Airbus Contribution to the 3rd AIAA Ice Prediction Workshop

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COMMERCIAL AIRCRAFT

3rd AIAA Ice Prediction Workshop

September 21st-24th, 2026

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Flight Physics Capabilities
Airbus Operations SAS

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Outline

- Computational Framework
  - Overview & Solvers
- Numerical Parameters
- Test Cases & Convergence Studies
  - Aerodynamics
  - Particle Tracking
  - HTC & Freezing Fraction
  - Ice Shapes
- Conclusions

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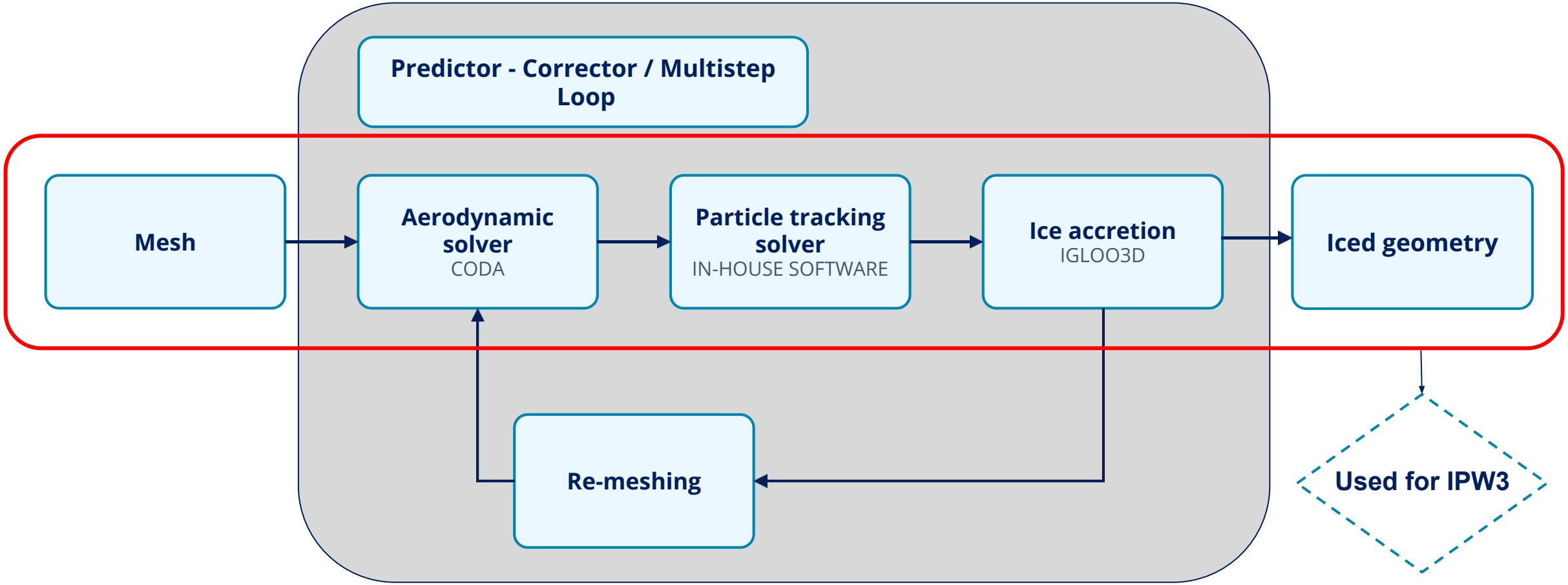
Computational Framework Overview



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Computational Framework
Aerodynamic Solver: CODA

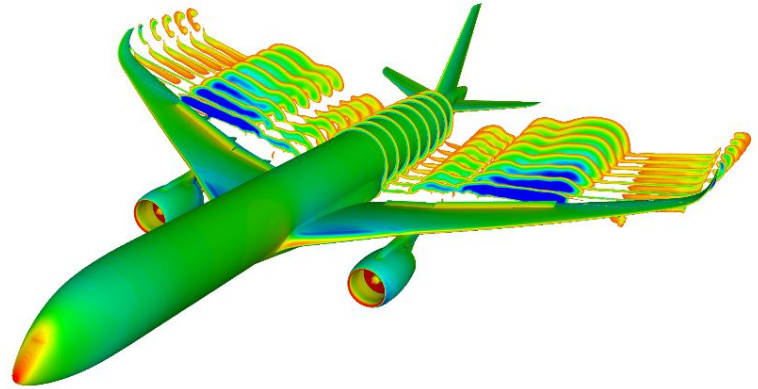
> **Jointly owned and developed by ONERA, DLR, and Airbus, CODA delivers highly accurate, flexible flow simulation for complex design and analysis.**

Advanced Meshing & Discretisation: Generic unstructured elements. Finite Volume and Discontinuous Galerkin methods.

Robust Solvers & Optimization: Strong implicit solvers, Automatic Differentiation. Gradient-based optimization.

Physics Regimes & Integration: Compressible, incompressible flows. State-of-the-art turbulence models.

HPC Scalability & Performance: Hybrid parallelisation utilizing both multi-threading and MPI.



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Computational Framework
Particle Tracking Solver: in-house tool

> **Developed in Airbus, it is an efficient polydisperse Lagrangian particle tracking solver designed to trace the motion of individual particles in fluid flows.**

Implementation & Architecture: Utilizes libraries for high-performance ray tracing.

Physical Modelling & Trajectory: Spherical droplets. Supports rotating reference frames.

Physics Regimes & Integration: Polydisperse clouds, automatic adaptive cloud refinement, particle splashing and re-emission.

HPC Scalability & Performance: Cloud decomposition for parallelization and adaptive time stepping.

Lagrangian particle tracking on a CRM65 wing-body model. Credits: © Airbus / 2026

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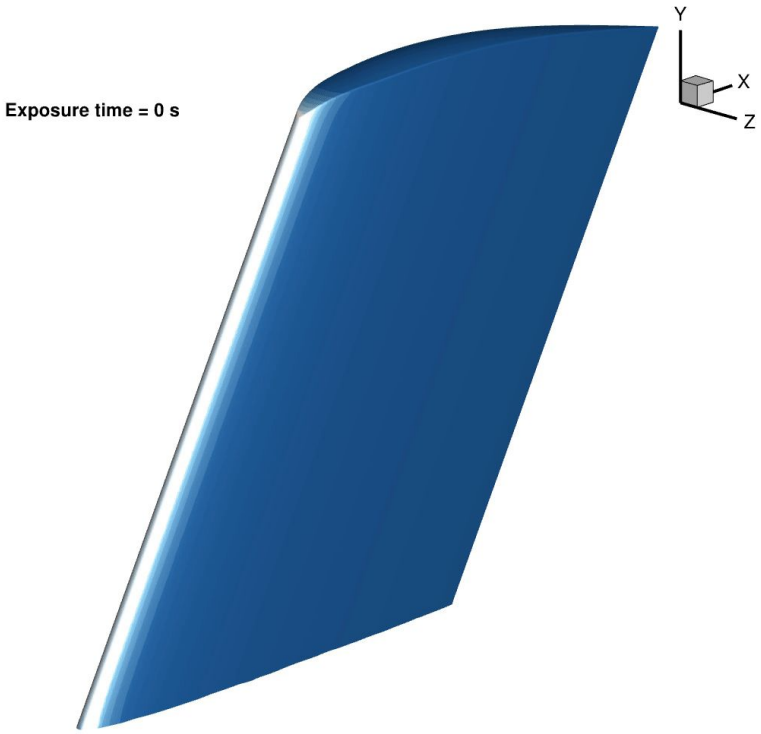
Computational Framework
Ice Accretion Solver: IGLOO3D

> **Developed by ONERA, IGLOO3D is a highly modular 3D numerical suite designed to predict and compute complex ice accretion on aircraft surfaces.**

Core Thermodynamics Modules: Messinger mass and energy balance.

3D Ice Accretion Toolbox: Couples external aerodynamics and water droplet trajectory solvers with the internal thermodynamic module.

Simplified Roughness & Convective Transfer: Makkonen integral model, experimental correlations or Navier-Stokes-derived heat transfer coefficients.



IGLOO3D multistep ice accretion. Case 362 from the 1st AIAA Ice Prediction Workshop.
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Numerical Parameters Used for IPW3 Simulations

CODA

- **Solver:** Finite Volume RANS smooth
- **Turbulence model**: negative Spalart-Allmaras
- **Convective fluxes**: 2nd order Roe scheme
- **Gradients**: extended Green-Gauss
- **Time integration**: implicit backward Euler
- **Linear solver**: matrix-free AD GMRES

PARTICLE TRACKING

- **Drag law:** Clift & Gauvin (sphere)
- **Cloud definition**: mono/poly dispersed (1-3-7-15 bins)
- **Cloud refinement**: automatic
- **Time integration**: Runge-Kutta 4th order
- **Splashing model**: No
- **Bouncing model** No

IGLOO3D

- **Simulation type:** one step
- **Roughness height**: chord/1000
- **HTC**: Prandtl & Schlichting correlation (cf rough)
- **Thermodynamics**: Messinger
- **Ice density**:
  - 917 kg/m3 for glaze ice
  - Macklin formula for rime ice ($750\ kg/m^3 < \rho < 917\ kg/m^3$)
- **Node displacement**: algebraic

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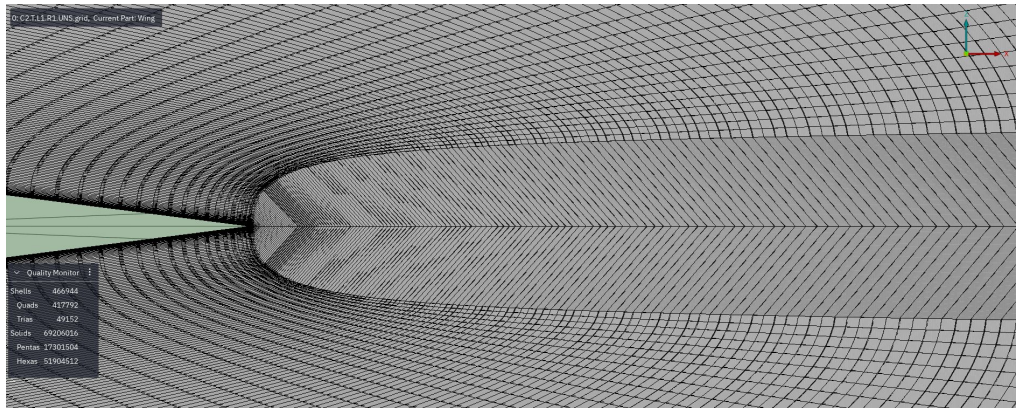
Test Cases

	NACA0012		ONERA M6
	AE3932	AE3933	
L4 - coarse	1 bin	1 bin	1 bin
	3 bins	3 bins	3 bins
	7 bins	7 bins	7 bins
	15 bins	15 bins	15 bins
L3 - medium	1 bin	1 bin	1 bin
	3 bins	3 bins	3 bins
	7 bins	7 bins	7 bins
	15 bins	15 bins	15 bins
L2 - fine	1 bin	1 bin	1 bin
	3 bins	3 bins	3 bins
	7 bins	7 bins	7 bins
	15 bins	15 bins	15 bins
L1 - extra fine	1 bin	1 bin	1 bin
	3 bins	3 bins	3 bins
	7 bins	7 bins	7 bins
	15 bins	15 bins	15 bins

- **ONERA M6 test cases were omitted** from the analysis due to a **lack of mesh convergence**.
- **Poor resolution of the trailing edge/wake region** had a significant effects on the calculation of aerodynamic coefficients.
- **No experimental data** available.

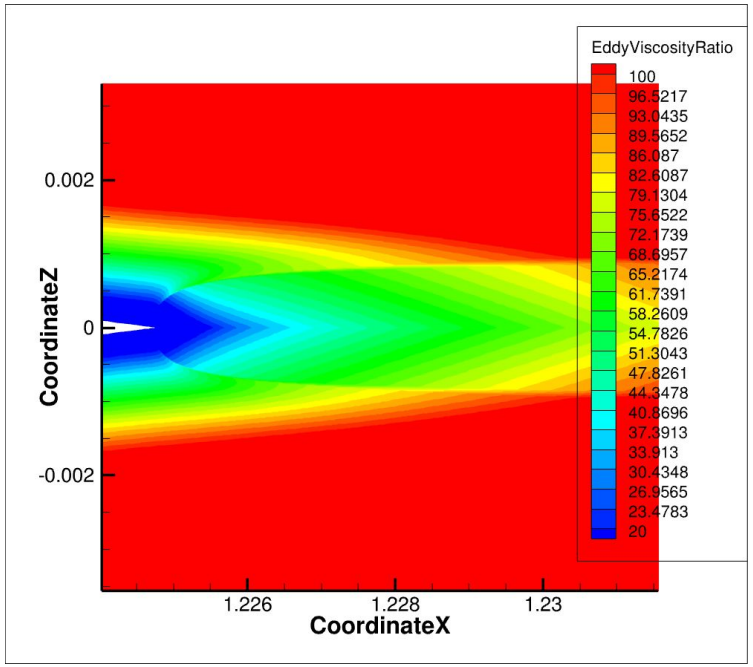


Mesh quality issues

- **Sharp trailing edge singularity**: highly skewed elements, collapsed faces at the junction.
- **Block interface transition**: significant jump in elements aspect ratio.

Solver issues

- **Turbulence model:** fails to accurately represent the shear layer.
- **Contour lines:** exhibit dependency on the mesh cell distribution.



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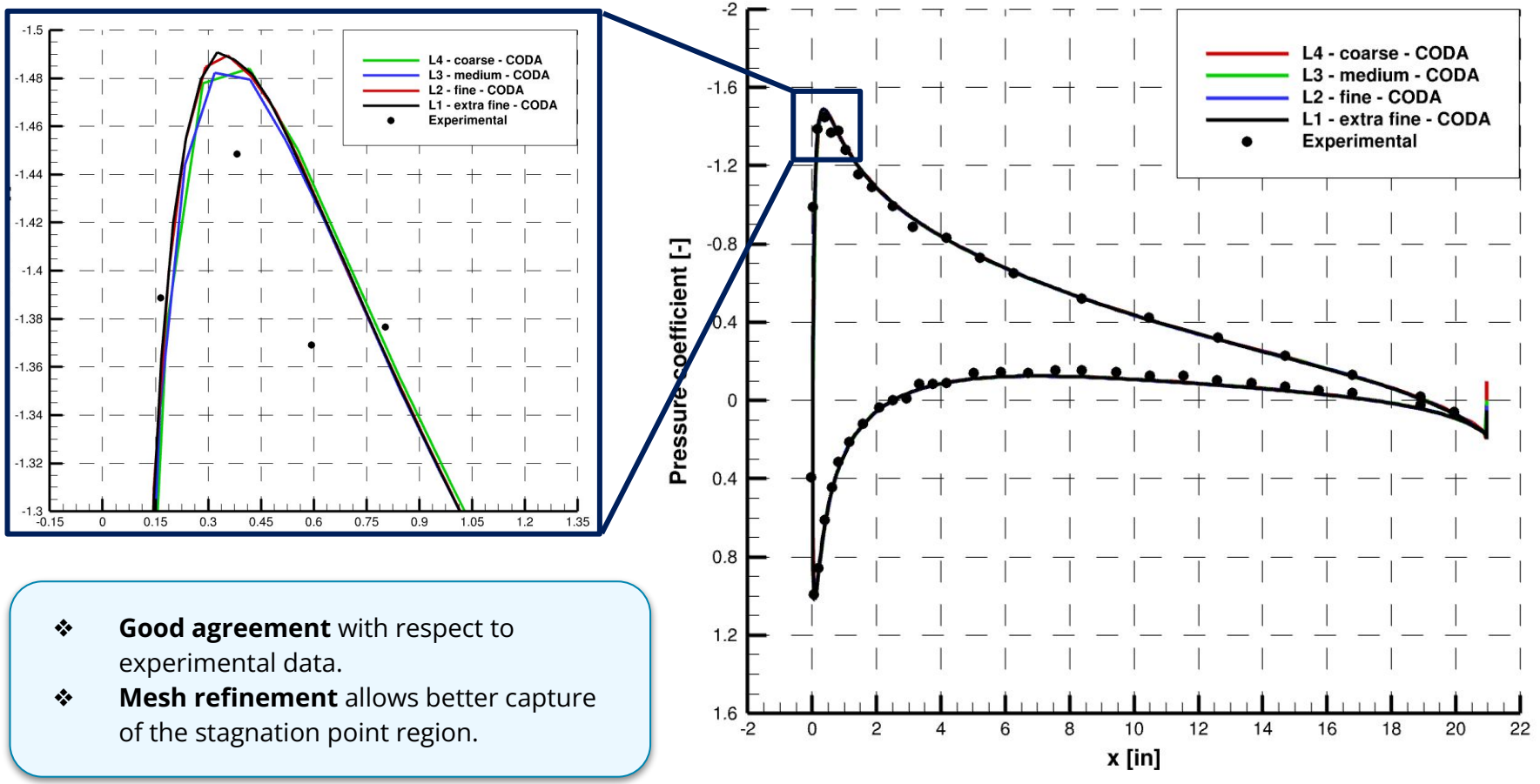
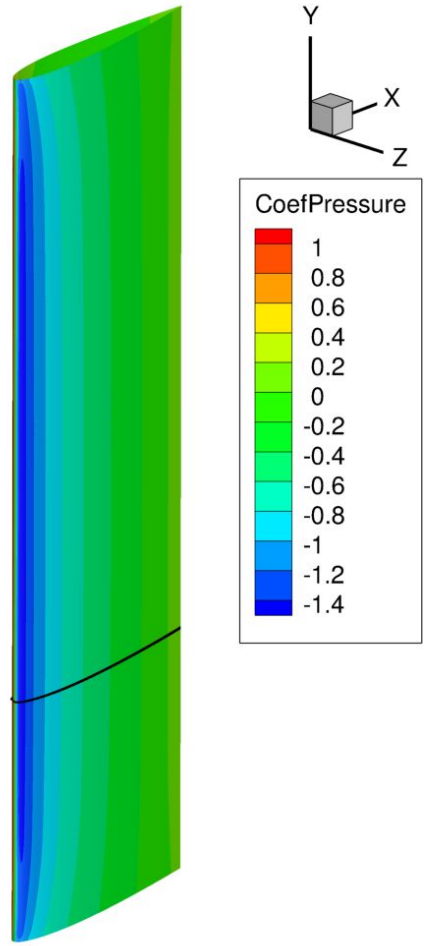
Aerodynamics Convergence Study (1)





- **Good agreement** with respect to experimental data.
- **Mesh refinement** allows better capture of the stagnation point region.

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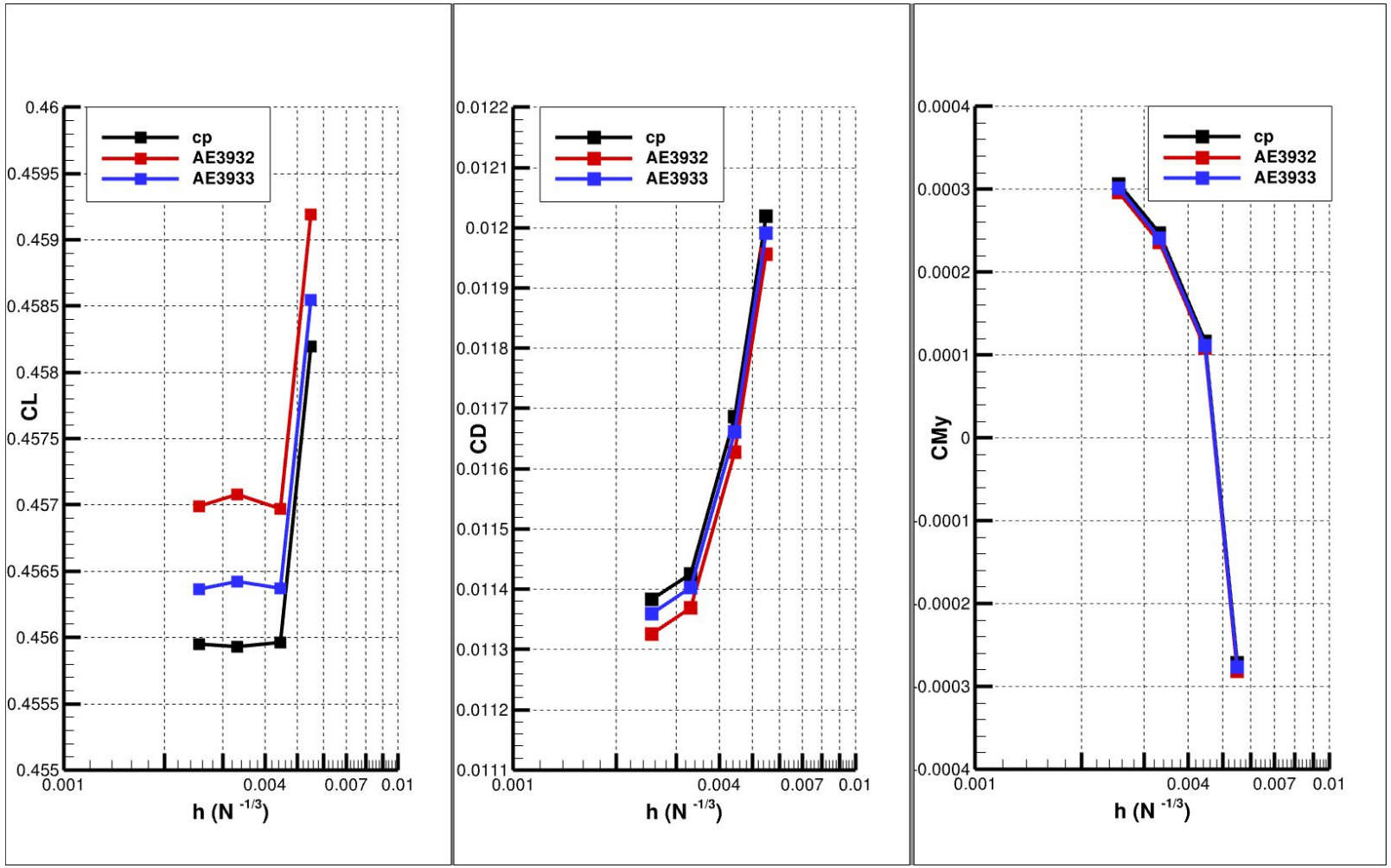
Aerodynamics Convergence Study (2)



Input verification

- **Minor coefficient variations observed**, attributed to near-identical freestream conditions.

Mesh sensitivity

- **CL**: converged at **L3** mesh (< 0.02 lift counts difference vs. L1).
- **CD**: approaching convergence at **L2** mesh (~ 0.5 drag counts difference vs. L1).
- Further refinement (**ultra-fine**) required to fully assess **asymptotic drag behavior**.

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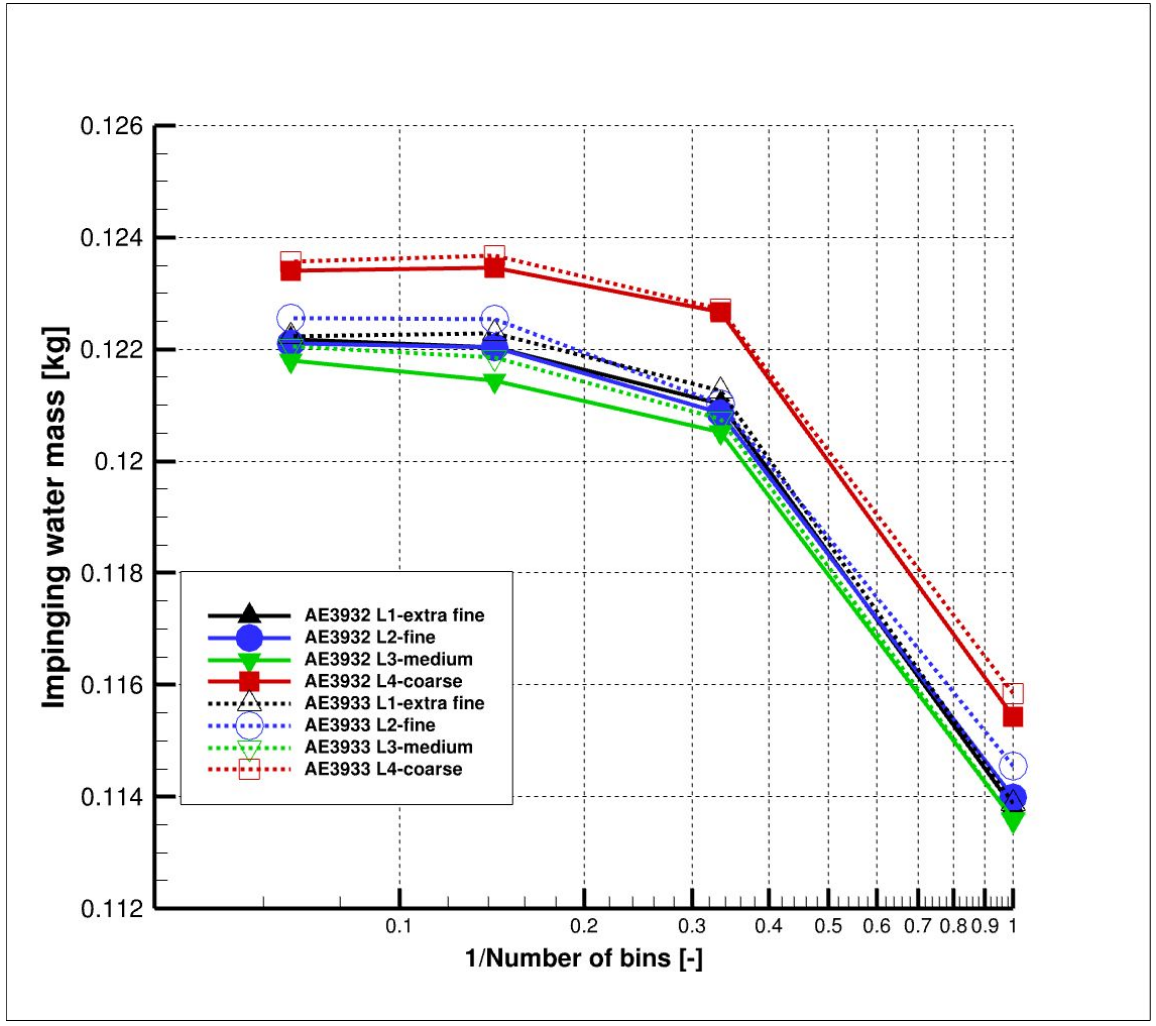
Particle Tracking Convergence Study (1)



Input verification

- Negligible variation between cases AE3932 and AE3933 due to identical pressure distributions.

Droplet sensitivity

- **Monodisperse distribution underestimates** total water mass (~7%).
- **Impinged water mass plateau at 7 bins** (Langmuir distribution).

Mesh sensitivity

- **L3** mesh yields **lower impinged mass than expected** compared to finer meshes. Investigation is ongoing.
- **L2** mesh provides a **reasonable refinement** for accurate results.
- **L4** mesh demonstrates **conservative** behavior.

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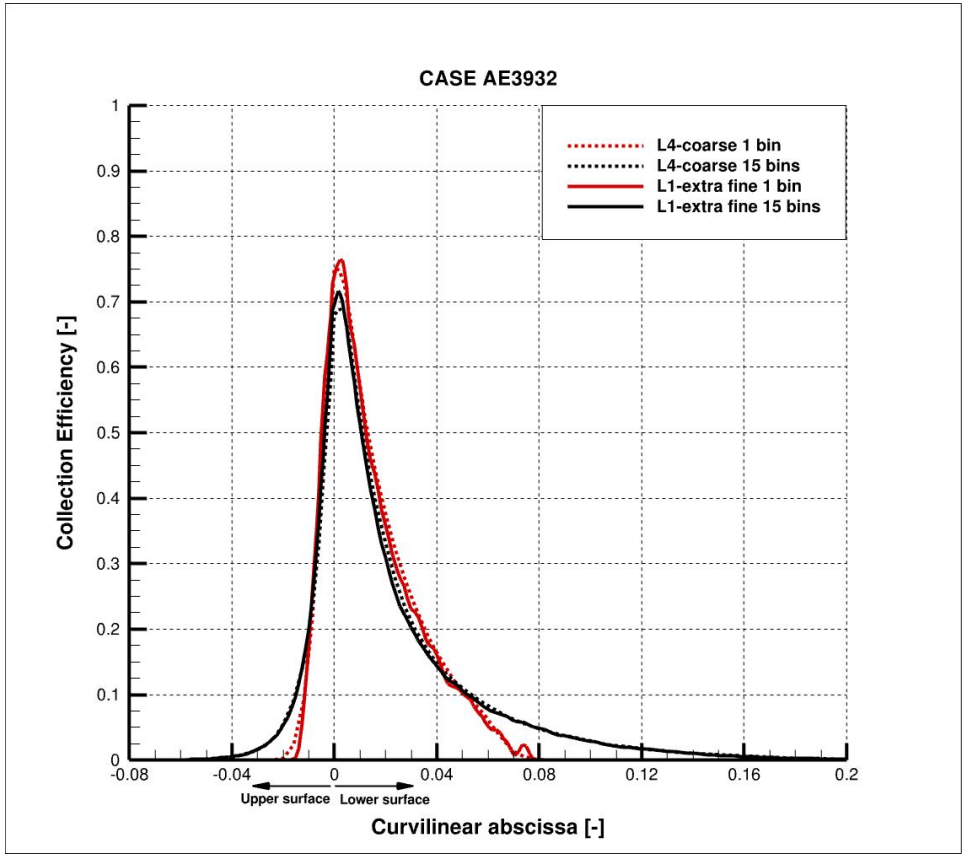
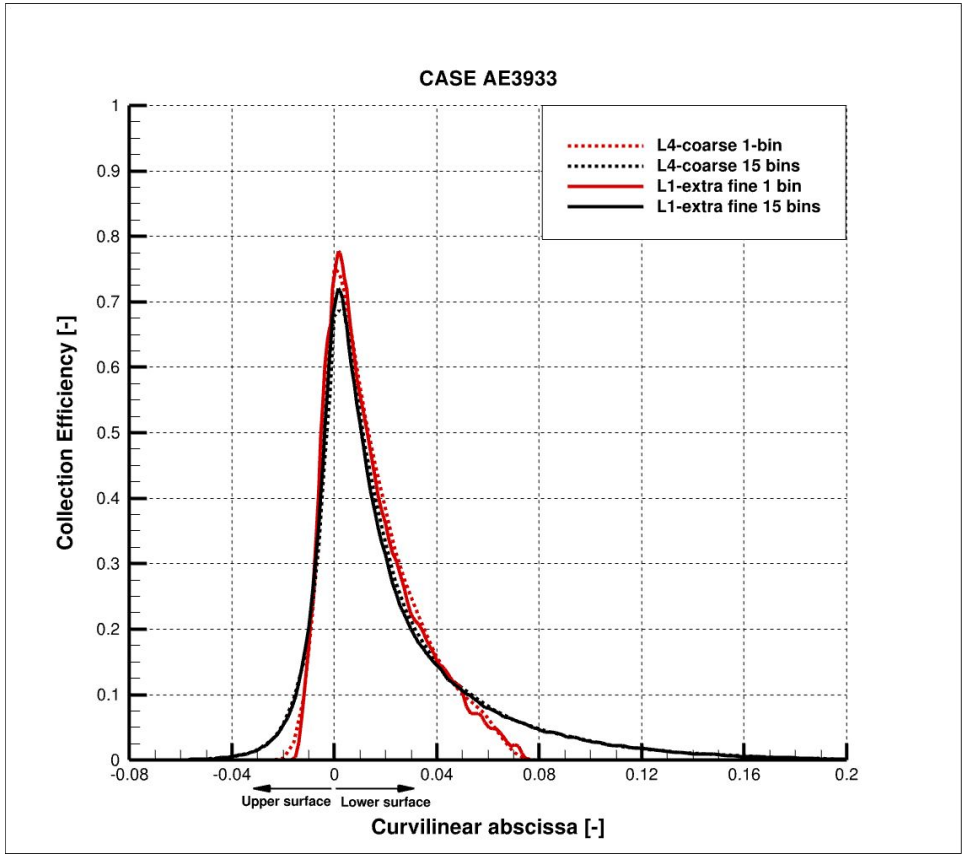
Particle Tracking Convergence Study (2)





- Negligible variation between cases AE3932 and AE3933 due to nearly identical freestream conditions.
- **Monodisperse** simulations significantly **underestimate impingement limits**.
- **Mesh refinement** allows for **better peak capture**.

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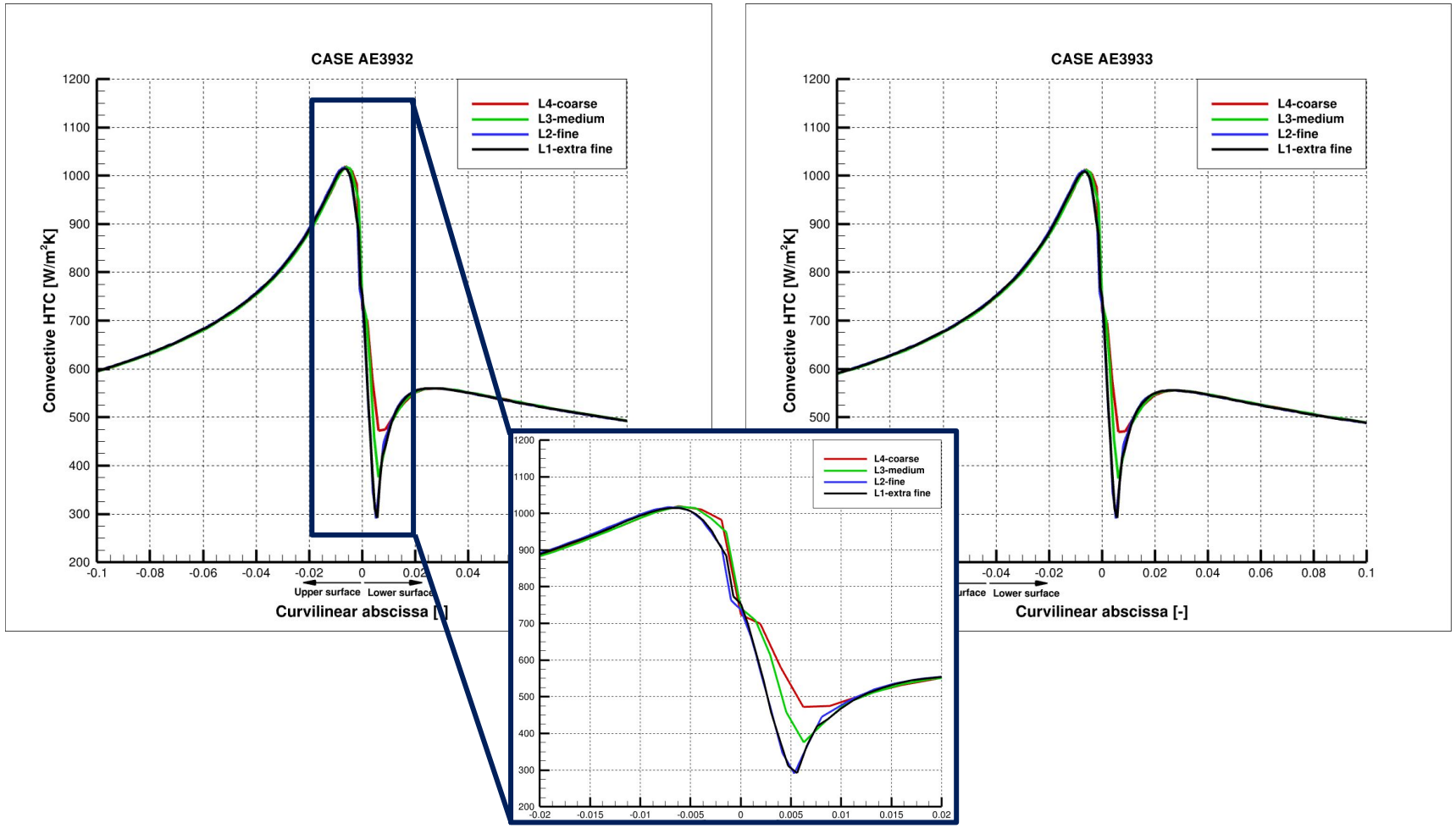
HTC Convergence Study



Input verification

- Negligible variation between cases AE3932 and AE3933, as the **3°C temperature difference** results in a **negligible impact on the local Reynolds number** used to compute the Nusselt number.

Mesh sensitivity

- **Significant sensitivity** observed at the **stagnation point**, with an approximately **38% difference** in HTC values between coarse and fine meshes.
- As the **HTC** model depends on the **curvilinear abscissa**, a **good discretization of the leading edge** region is required.

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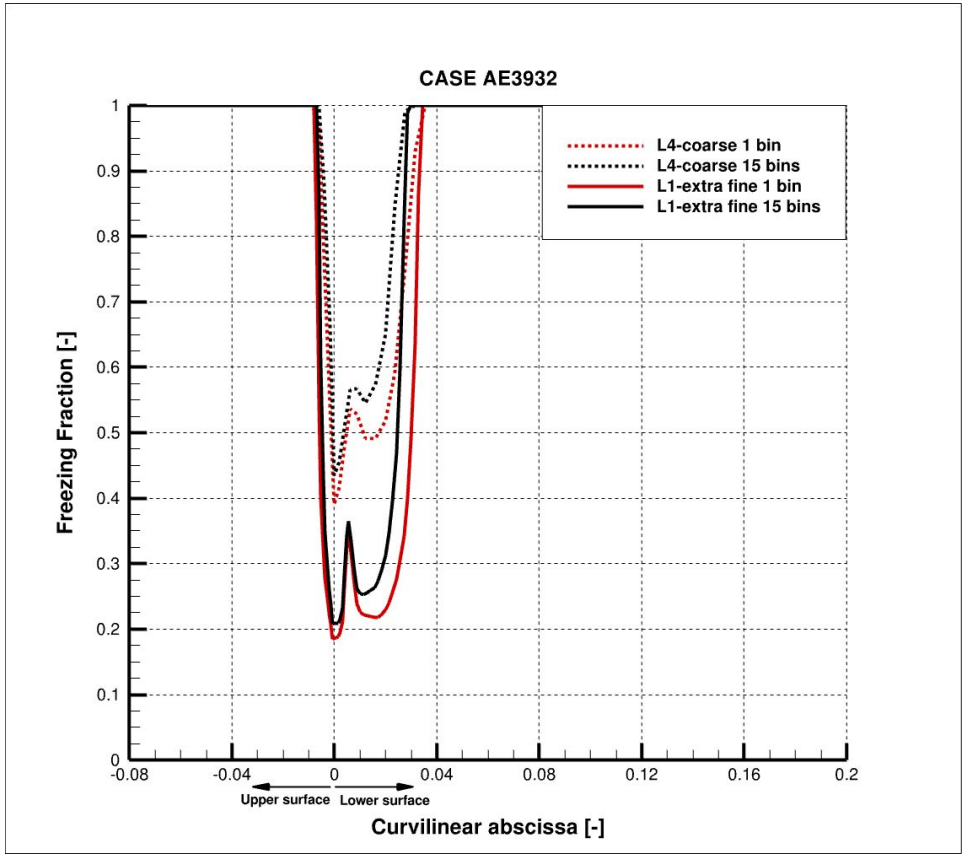
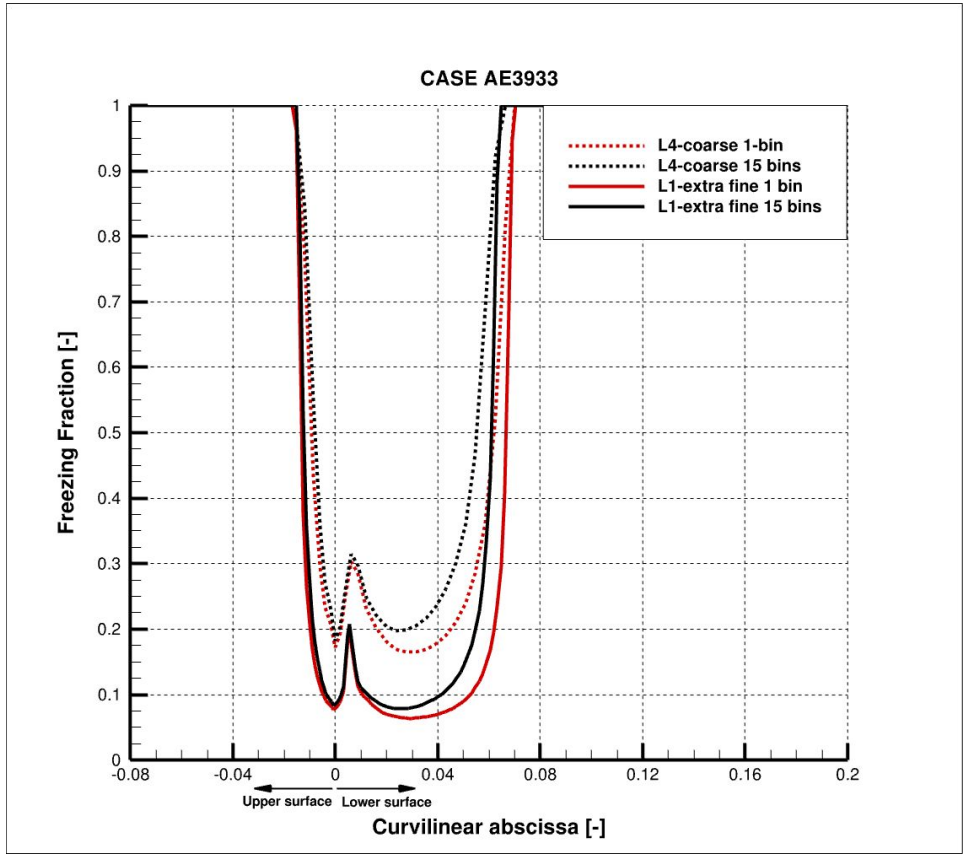
Freezing Fraction Convergence Study





- **Significant effect of temperature** on the two test cases.
- **Monodisperse** simulations predict a lower freezing fraction and a wider runback region.
- **Mesh refinement improved** predictions at the **stagnation point**.

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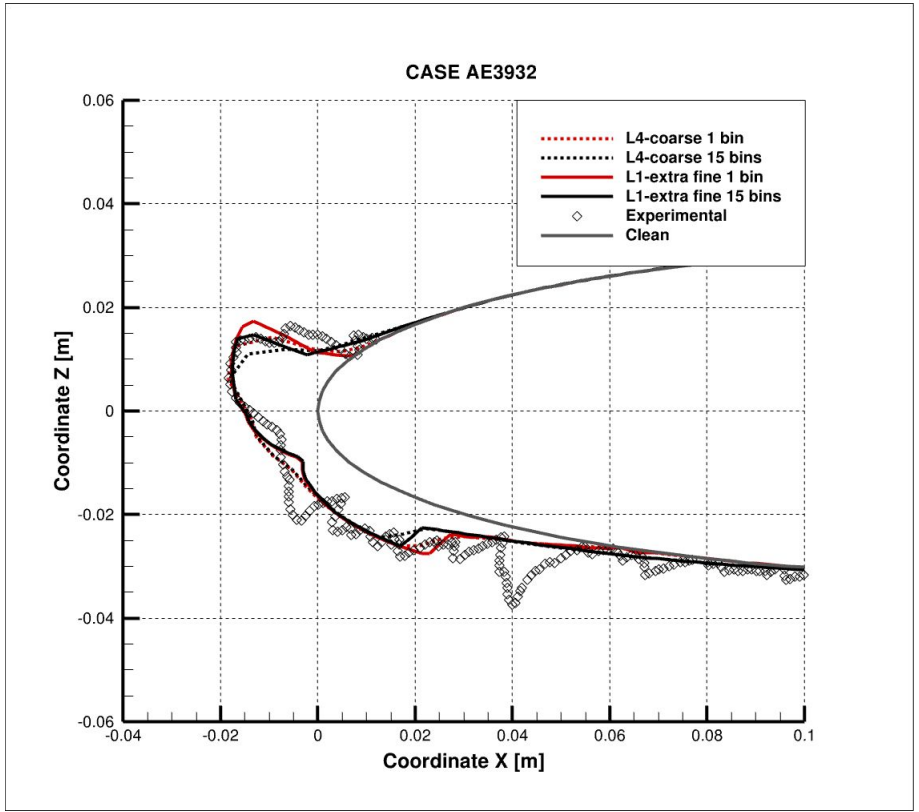
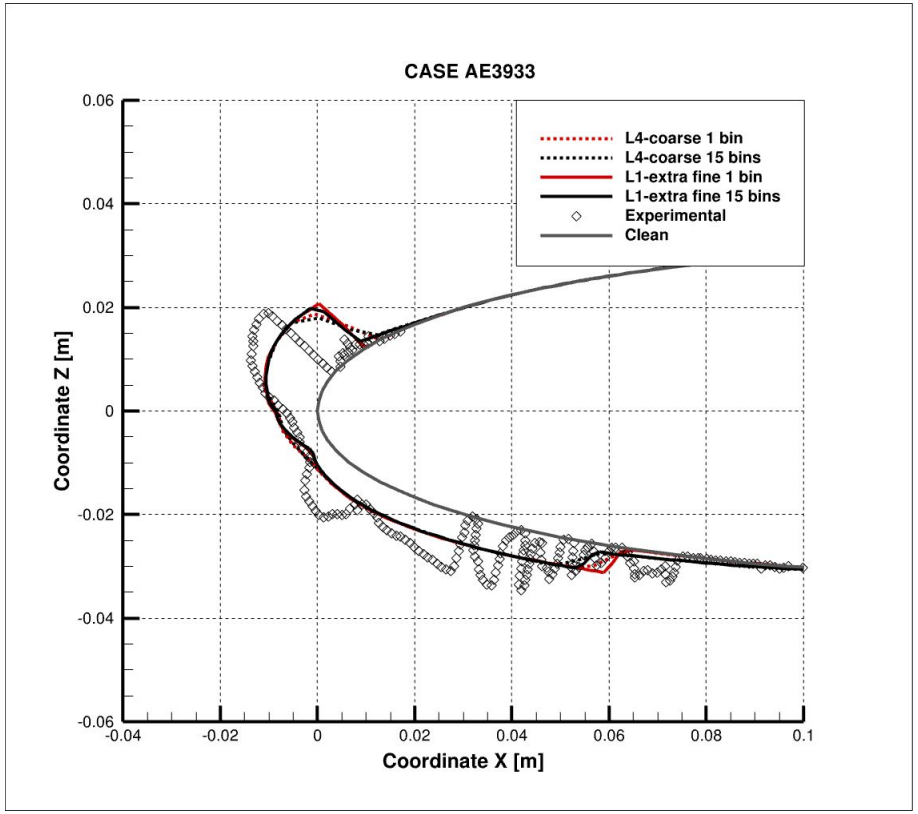
Ice Shapes





- **Monodisperse** simulations significantly **underestimate impingement limits**.
- **Monodisperse** simulations predict **wider runback**.
- **Mesh refinement** allows for **better capture of peaks.**.
- **Mesh refinement improves** the prediction of **ice thickness** at the **stagnation point**.
- In some cases, the **HTC model has limited accuracy**, leading to deviations from experiments.

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Conclusions

Mesh

- A fine mesh (L2-like) is required to achieve aerodynamic mesh independence, ensuring accurate predictions of impinging water mass, HTC and ice shapes.
- Coarse meshes are conservative regarding collection efficiency.
- Further investigation of the L3 mesh is required, as it may affect the CFD and particle tracking solution.

Droplet distribution

- Monodisperse simulations underestimate impinging water mass.
- Monodisperse simulations predict lower freezing fractions and wider runback regions but underpredict impingement limits.
- Langmuir distributions effectively represent impinging water mass convergence in Appendix C conditions and should be used for further analysis.

Modeling

- The used HTC model (Prandtl & Schlichting correlation) may lack accuracy for complex glaze ice configurations.

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Thank you

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