

IPW3: Participant 002 Results – NACA0012 AE3932/AE3933 and ONERA M6

Ariane Vieira

AeroTex GmbH

Presented 24 September 2026

CC BY-NC-ND 4.0

This work is licensed by the author(s) under a **Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International licence (CC BY-NC-ND 4.0)**. To view a copy of this licence, visit <https://creativecommons.org/licenses/by-nc-nd/4.0/>.

Suggested citation: Vieira, A. (2026). *IPW3: Participant 002 Results – NACA0012 AE3932/AE3933 and ONERA M6*. Presented at the 3rd AIAA Ice Prediction Workshop, online, 24 September 2026.

IPW3: Participant 002 results

NACA0012 AE3932 / AE3933 and ONERA M6

Presenter:

Ariane Vieira

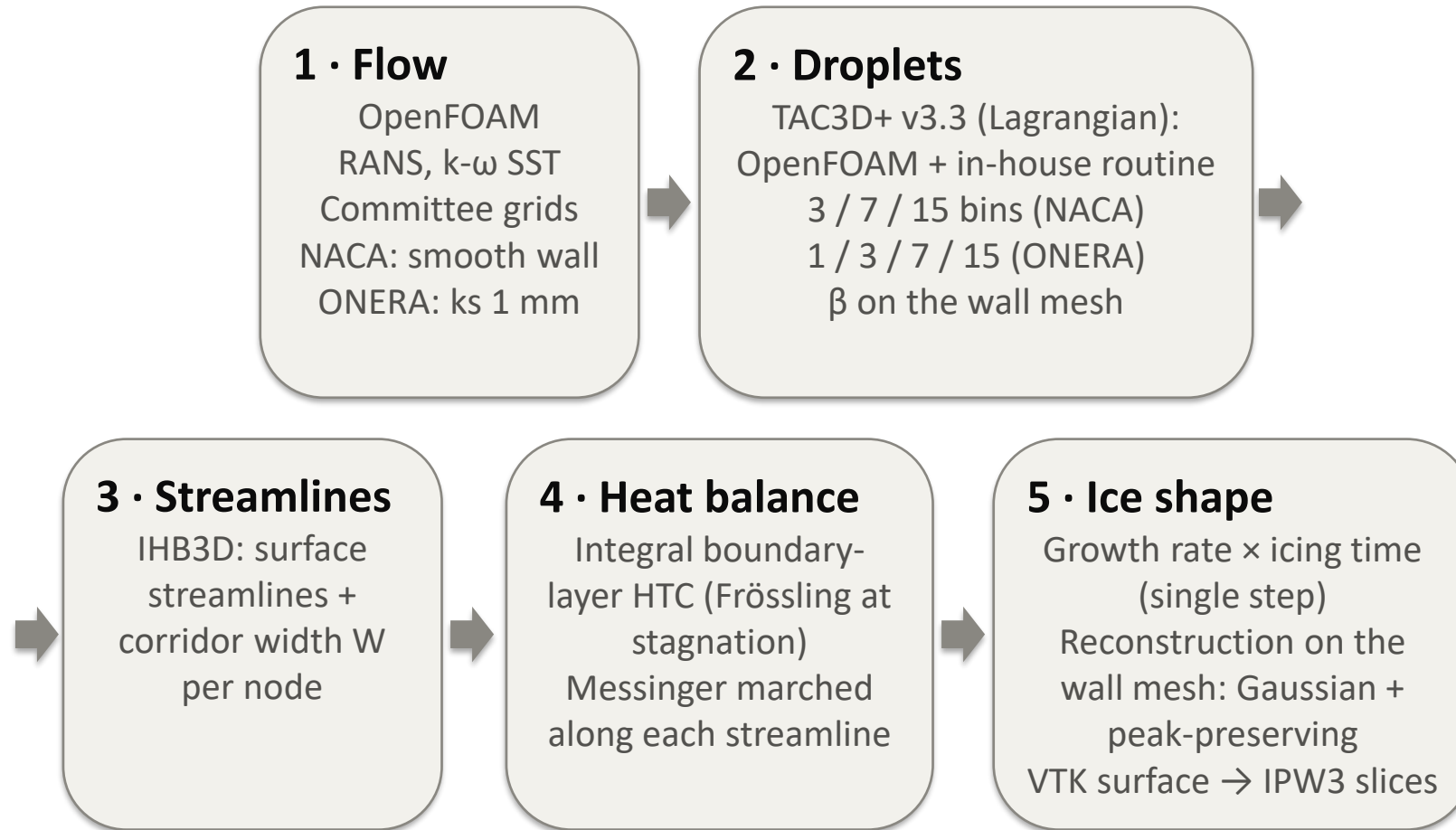
3rd Ice Prediction Workshop

24/09/2026

Numerical methodology

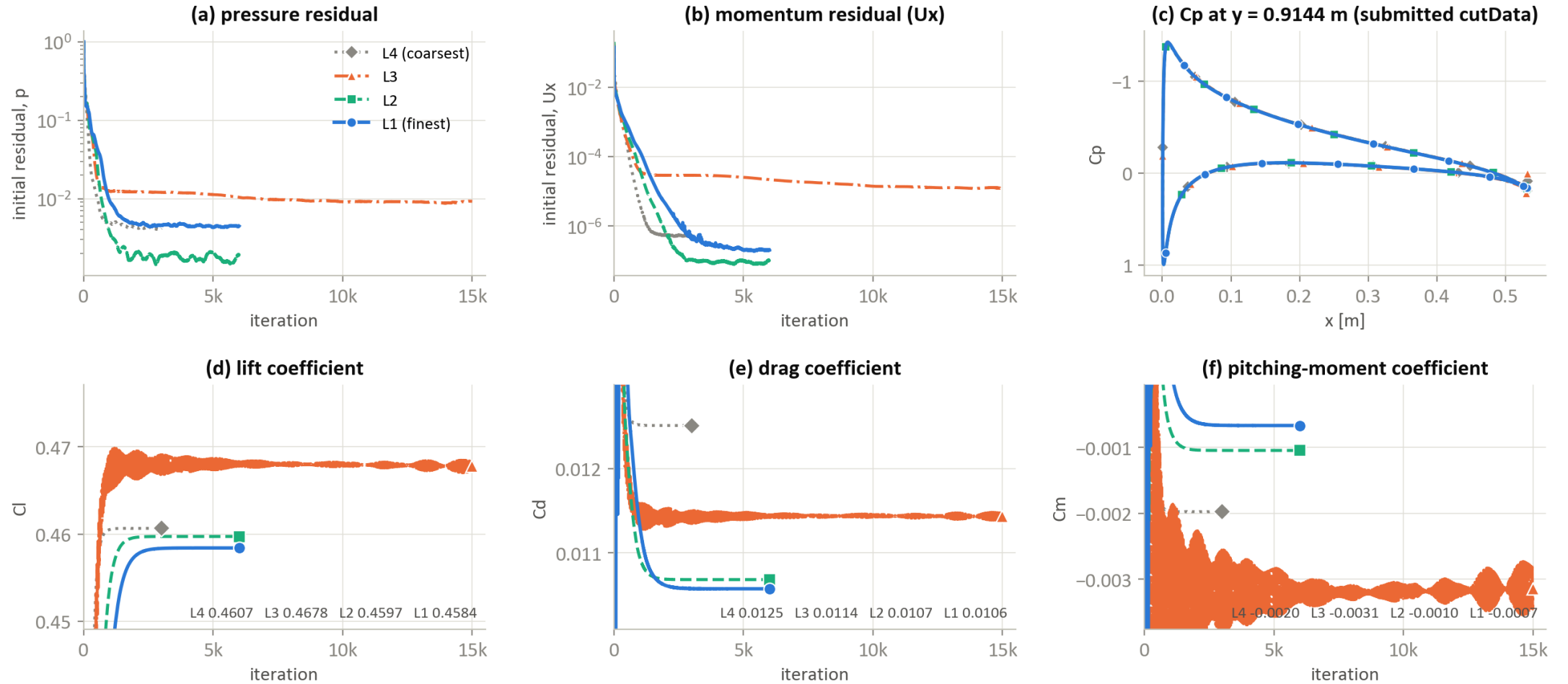
Model / Method	NACA0012 (AE3932 / AE3933)	ONERA M6
CFD Model	RANS, steady-state, OpenFOAM	RANS, steady-state, OpenFOAM
Turbulence Model	k- ω SST	k- ω SST
HTC Method	Integral boundary-layer method along surface streamlines (Frössling at stagnation)	Integral boundary-layer method along surface streamlines
Droplet Formulation	Lagrangian (TAC3D+ v3.3)	Lagrangian (TAC3D+ v3.3)
Droplet Drag Model	ATX Drag Model	ATX Drag Model
SLD Effects	None	None
Thermodynamic Model	Messinger: thin-strip conducting surface, marched along each streamline	Messinger, as NACA0012
Ice Density Model	Constant: 917 kg/m ³	Constant: 680 kg/m ³
Roughness Height	Constant: $k_s = 0.692$ mm (NASA correlation, code standard); CFD smooth wall	Constant: $k_s = 1.0$ mm (baseline); 0.5 mm and 1.5 mm at 7 bins, all levels
Geometry Evolution	Algebraic: thickness along the surface normal, reconstructed on the wall mesh	Algebraic, as NACA0012
Ice Accretion Steps	Single-step (420 s)	Single-step (1350 s)

Solution chain and what was run

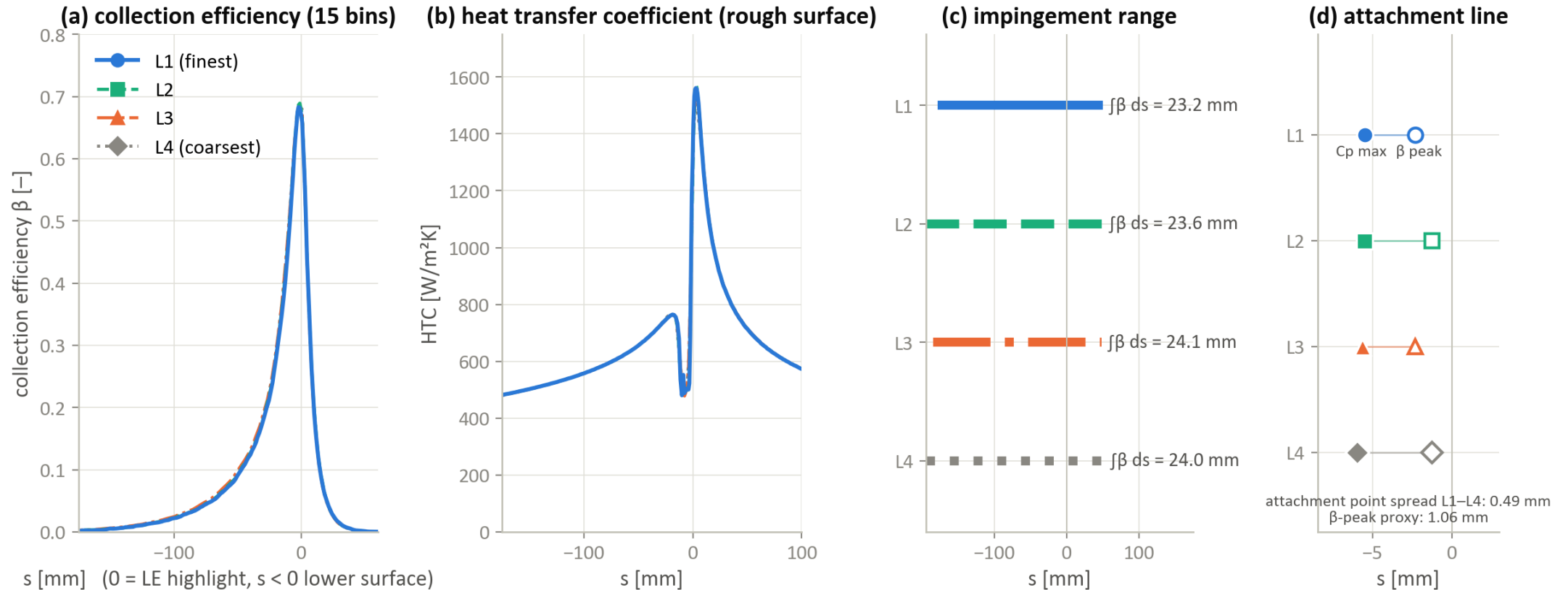


Single step; Modelled region = streamline-covered region;
Outside covered region: HTC / T_s are solver defaults (0 W/m²K, 273.15 K).
Mass Budget = streamline mass budget.
Mass Budget vs CFD- β surface true catch closes within $\approx 2\%$ at every level.

NACA0012: Aero solution

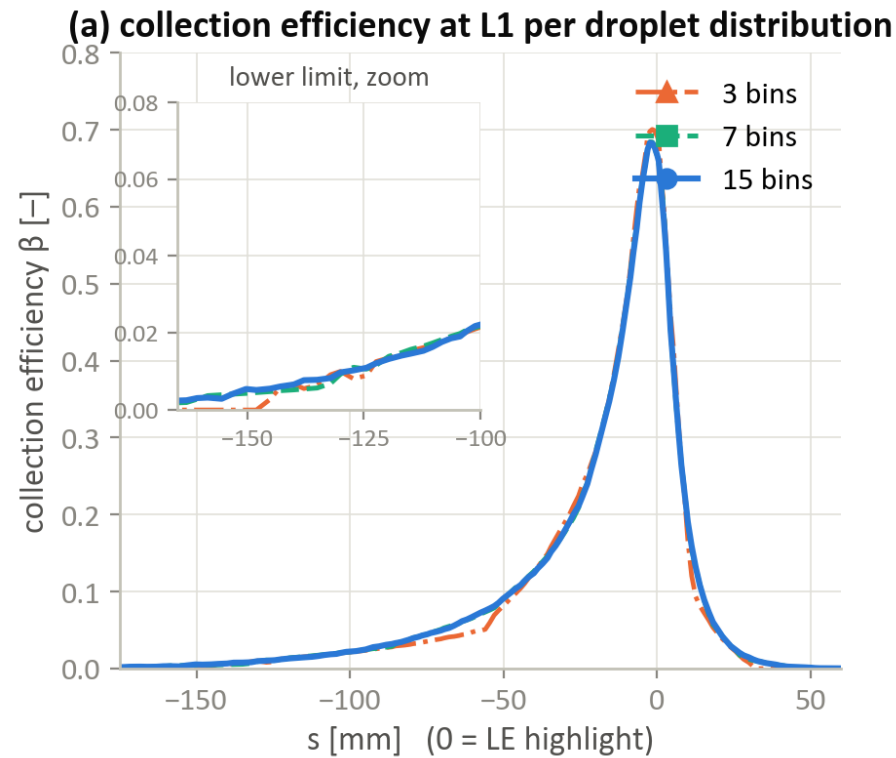
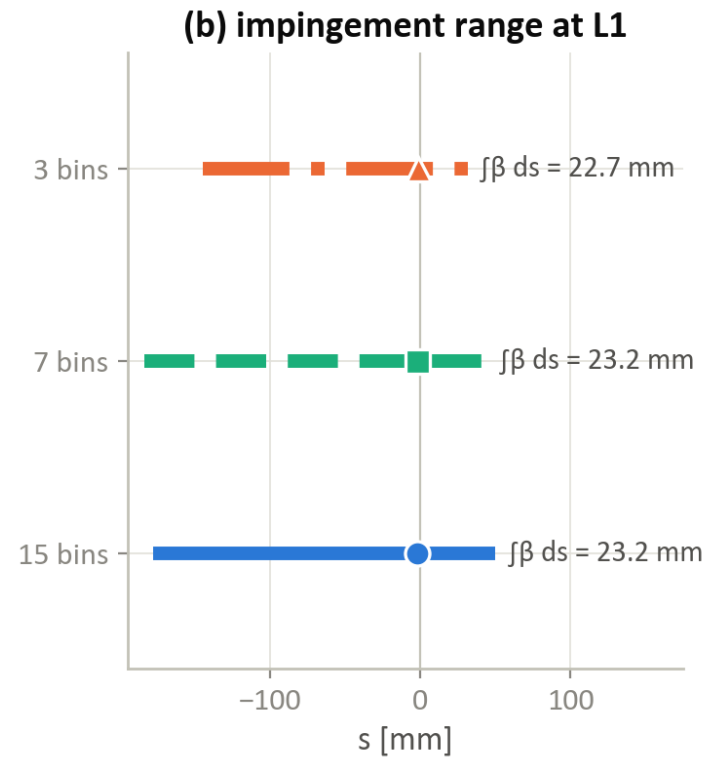
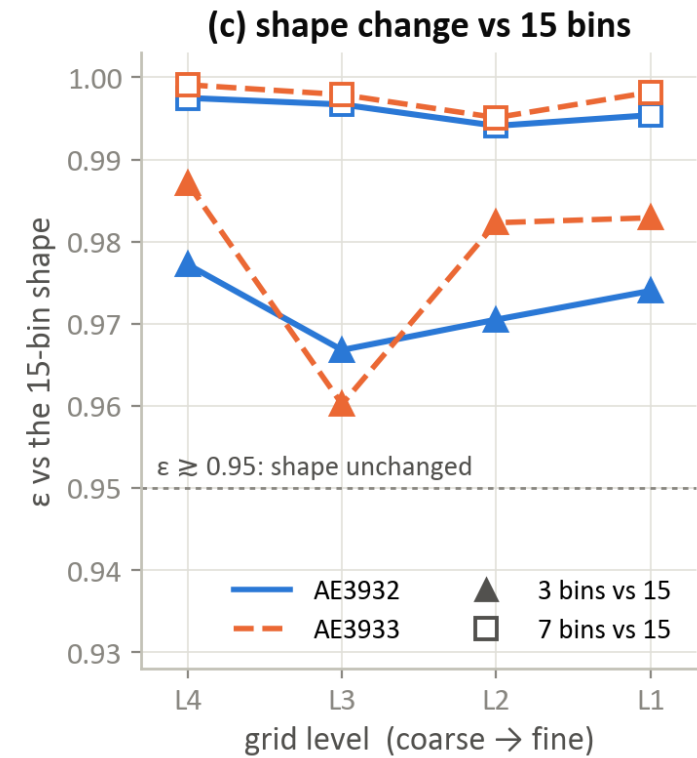


NACA0012: collection and heat transfer vs grid



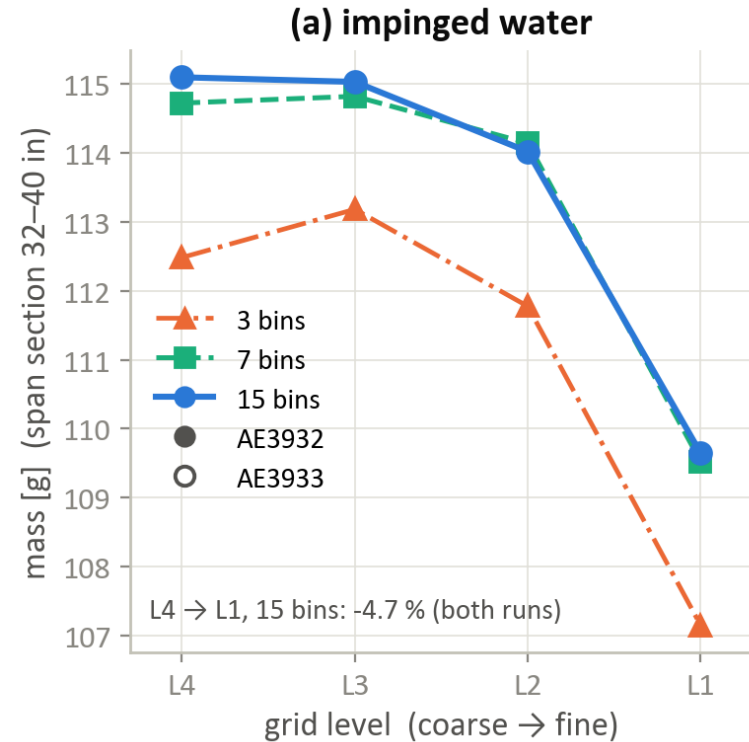
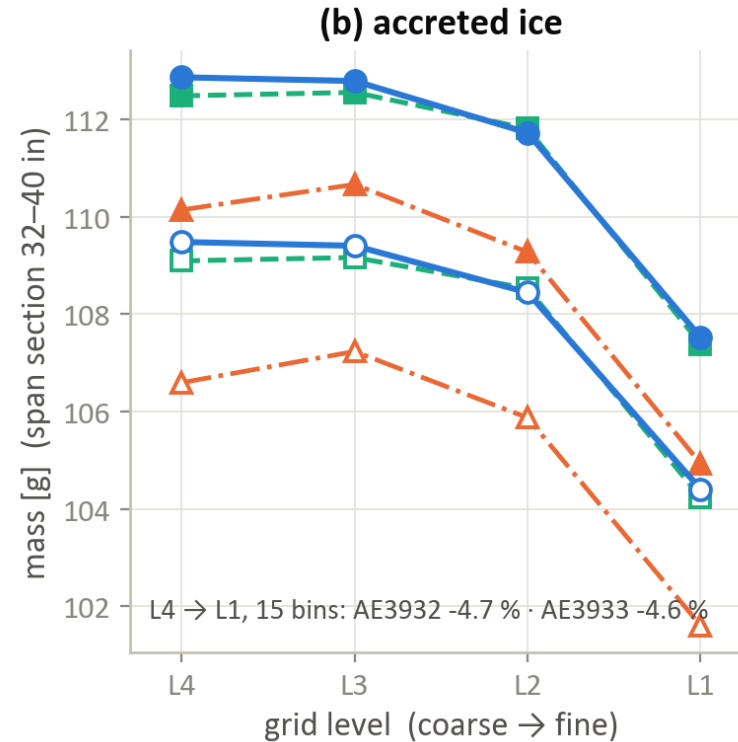
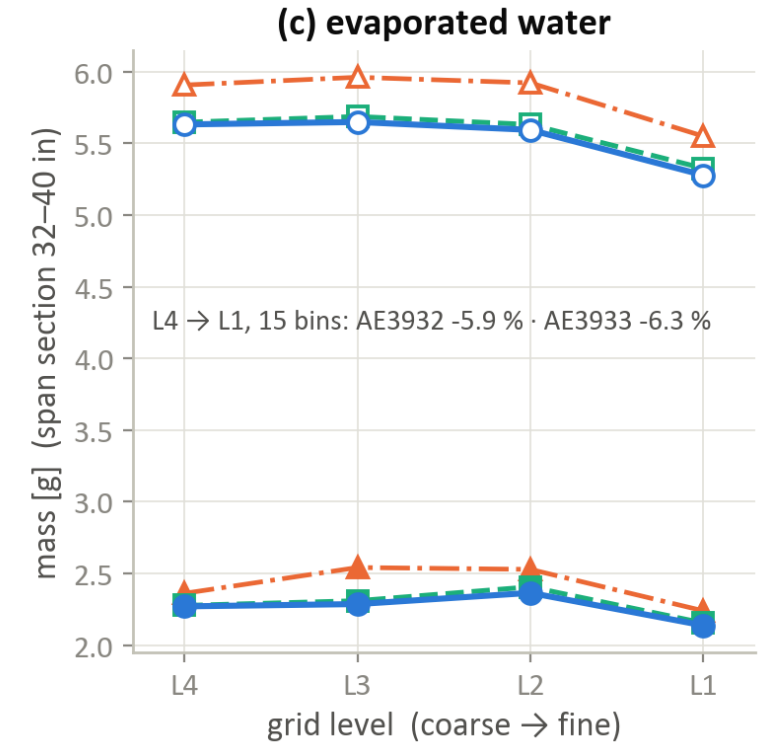
slice $y = 0.9144$ m · β peak 0.68 and $\int \beta ds$ 23.2 mm at L1 · attachment line within 0.49 mm over L1–L4 · HTC changes only near the stagnation region

NACA0012: droplet distribution



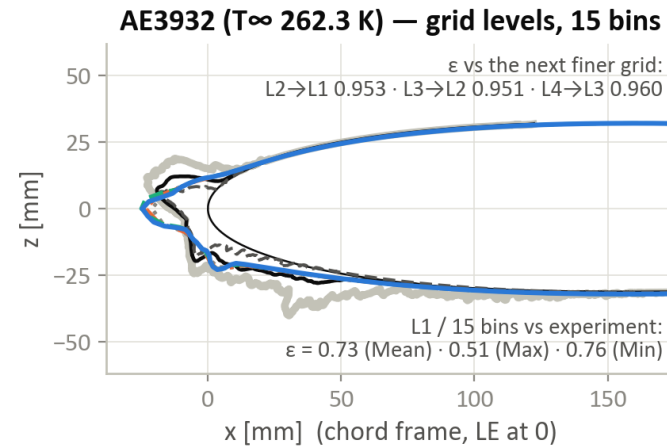
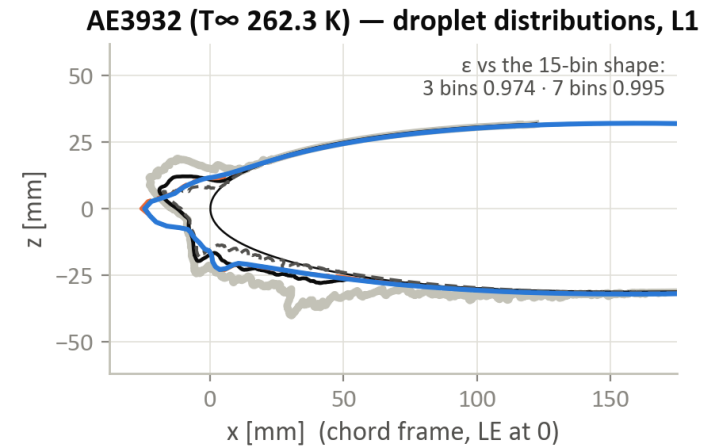
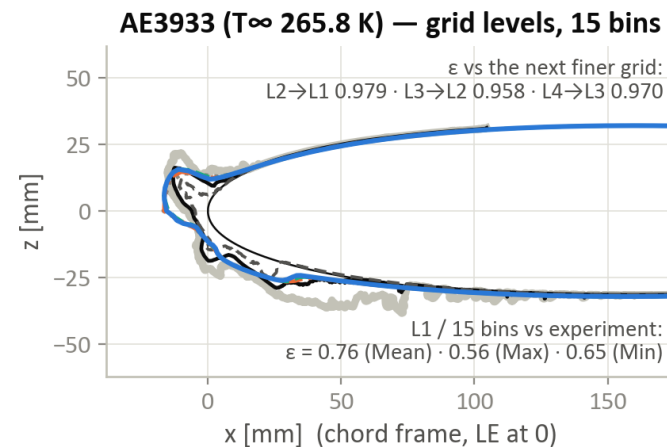
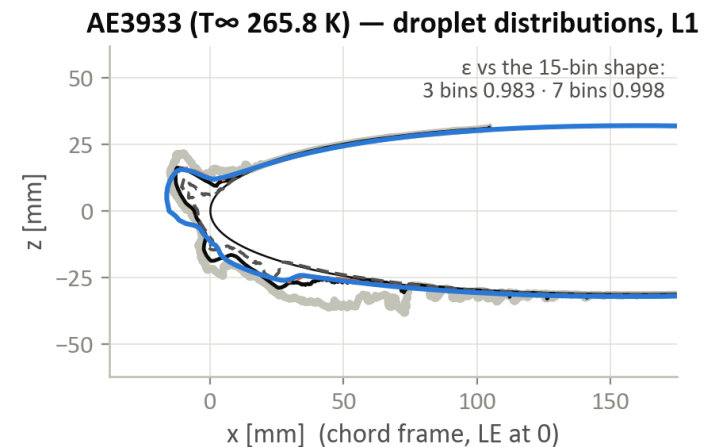
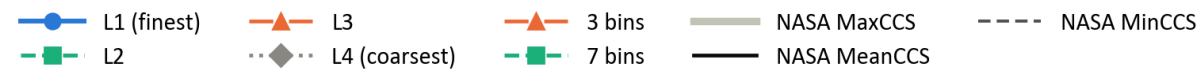
peak β unchanged by the spectrum
 the large-droplet tail moves the lower impingement limit $-145 \rightarrow -178$ mm
 7 bins reproduce the 15-bin shape ($\epsilon \geq 0.994$)

NACA0012: integrated masses



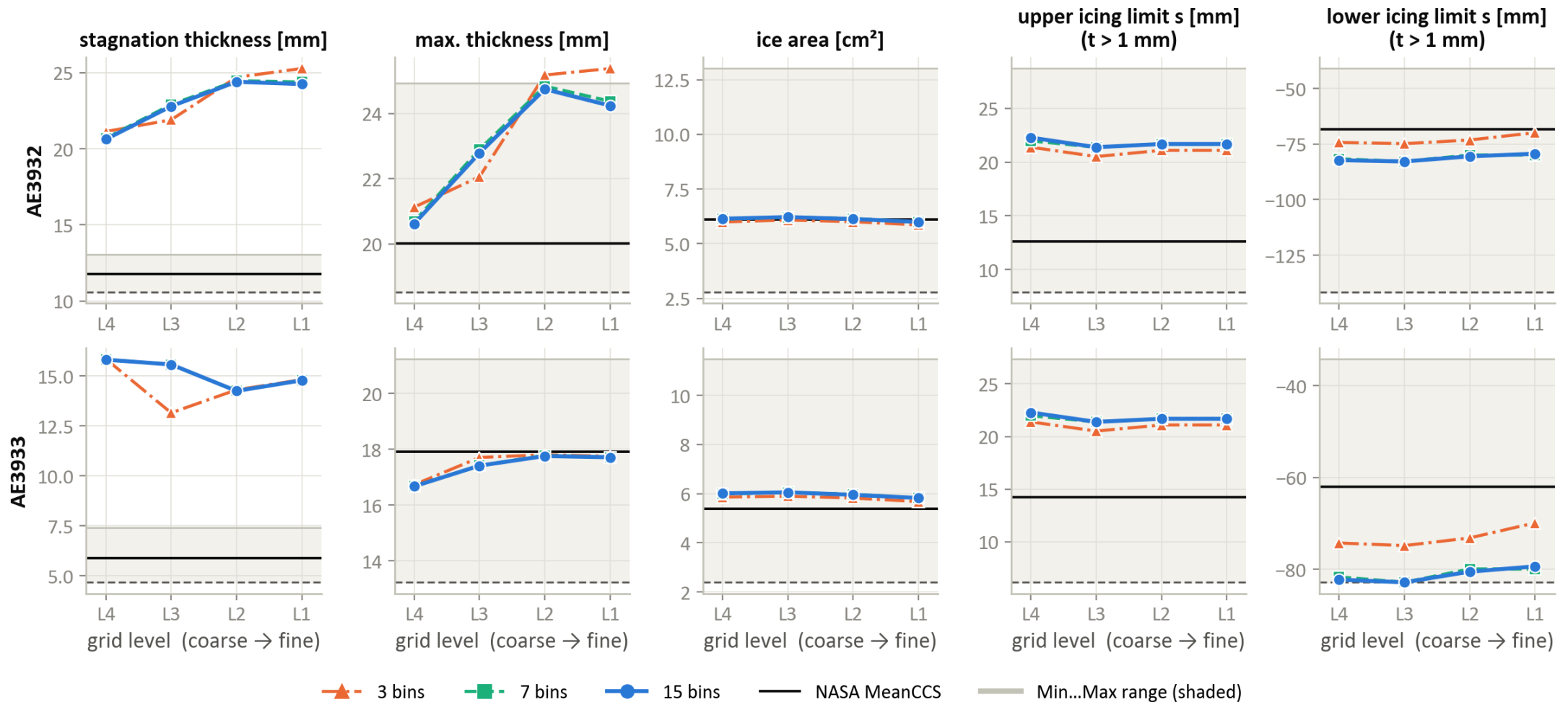
catch -4.7 % L4→L1 (largest step L2→L1) · freezing ratio 0.98 (AE3932) / 0.95 (AE3933) · evaporation ×2.5 on the warm run · 7 vs 15 bins within 0.2 %

NACA0012: ice shapes

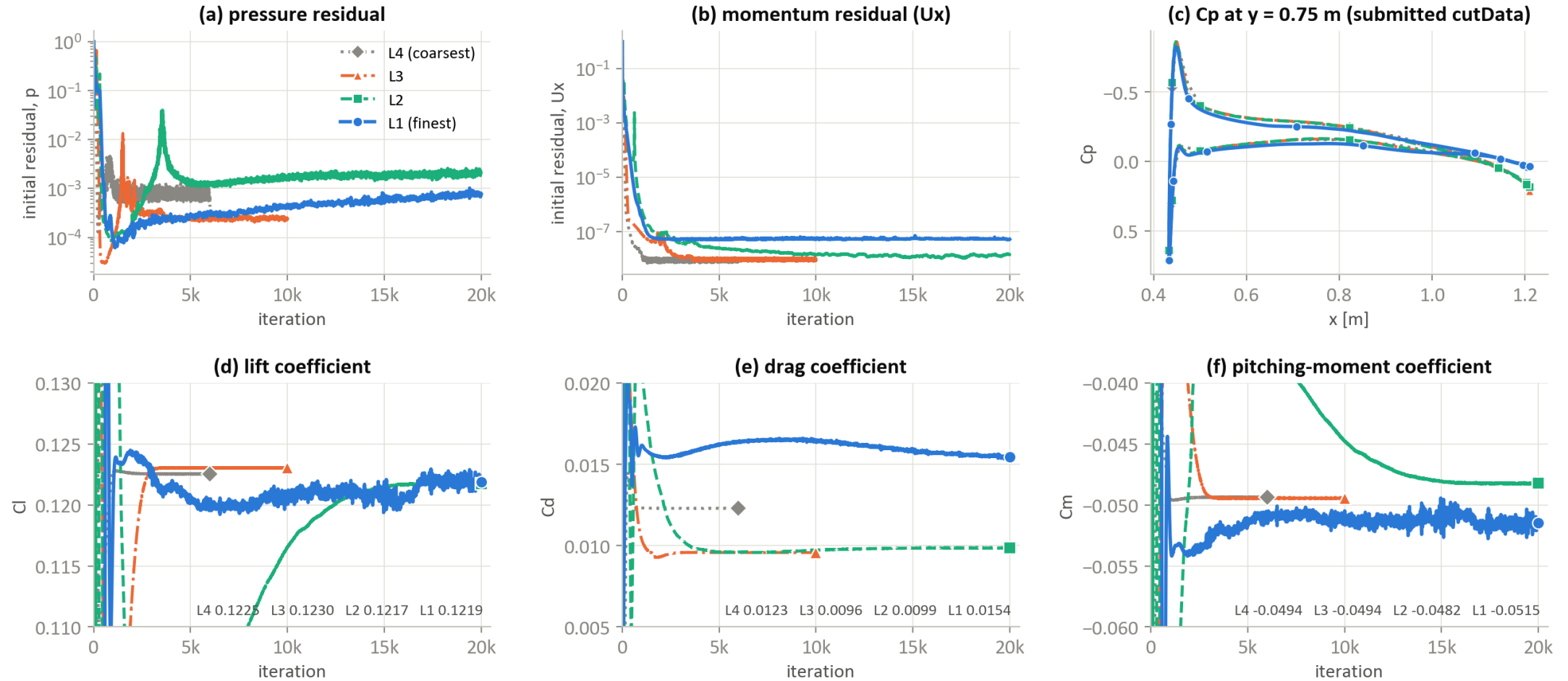


final grid step ϵ 0.95 / 0.98 (AE3932 / AE3933) · 7 bins $\equiv$ 15 bins · vs NASA MeanCCS at L1 / 15 bins: ϵ 0.73 / 0.76

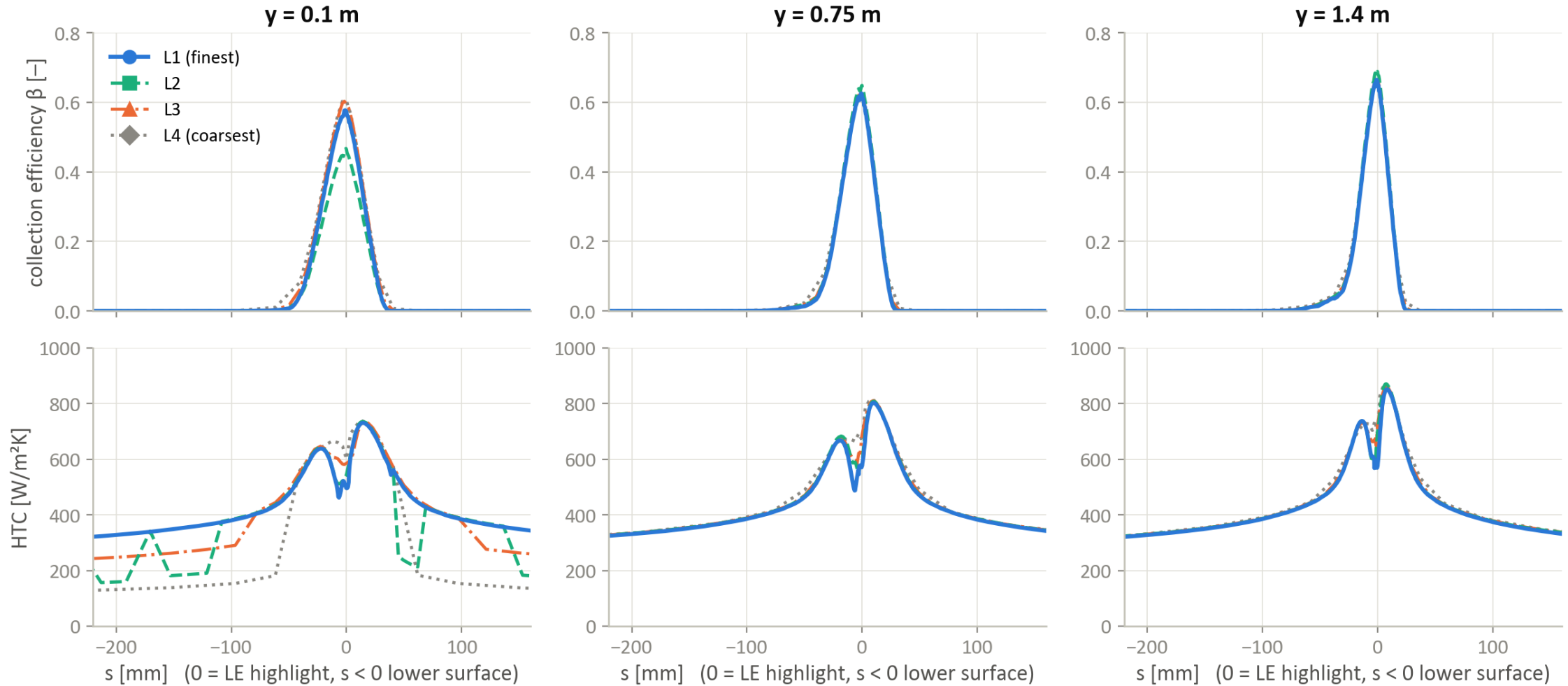
NACA0012: shape metrics vs experiment



ONERA M6: Aero solution

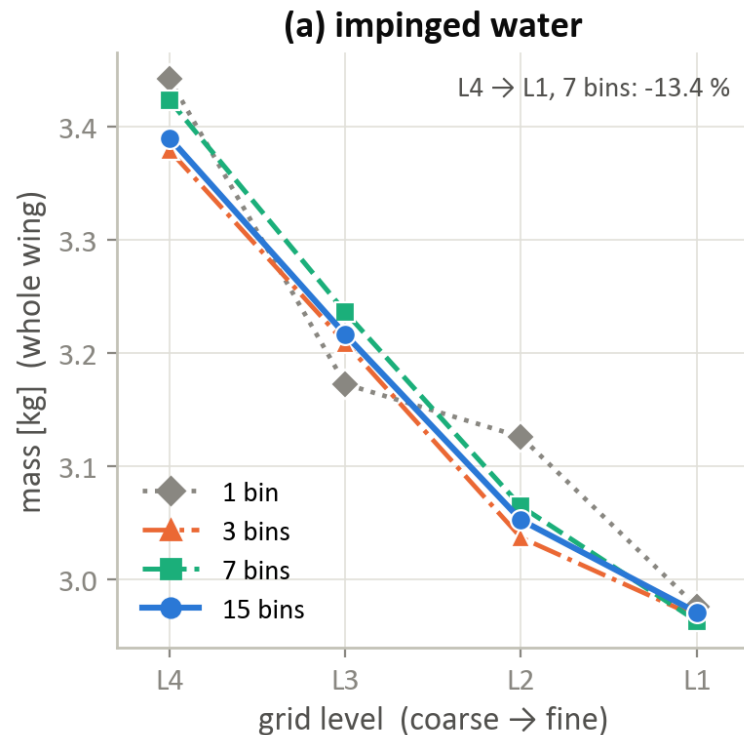
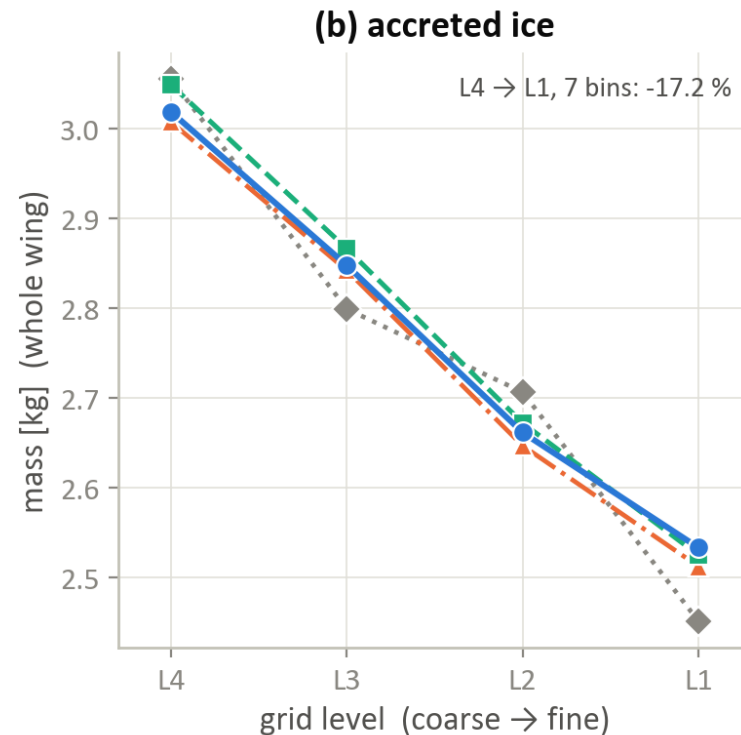
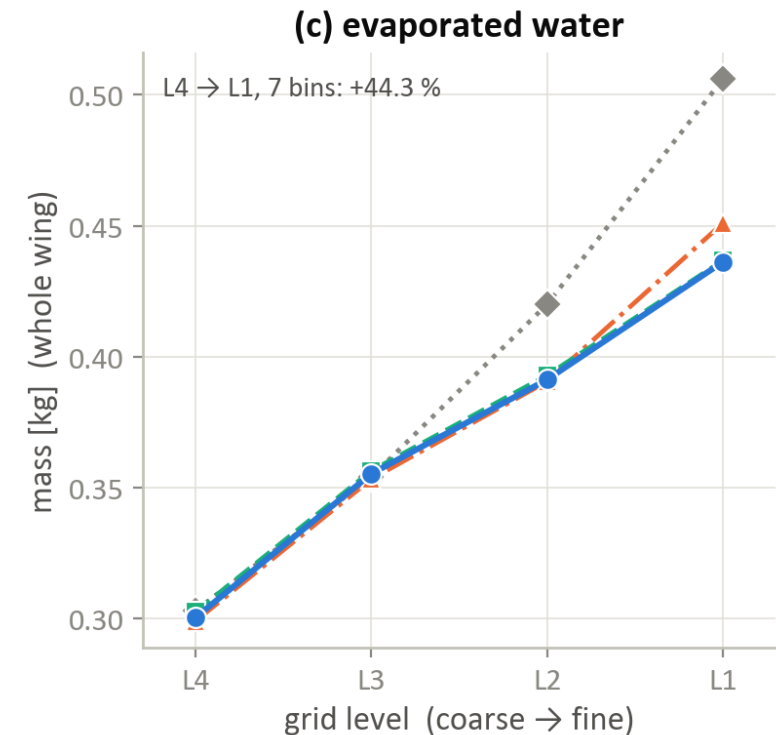


ONERA M6: collection and heat transfer



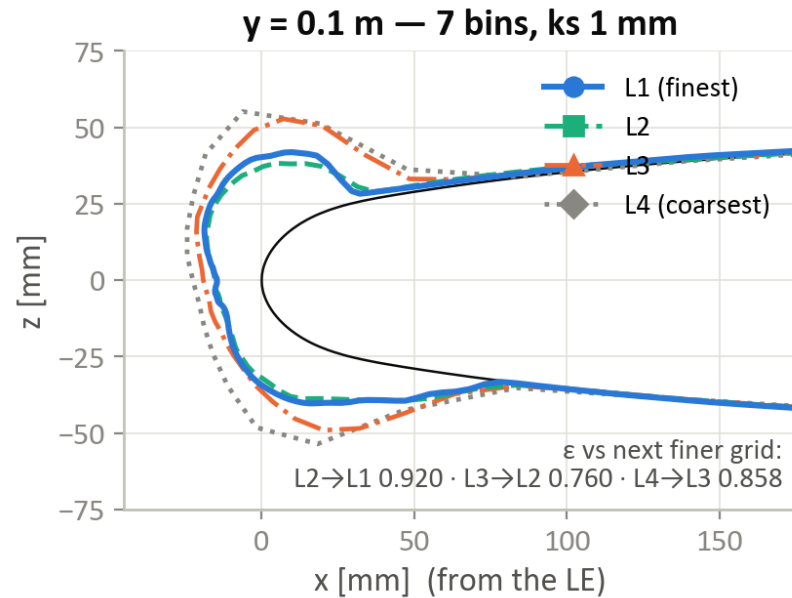
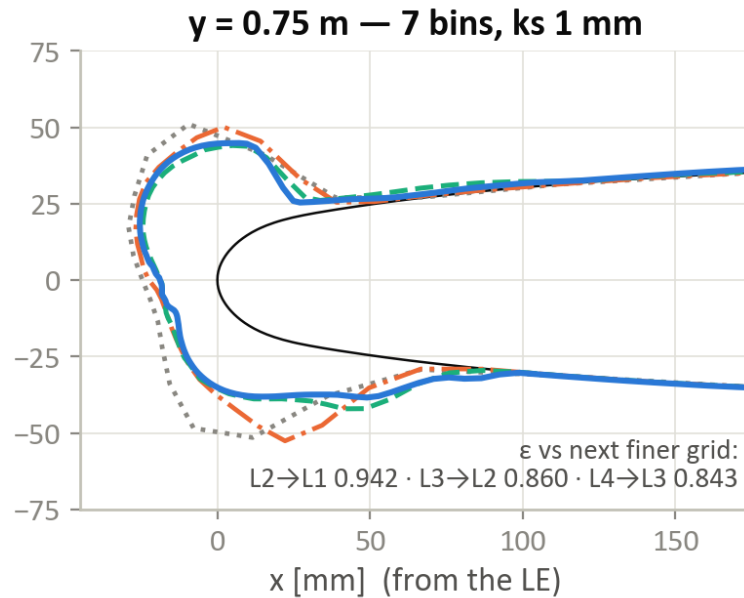
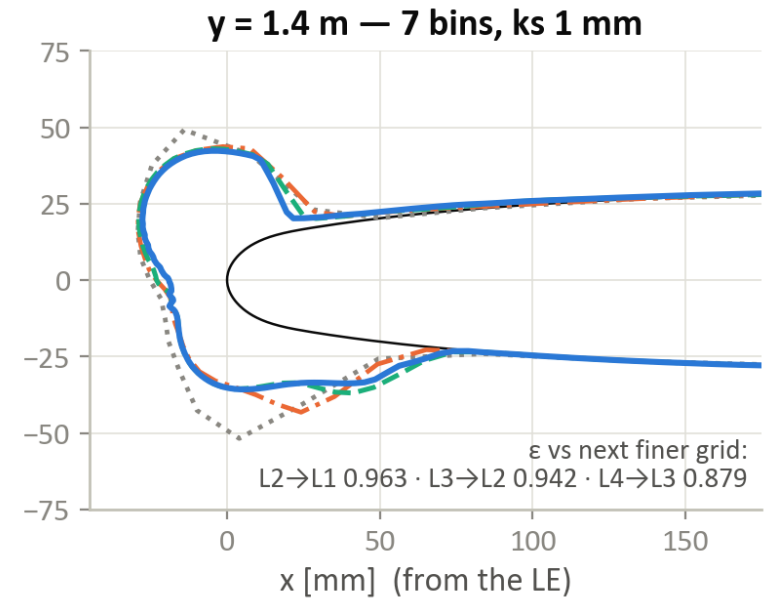
β peak 0.58 / 0.63 / 0.66 inboard $\rightarrow$ outboard · attachment point stable across levels · coarse grids widen the impingement range

ONERA M6: integrated masses



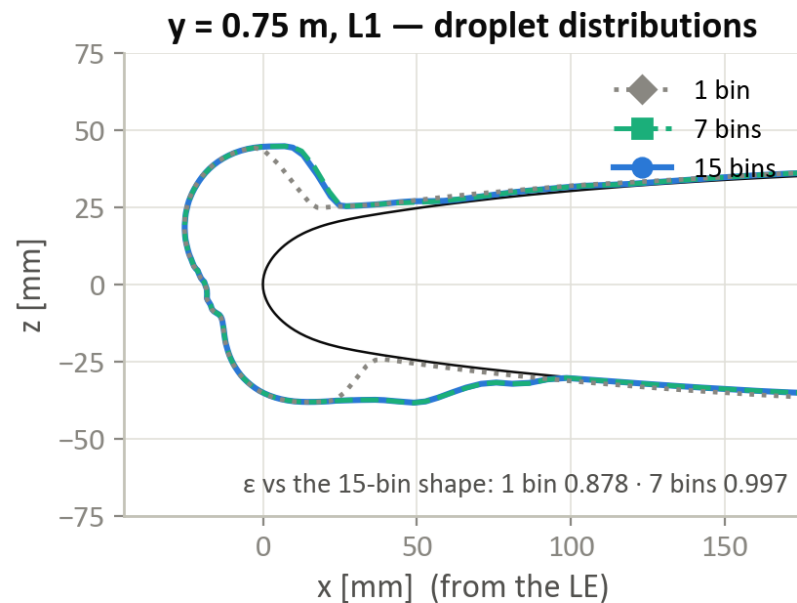
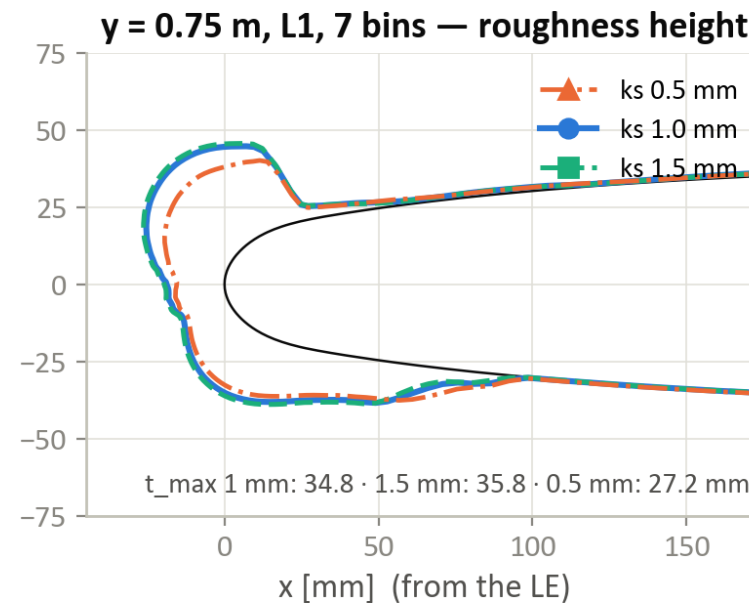
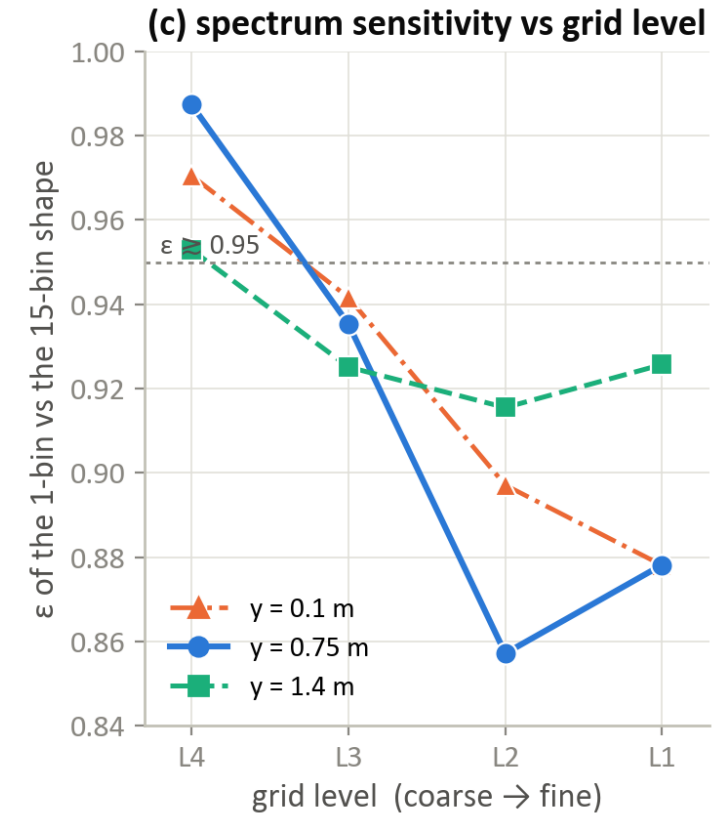
catch -13.4 % L4→L1 with shrinking steps · all bins within 1 % · ledger closure vs the CFD β field within 2 % at every level

ONERA M6: ice shapes vs grid level



final grid step ϵ 0.92 / 0.94 / 0.96 inboard → outboard · coarsest grid over-predicts the horn · converged by L2 at the outboard stations

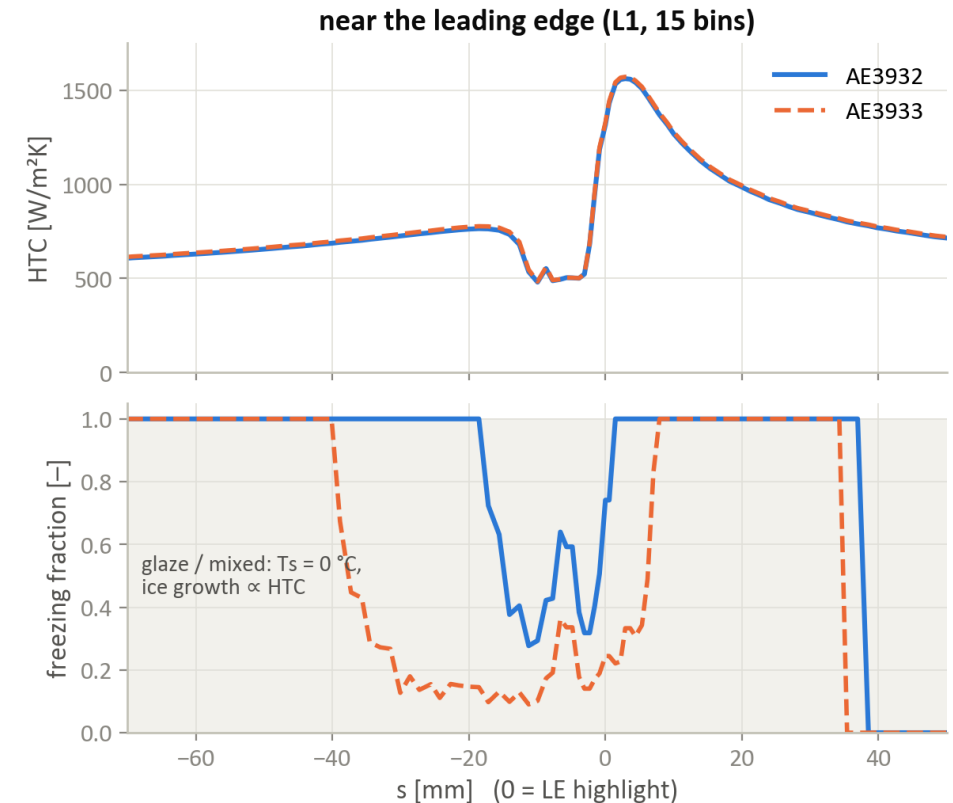
ONERA M6: droplet distribution and roughness



1 bin vs 15 bins: same horn, different flanks (ϵ 0.88 at L1, ≥ 0.95 at L4) · ks 0.5 $\rightarrow$ 1.0 $\rightarrow$ 1.5 mm: t_max 27 $\rightarrow$ 35 $\rightarrow$ 36 mm

What we learned, what comes next

- **Grid:** shapes converged by L2 on both cases;
- **Droplet distribution:** 7 bins are enough; total mass reduction with refinement: under evaluation
- **NACA0012:** AE3932 vs. AE3933 temp. increase $\rightarrow$ -40 % stagnation ice, $\times 2.5$ evaporation; section ice -3 % vs. scanned area loses $\approx$ 12 %
Observed: $\approx 2\times$ too much ice at the stagnation region: traced to the heat-transfer chain near the attachment line; corrected in the next IHB3D version, not in the submitted dataset
- **ONERA M6:** inboard station still moving with refinement; fine-grid runback: under evaluation



HTC and freezing fraction near the LE (submitted data, L1 / 15 bins)

Summary

- IHB3D v8 (OpenFOAM · TAC3D+ · streamline Messinger, single step) on all three cases, L1–L4, all bins, ks variants
- Shapes grid-converged by L2; catch converging; 7 droplet bins reproduce 15
- NACA0012: right ice area, $\approx 2\times$ too thick at the stagnation region; root cause found in the near-LE heat transfer, fixed in the next version
- Temperature and roughness sensitivities in the physically expected direction; ONERA inboard station and catch reduction with grid refinement open