327.66$ m/s
- Dynamic Viscosity, $\mu_\infty = 1.68626\text{E-}5$ Pa.s
- Reynolds Number, $Re_c = 4.2558\text{E}6$

Icing Conditions:

- Icing Temperature, $T_s = 267.15$ K
- Accretion Time, $t = 1350$ s
- Liquid Water Content, $LWC = 0.51$ g/m³
- Mean Volumetric Diameter, $MVD = 20$ μm



Numerical Methodology

3rd Ice Prediction Workshop Results: ONERA M6 Wing

Numerical Methodology Overview

3rd Ice Prediction Workshop Results: ONERA M6 Wing

Model / Method	ONERA M6
CFD Model	RANS
Turbulence Model	k- ω SST
HTC Method	Recovery Temperature
Droplet Formulation	Eulerian
Droplet Drag Model	Spherical
SLD Effects	None
Thermodynamic Model	SWIM
Ice Density Model	Impact Density Model
Roughness Height	Constant (1 mm)
Geometry Evolution	Lagrangian/Remesh
Ice Accretion Steps	Multi-shot, 6 Layers

Numerical Methodology Overview

3rd Ice Prediction Workshop Results: ONERA M6 Wing

- Multi-Shot Icing Simulation in ANSYS FENSAP-ICE
 - Air Solver: Fluent
 - Droplet Solver: DROP3D
 - Icing Solver: ICE3D
- Fluent
 - Steady-State, Coupled Flow
 - k- ω SST model with viscous heating
 - High Roughness (Sand-Grain) with specified height of 1 mm
- DROP3D
 - Steady-State, Eulerian approach
 - Implicit FEM formulation with upwind scheme
 - Local time stepping with specified CFL number
 - Droplet distribution: composite solution from mass-weighted averaging of individual droplet size runs
- ICE3D
 - Shallow Water Icing Model (SWIM)
 - Eulerian approach with FVM formulation
 - HTC computed based on recovery temperature
 - Impact Ice Density Model
 - Ice Displacement using Lagrangian approach
 - Constant Roughness (Beading model disabled)
- Fluent Remeshing
 - Shrink-wrap technique with ability to handle negative volume/degenerate elements
 - Air (HTC) and Droplet (Collection Efficiency) solutions updated after every remeshing step

Multi-Shot Remeshing Technique

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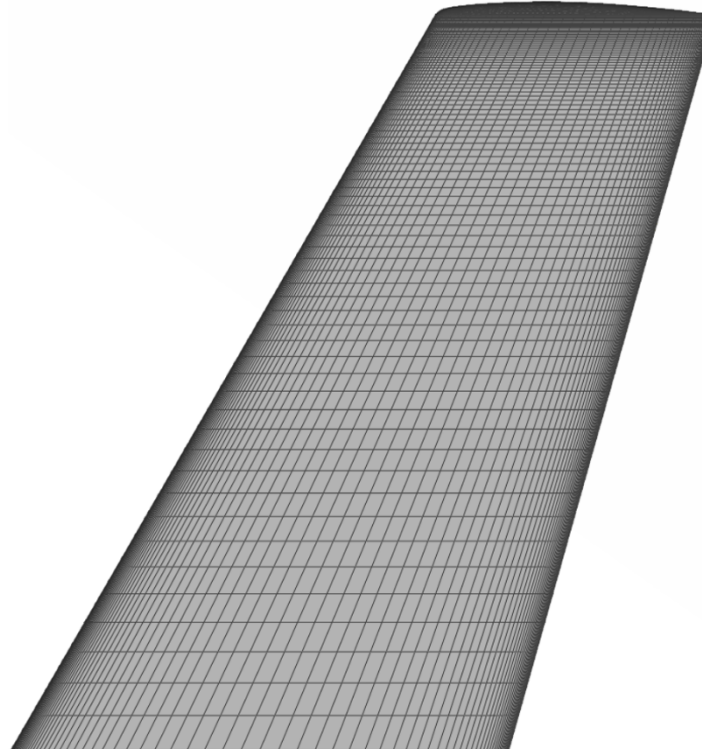
Fluent Remeshing: L2, 7-bin , Rough 1 mm

3rd Ice Prediction Workshop Results: ONERA M6 Wing

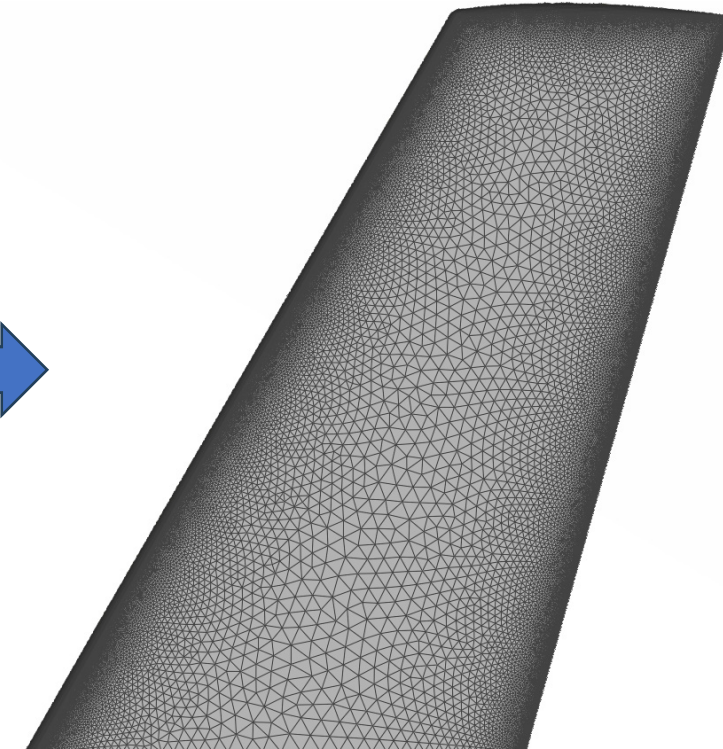
Mesh Type	Original Grid (Shot 1)	Remeshed Grid (Shot 2)
Surface	116,736	563,832
Volume	8,650,752	23,815,842

Resulting total grid elements during Ice Accretion		
	Surface	Volume
Initial Grid (Shot 1)	116,736	8,650,752
Shot 2	563,832	23,815,842
Shot 3	625,484	25,102,576
Shot 4	692,028	28,161,596
Shot 5	760,638	31,292,471
Shot 6	841,622	34,426,348

Original Grid for Shot 1 at
 $t = 0$ s (Quad Dominant)

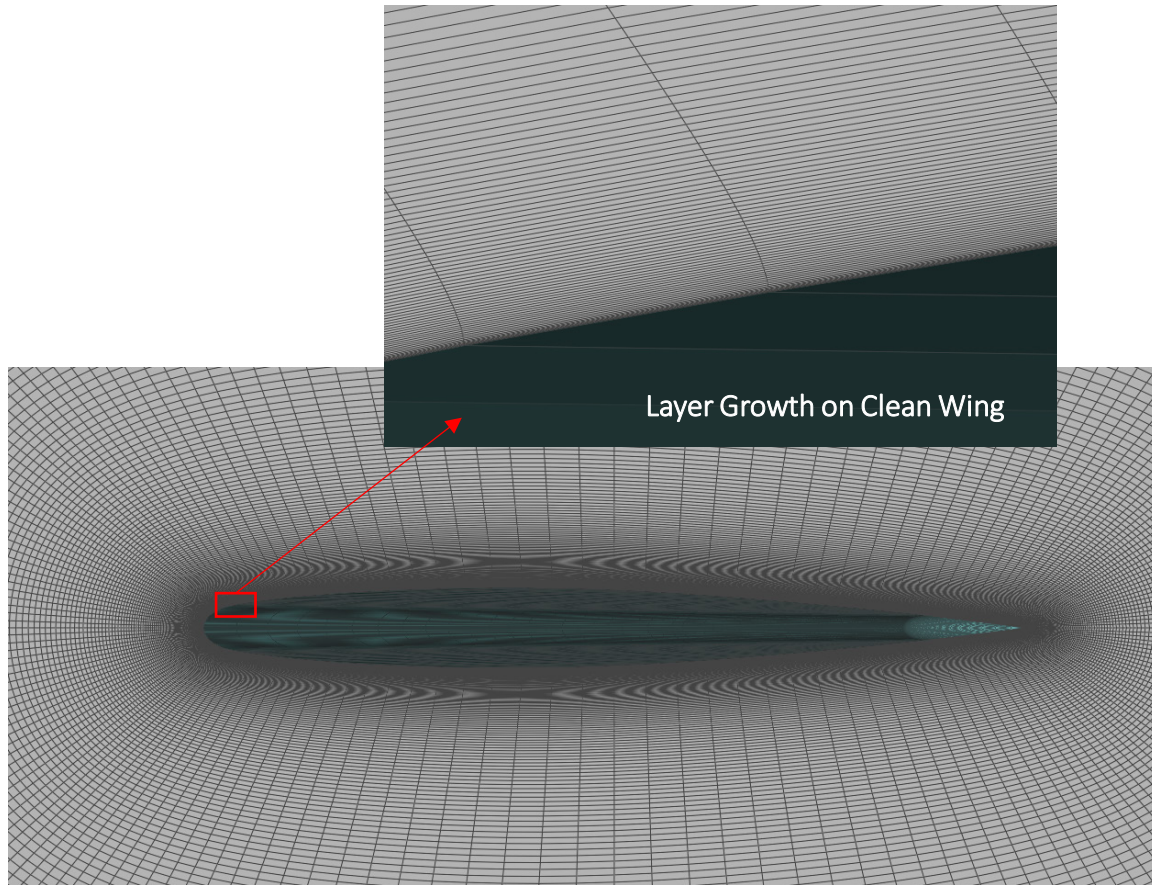


Remeshed Grid for Shot 2 at
 $t = 225$ s (Tria)

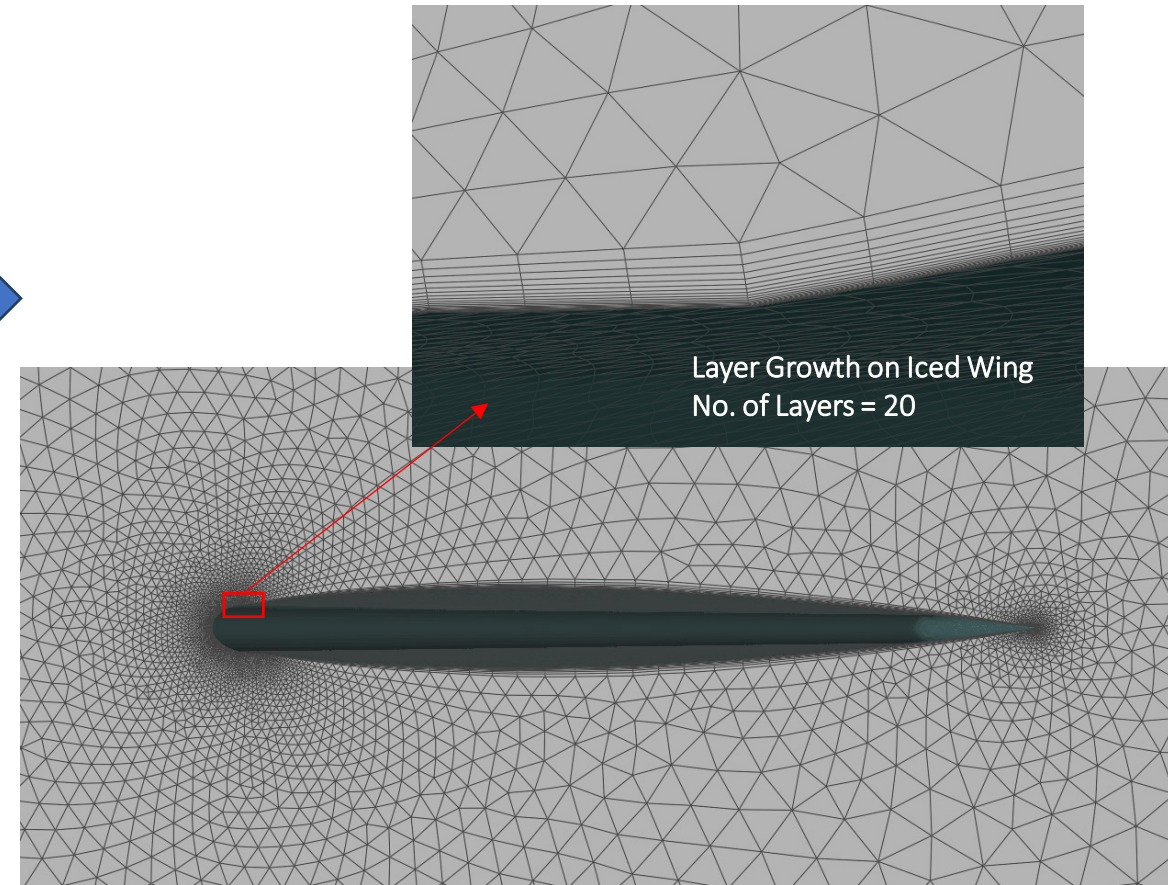


Fluent Remeshing: L2, 7-bin , Rough 1 mm

3rd Ice Prediction Workshop Results: ONERA M6 Wing



Original Grid at t = 0 s (Hex Elements)



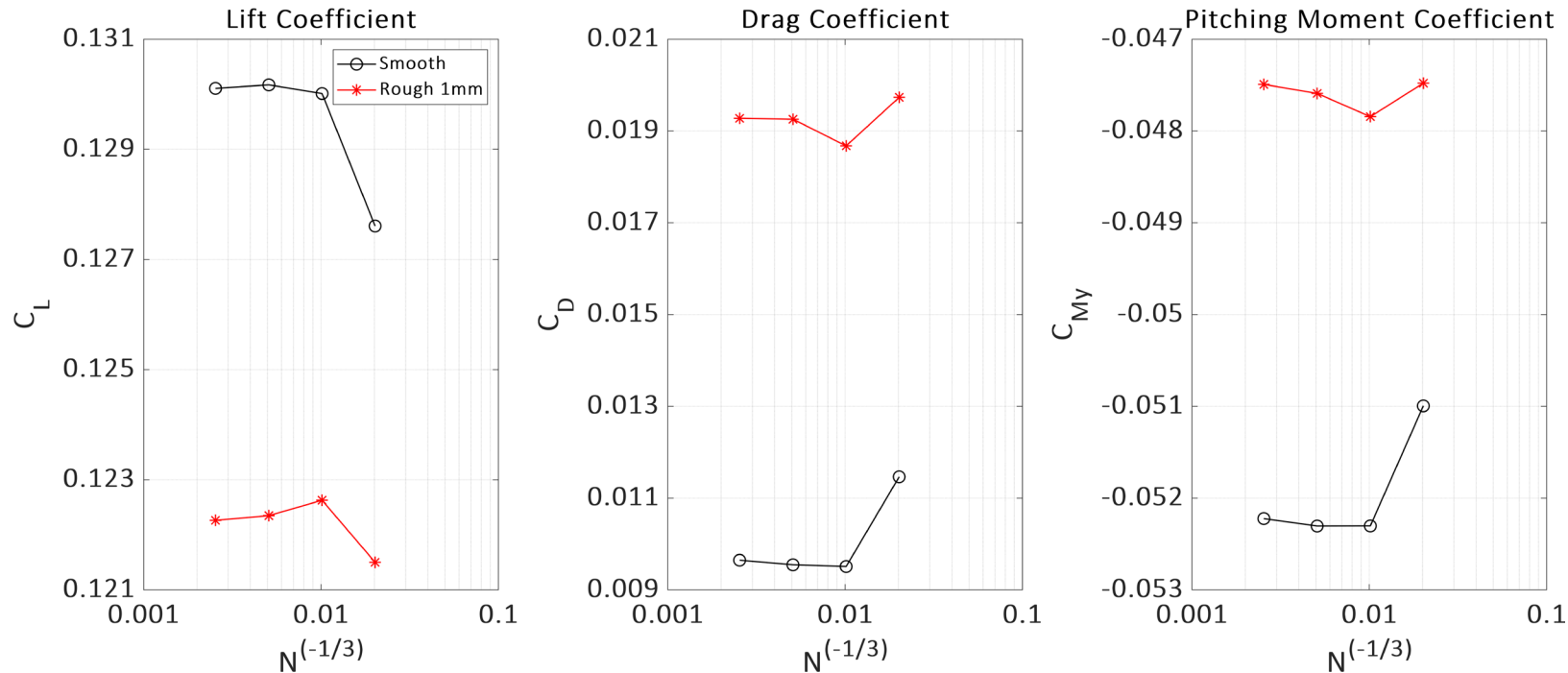
Remeshed Grid for Shot 2 at t = 225 s (Tet + Prism Elements)

Ice Accretion Results

3rd Ice Prediction Workshop Results: ONERA M6 Wing

Aerodynamic Coefficients

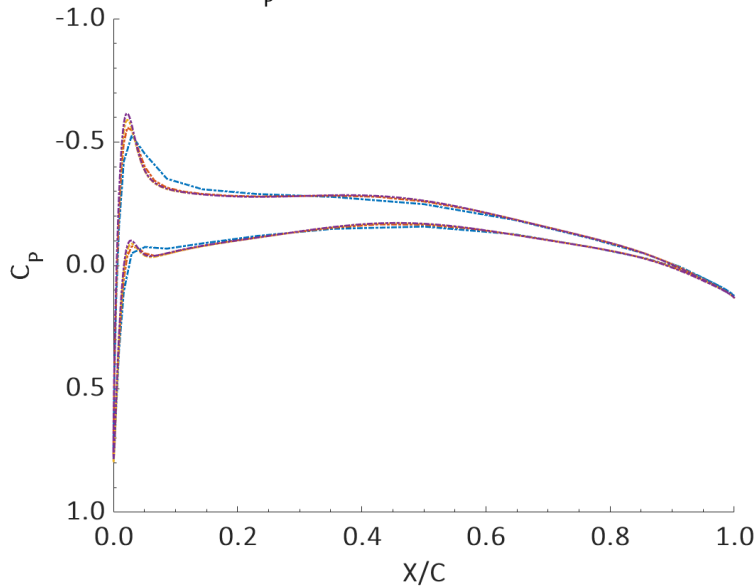
3rd Ice Prediction Workshop Results: ONERA M6 Wing



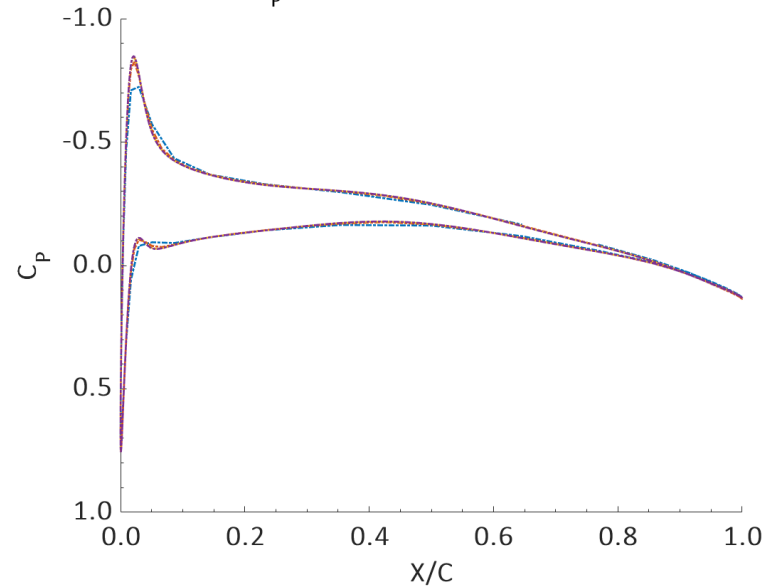
Pressure Coefficient

3rd Ice Prediction Workshop Results: ONERA M6 Wing

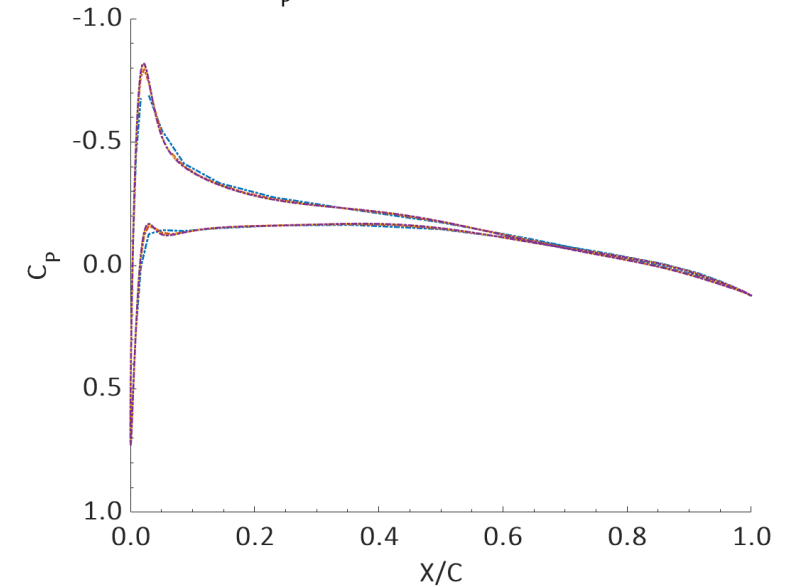
C_p at Wing Station: $Y = 0.100$ m



C_p at Wing Station: $Y = 0.750$ m



C_p at Wing Station: $Y = 1.400$ m



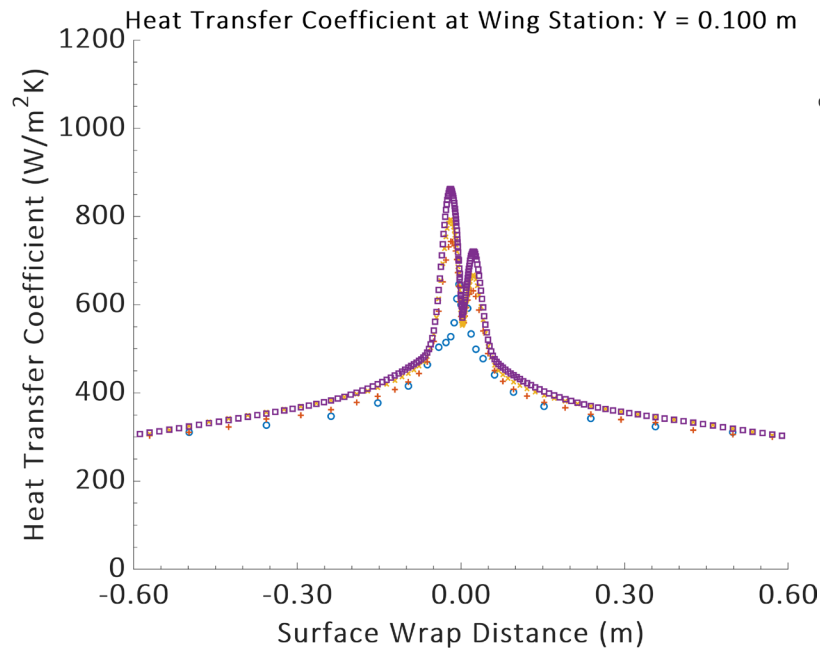
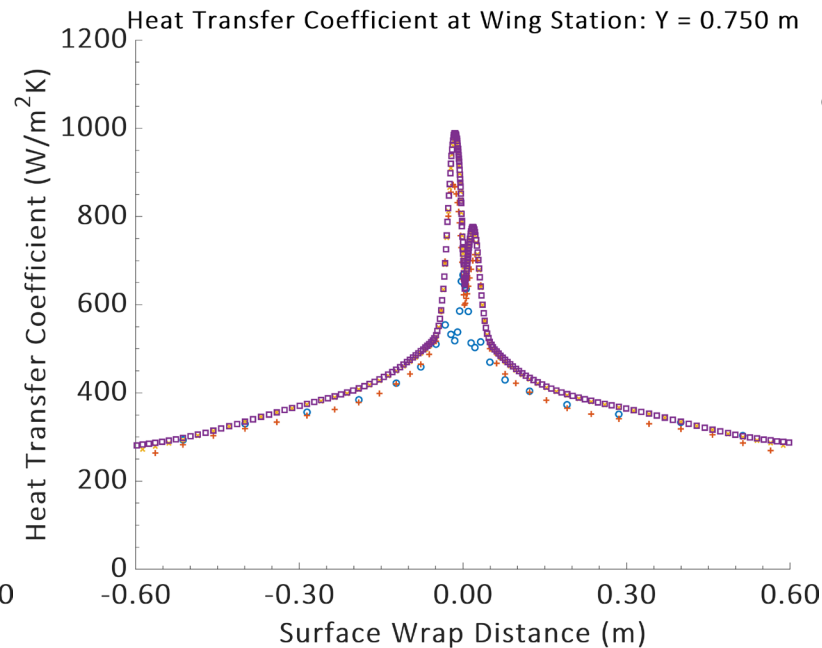
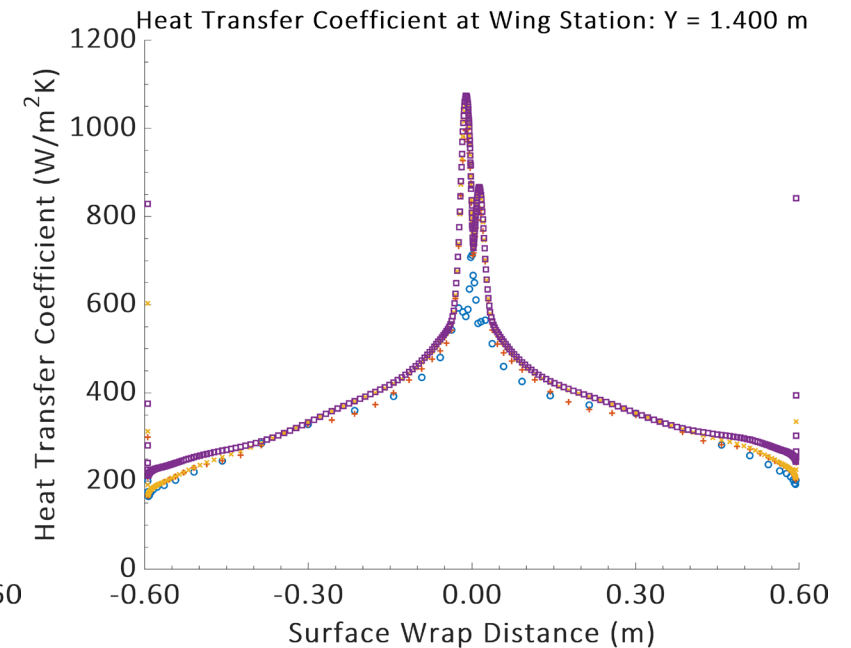
- L4, Rough 1mm
- L3, Rough 1mm
- L2, Rough 1mm
- L1, Rough 1mm

HTC: 7-bin, Rough 1 mm

3rd Ice Prediction Workshop Results: ONERA M6 Wing

- L2 and L1 grid result in a similar HTC distribution near the LE (including the peak)
- L3 results in a slightly lower peak, while L4 distribution is significantly lower near the LE

- L4, Rough 1mm, 7-bin
- + L3, Rough 1mm, 7-bin
- × L2, Rough 1mm, 7-bin
- L1, Rough 1mm, 7-bin

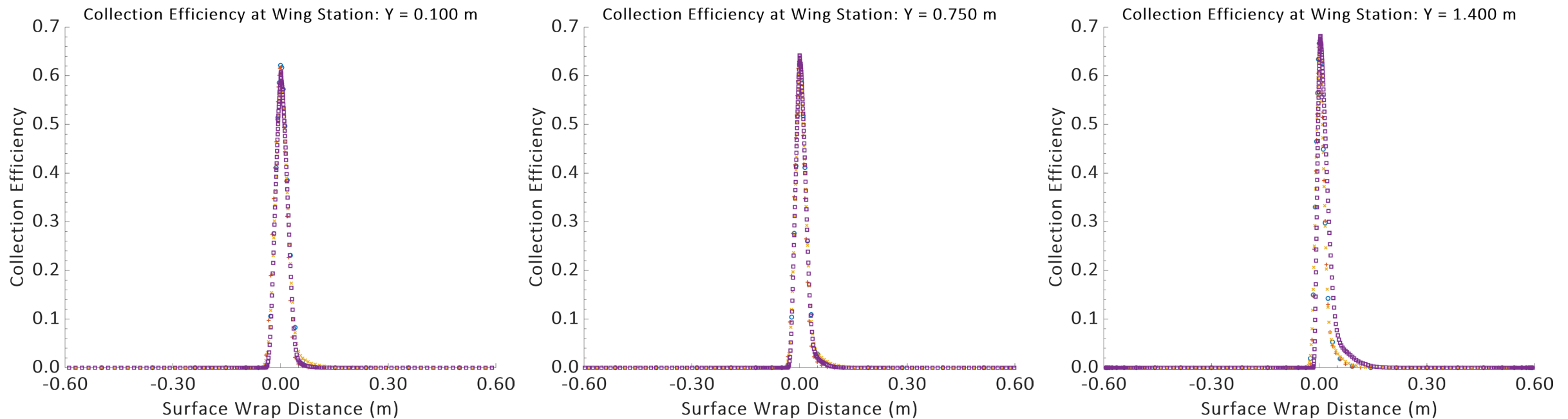


Collection Efficiency: 7-bin, Rough 1 mm

3rd Ice Prediction Workshop Results: ONERA M6 Wing

- Similar peak values across all grid levels for the 7-bin case
- L1 grid results in a higher impingement limit near the wing tip for the 7-bin case

- L4, Rough 1mm, 7-bin
- + L3, Rough 1mm, 7-bin
- × L2, Rough 1mm, 7-bin
- L1, Rough 1mm, 7-bin



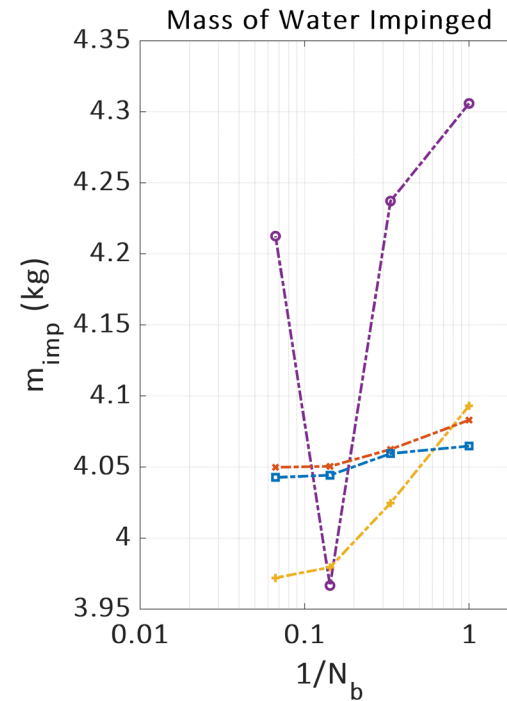
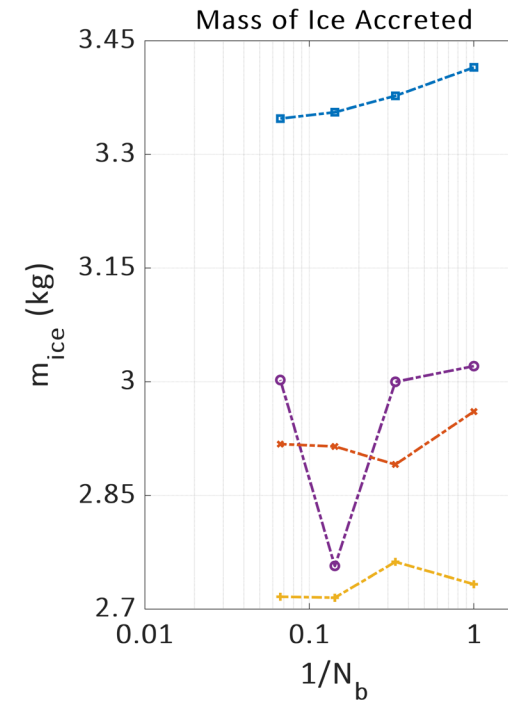
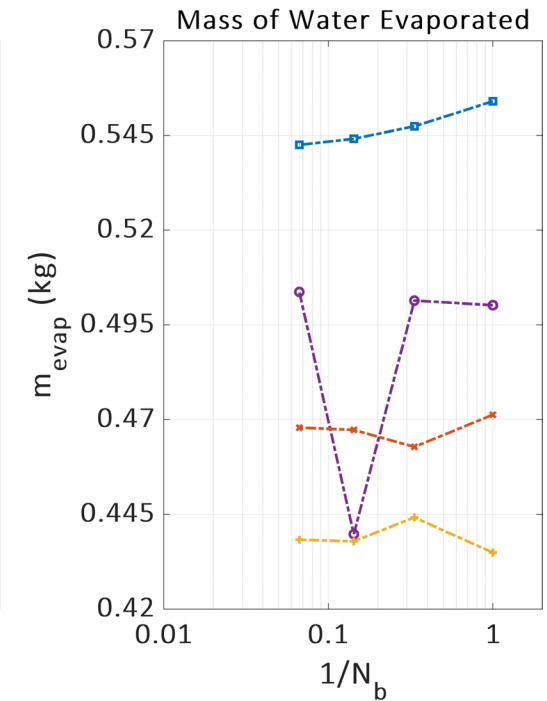
Ice Mass Convergence (Bins)

3rd Ice Prediction Workshop Results: ONERA M6 Wing

- Mass of ice accreted shows small sensitivity to the number of bins, except for the L1 7-bin case

— L4, Rough 1mm
— L3, Rough 1mm
— L2, Rough 1mm
— L1, Rough 1mm

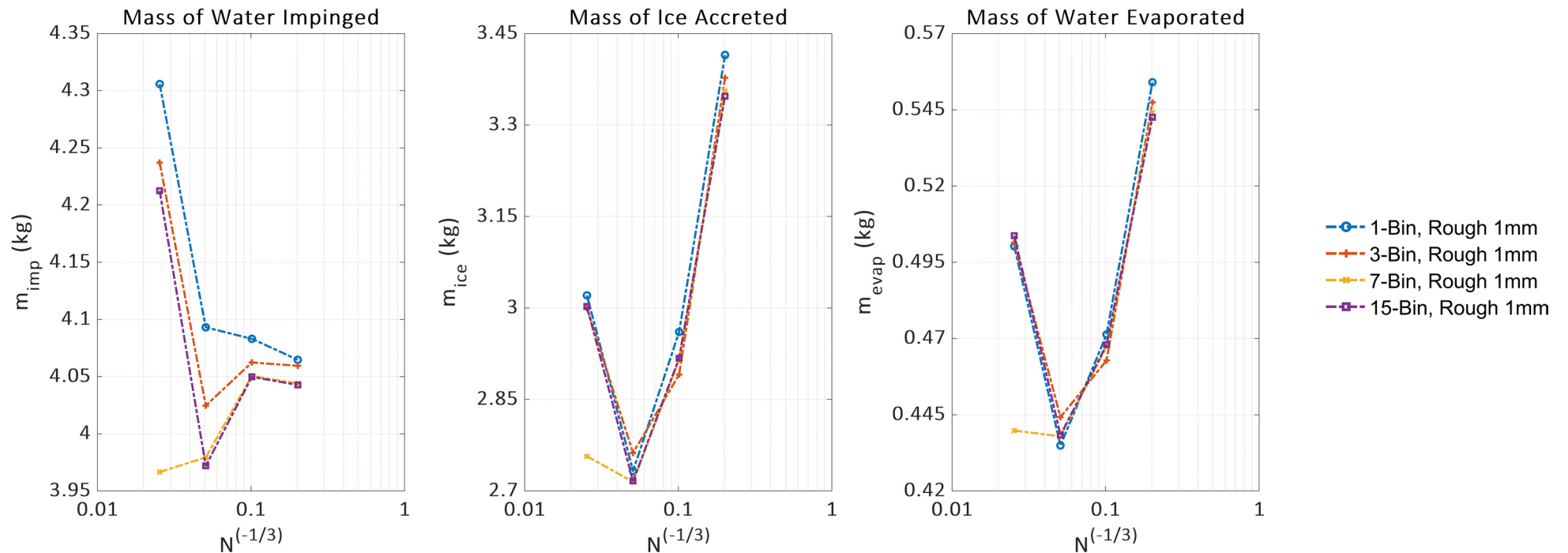
	L1, 15-bin	L1, 7-bin
m_{imp}	4.212	3.967
m_{ice}	3.002	2.757
m_{evap}	0.504	0.440
m_{shed}	0.705	0.768
m_{bal}	~ 0	~ 0



Ice Mass Convergence (Grid Levels)

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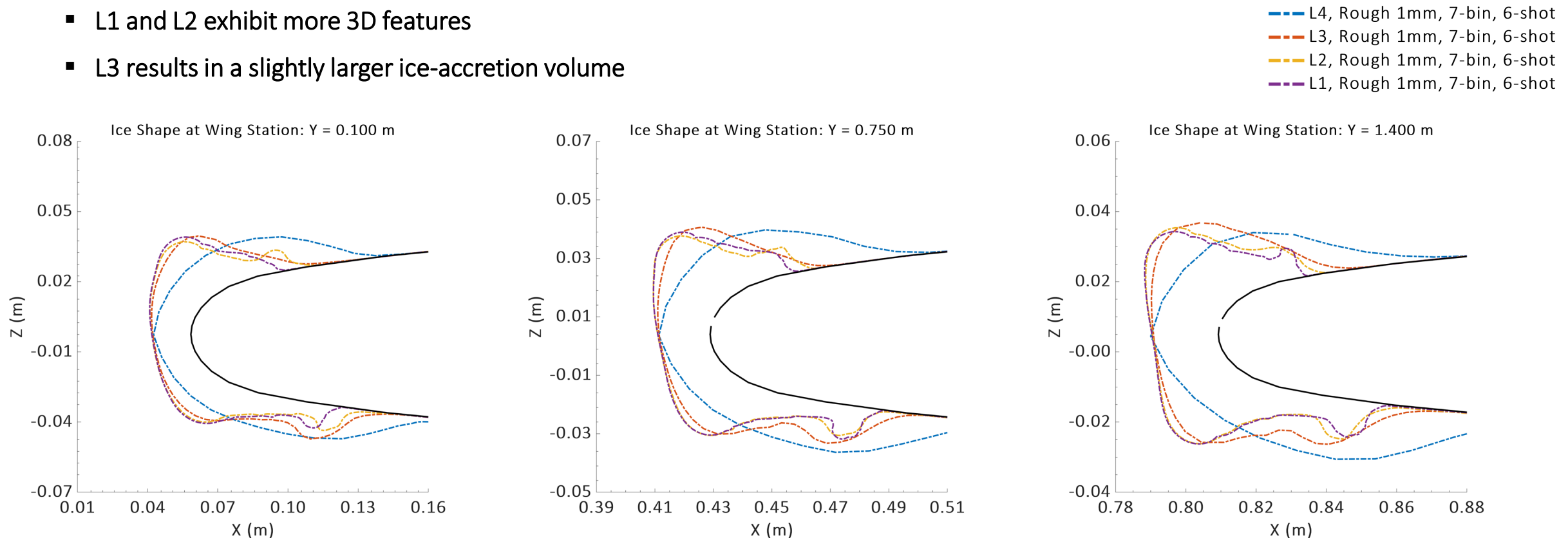
- Mass of ice accreted decreases from L4→L2 but increases at L1 (except 7-bin)



Ice Shape Sections: 7-bin, Rough 1 mm

3rd Ice Prediction Workshop Results: ONERA M6 Wing

- L4 grid fails to capture the horn shapes
- L1 and L2 exhibit more 3D features
- L3 results in a slightly larger ice-accretion volume

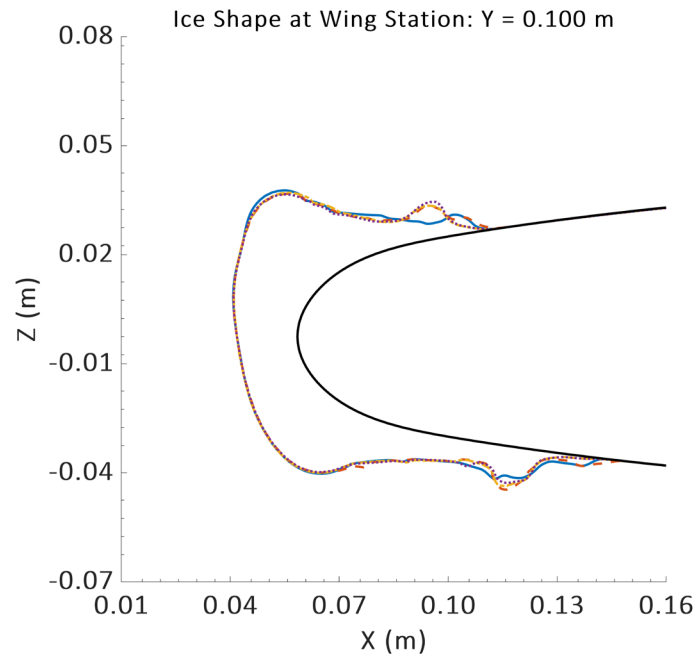
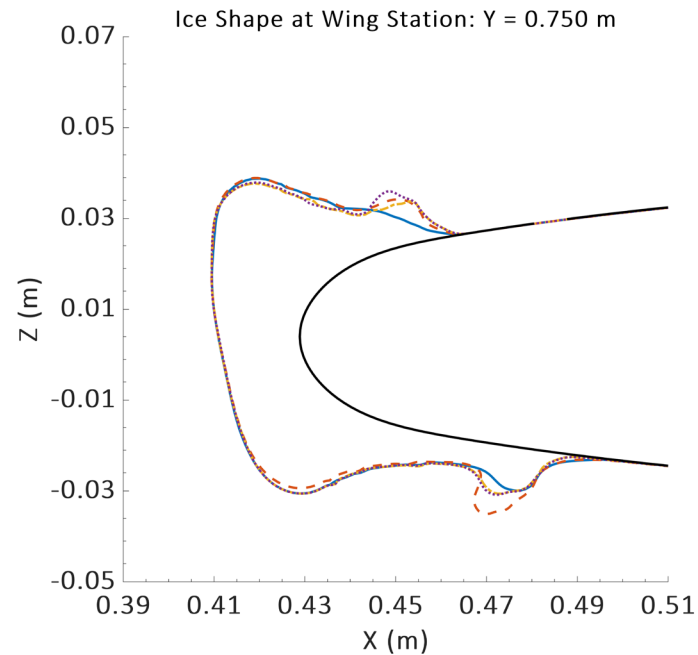
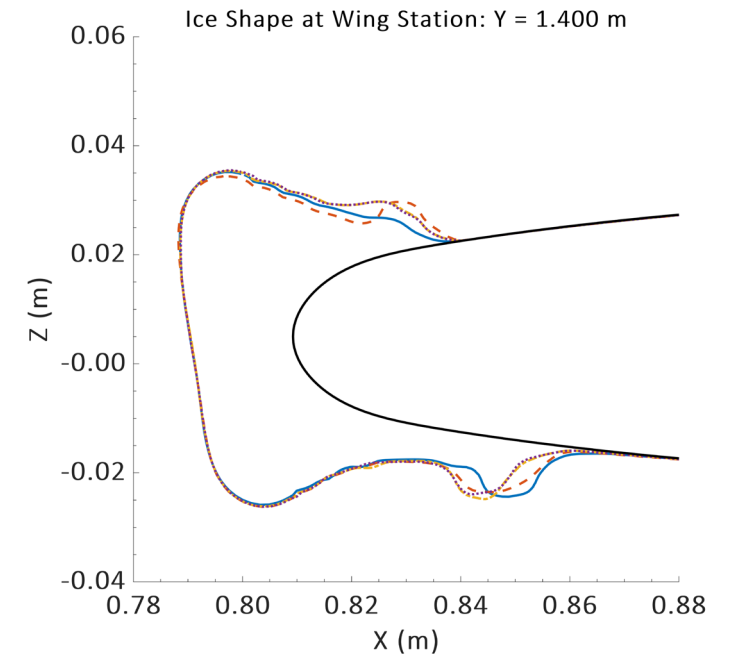


Ice Shape Sections: L2, Rough 1 mm

3rd Ice Prediction Workshop Results: ONERA M6 Wing

- Ice thickness exhibits small sensitivity to number of bins for the L2 grid
- 1-bin analysis fails to capture the secondary ice-shape features on the upper surface

— L2, Rough 1mm, 1-bin, 6-shot
— L2, Rough 1mm, 3-bin, 6-shot
— L2, Rough 1mm, 7-bin, 6-shot
... L2, Rough 1mm, 15-bin, 6-shot

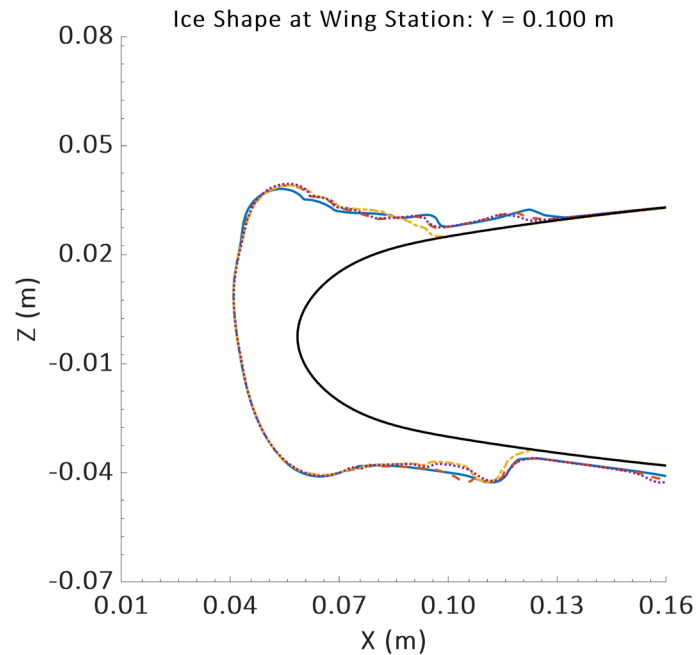
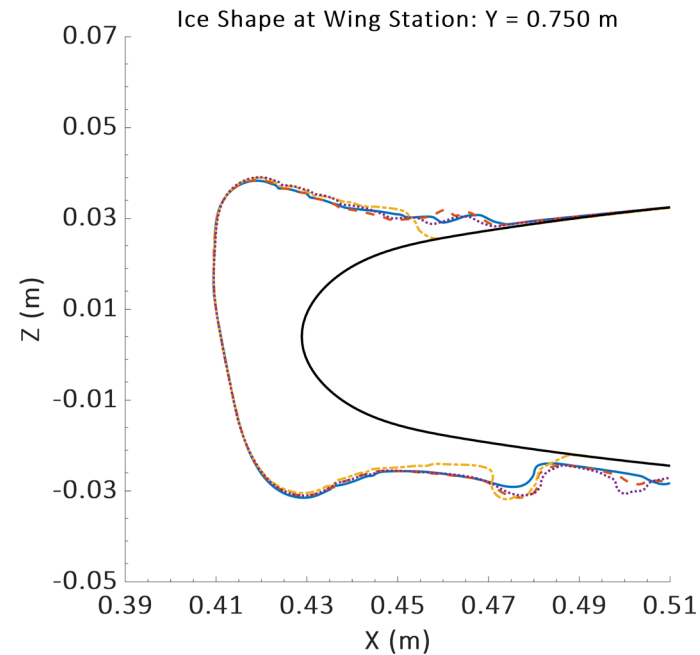
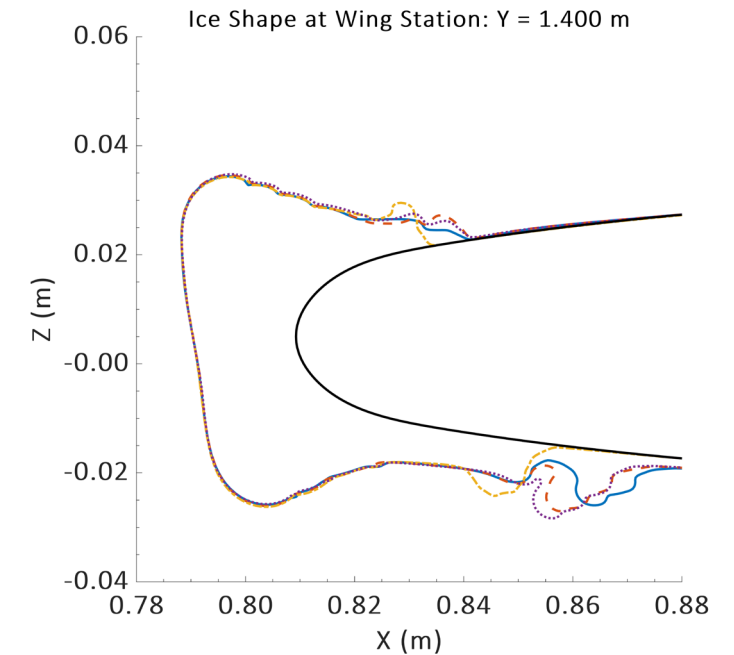


Ice Shape Sections: L1, Rough 1 mm

3rd Ice Prediction Workshop Results: ONERA M6 Wing

- Ice thickness comparable to L2, but with significantly larger impingement limits
- Secondary ice-shape features present on the lower surface
- 7-bin analysis appears to be an outlier in impingement behavior

— L1, Rough 1mm, 1-bin, 6-shot
— L1, Rough 1mm, 3-bin, 6-shot
— L1, Rough 1mm, 7-bin, 6-shot
— L1, Rough 1mm, 15-bin, 6-shot

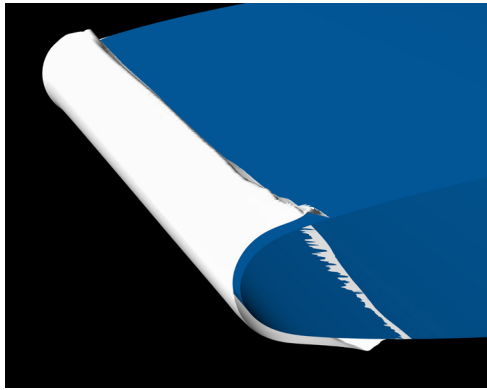


Ice Shape Buildup: L2, 7-bin , Rough 1 mm

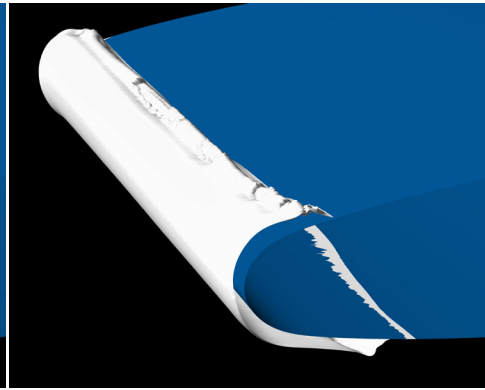
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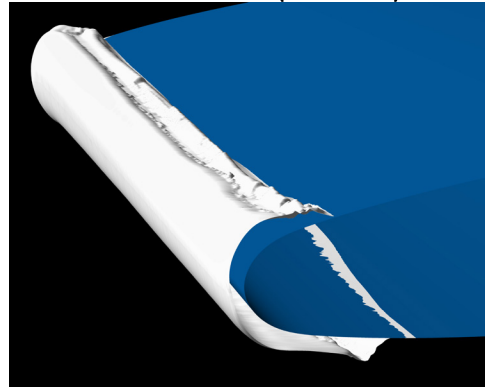
End of Shot 1 (t = 225 s)



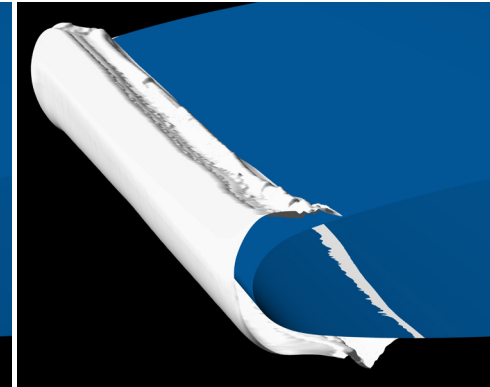
End of Shot 2 (t = 450 s)



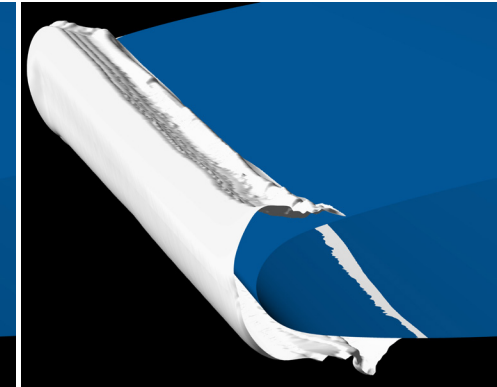
End of Shot 3 (t = 675 s)



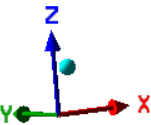
End of Shot 4 (t = 900 s)



End of Shot 5 (t = 1125 s)



End of Shot 6 (t = 1350 s)

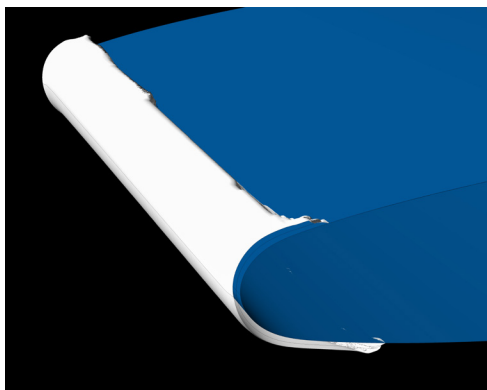


Ice Shape Buildup: L1, 7-bin, Rough 1 mm

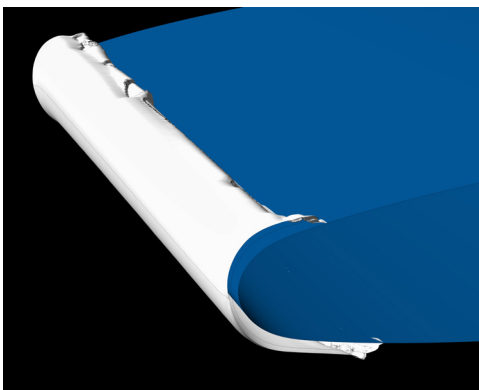
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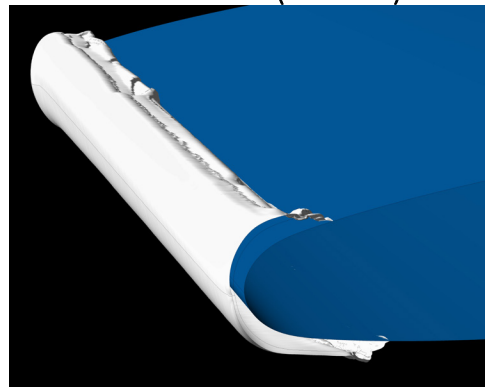
End of Shot 1 (t = 225 s)



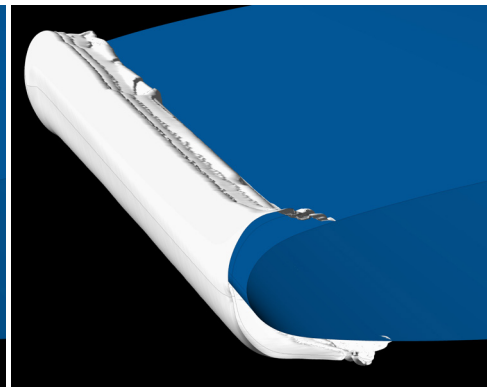
End of Shot 2 (t = 450 s)



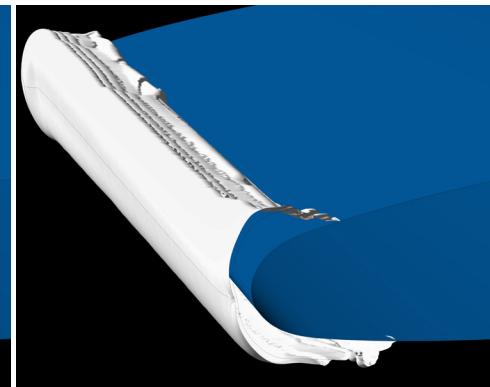
End of Shot 3 (t = 675 s)



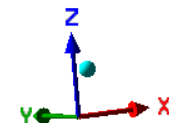
End of Shot 4 (t = 900 s)



End of Shot 5 (t = 1125 s)

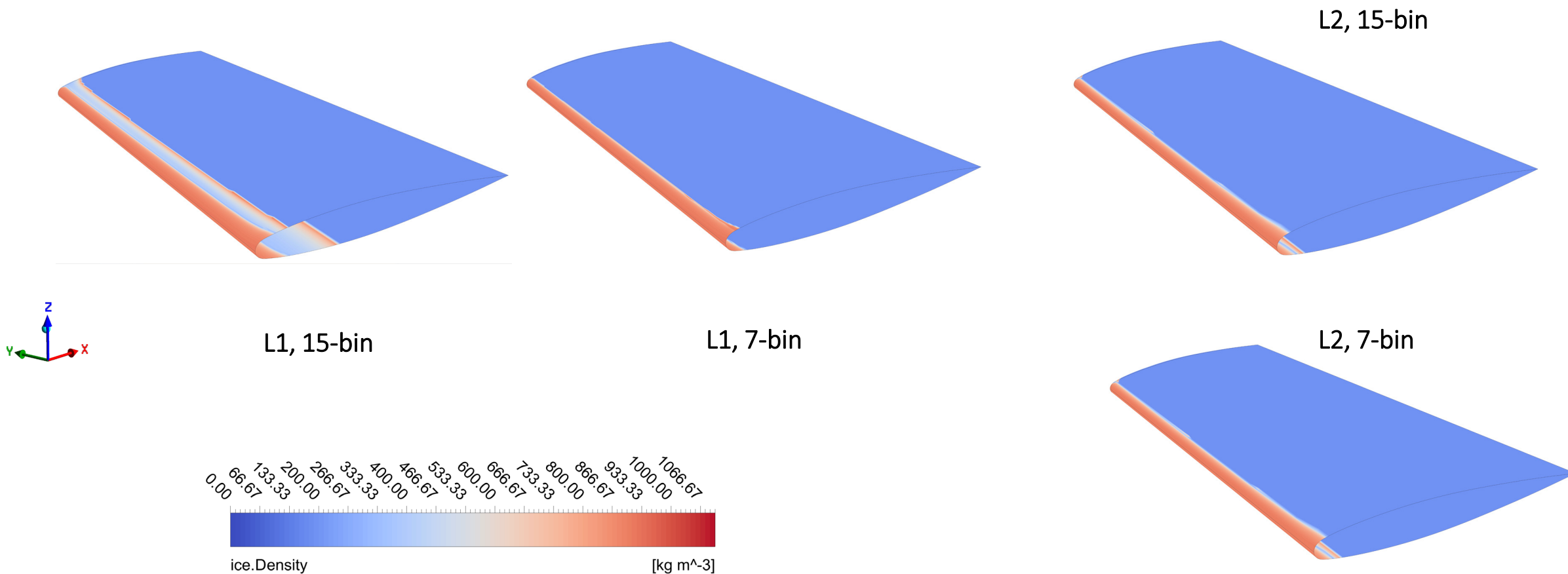


End of Shot 6 (t = 1350 s)



Ice Density Variation, Rough 1 mm

3rd Ice Prediction Workshop Results: ONERA M6 Wing





Conclusions and Future Work

3rd Ice Prediction Workshop Results: ONERA M6 Wing

Conclusions and Future Work

3rd Ice Prediction Workshop Results: ONERA M6 Wing

■ Conclusions:

- Absence of ONERA M6 experimental data limits confidence in observed trends
- Mass of ice accreted decreases from L4→L2 but increases at L1 (except 7-bin)
- L1 shows greatest water impingement and secondary ice-shape features on the lower surface
- L1 7-bin case is an outlier
- 6-shot ice shapes are relatively smooth; >10 shots likely needed for 3D features

■ Future Work

- Run simulations with constant density
- Assess impact of number of shots
- Evaluate roughness heights of 0.5 and 1.5 mm
- Evaluate use of the Beading model
- Investigate sensitivity to turbulence models

