2nd AIAA Ice Prediction Workshop

IPW

Established 2019

Politecnico di Milano icing group contribution to the 2nd Ice Prediction Workshop

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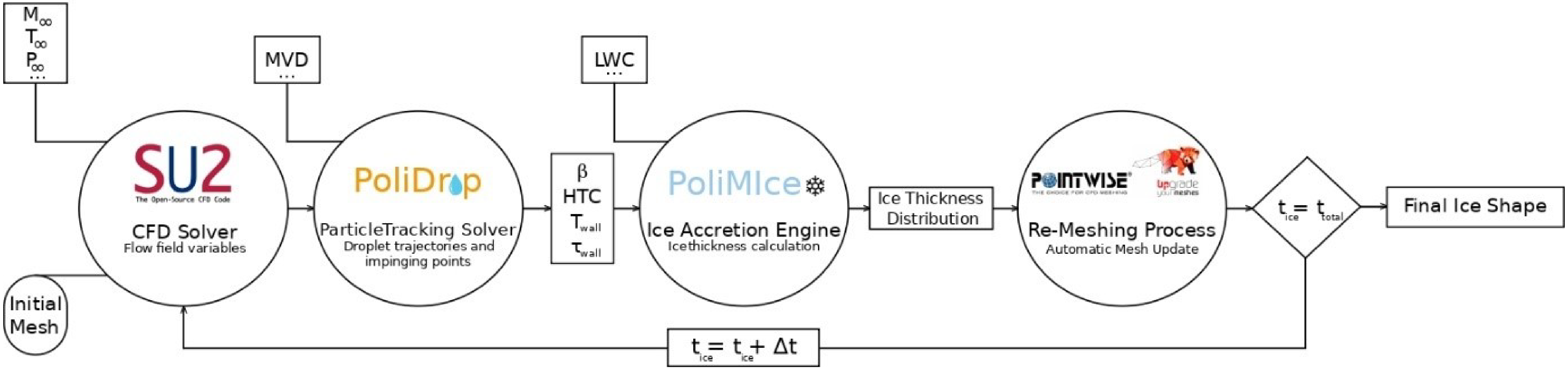
Tommaso Bellosta
Andrea Rausa
Alberto Guardone

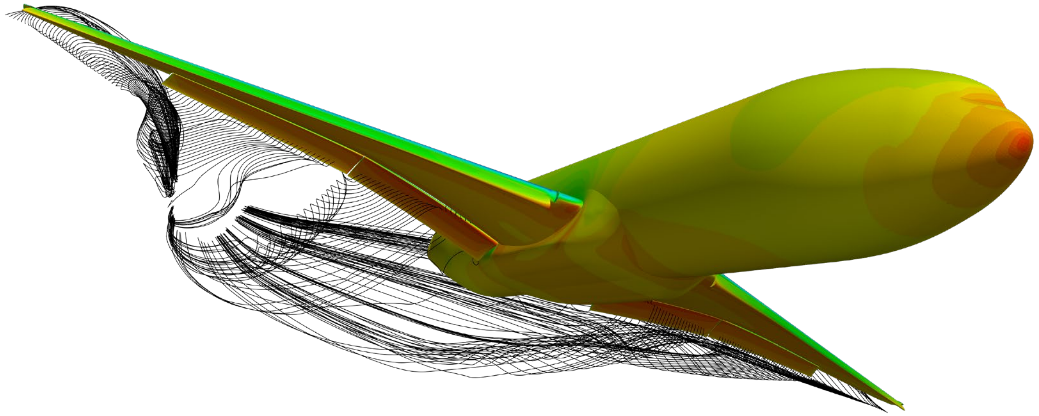
24-06-2023

PoliMIce Simulation Framework



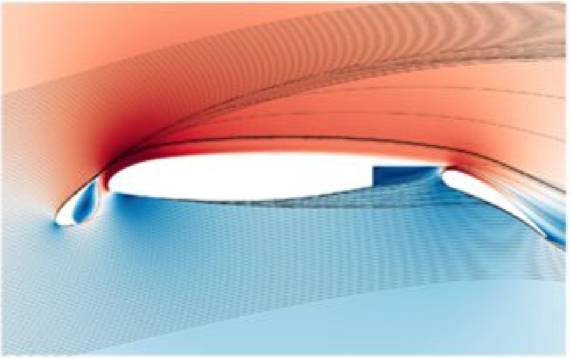
G. Gori, M. Zocca, M. Garabelli, A. Guardone, and G. Quaranta. Polimice: *A simulation framework for three-dimensional ice accretion.* Appl. Math. Comput.

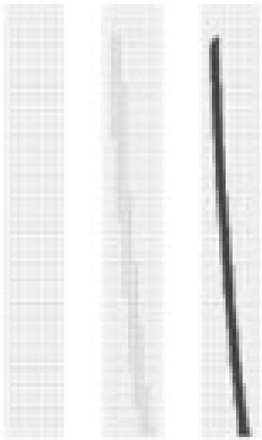
SU2

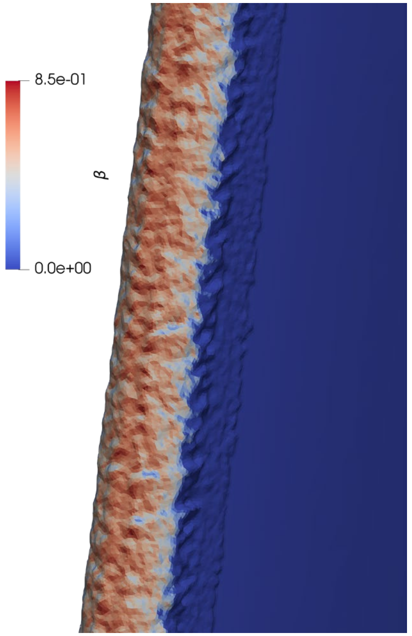


- Finite Volume solver
- Unstructured grids
- Node centered
- RANS solver
- SA turbulence model
- Convective flux discretization schemes:
  2 order upwind Roe scheme

PoliDrop



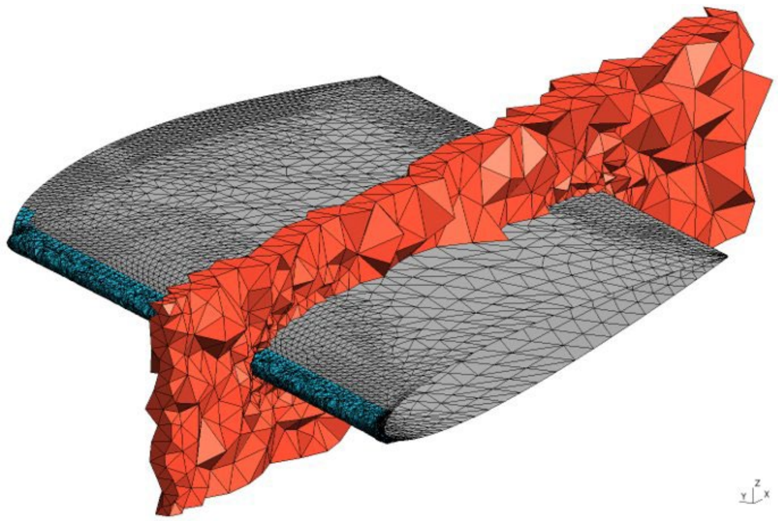


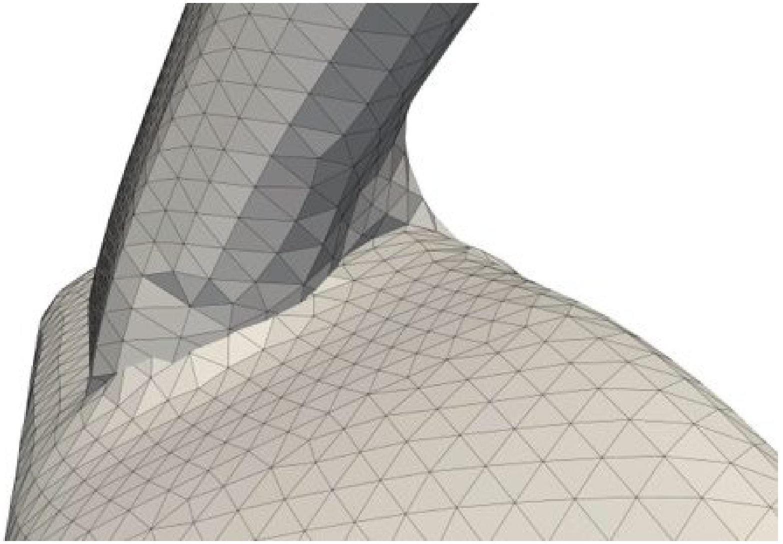


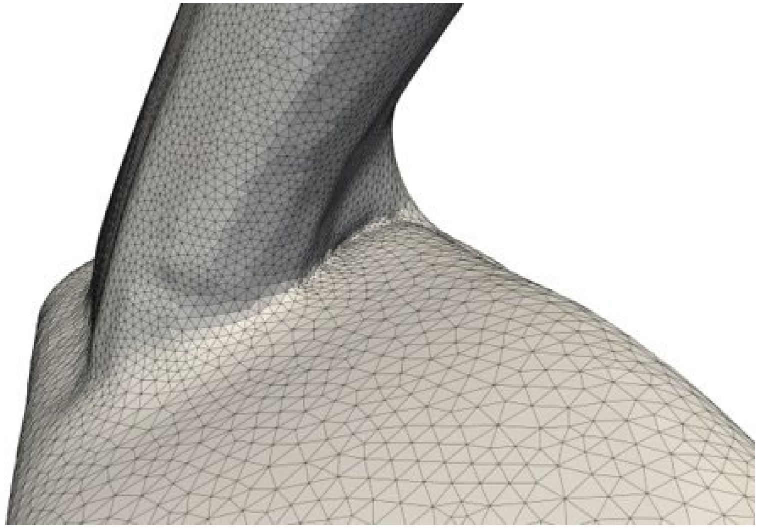
- In-house Lagrangian particle tracking code.
- Wall interaction models are used to take into account droplet rebound, splash and spread at the walls.
- Automatic mesh refinement.

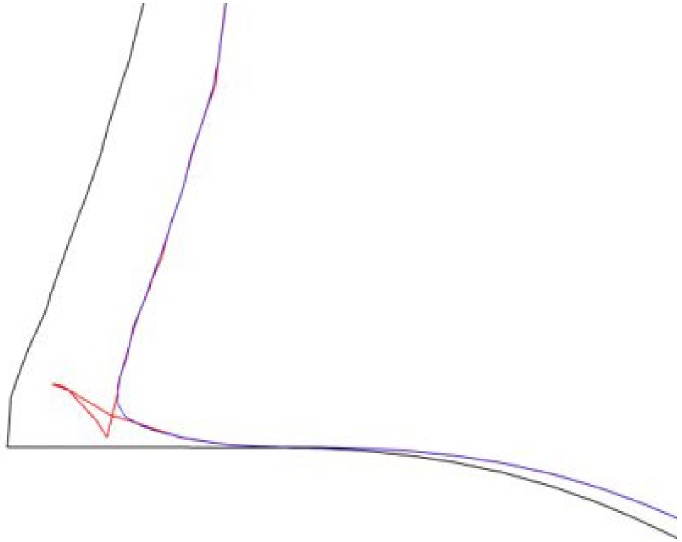
Bellosta, T., Baldan, G., Sirianni, G., & Guardone, A. (2023). Lagrangian and Eulerian algorithms for water droplets in in-flight ice accretion. *Journal of Computational and Applied Mathematics*, *429*, 115230.

Meshing Update









- Level-set and implicit domain meshing based methodology.
- Fully automatic and robust procedure.
- Possible to handle complex geometries and front intersections.
- Good quality body-fitted mesh for further CFD computations.
- Long exposure times can be simulated.

Meshing Update

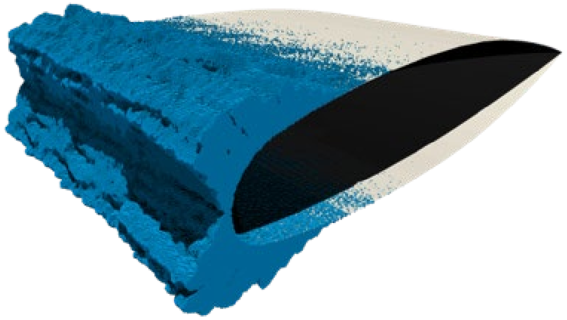
Local curvature indicator, based on the computation of the normalized angle deficit at each surface vertex.

Final surface discretization.

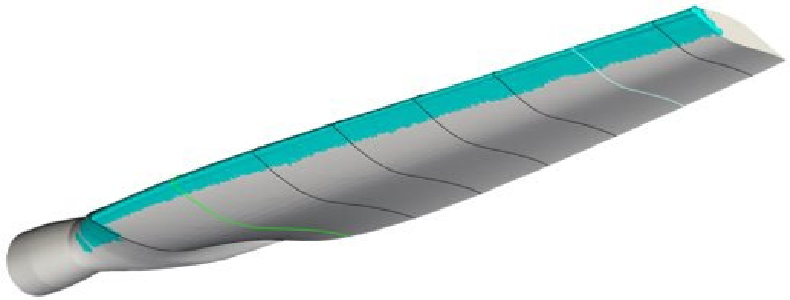
[1] Donizetti, Alessandro, Tommaso Bellosta, Andrea Rausa, Barbara Re, and Alberto Guardone. *"Level-set mass-conservative front-tracking technique for multistep simulations of in-flight ice accretion."* Journal of Aircraft (2023): 1-11.
[2] Donizetti, Alessandro, Andrea Rausa, Tommaso Bellosta, Barbara Re, and Alberto Guardone. *"A three dimensional Level-Set front tracking technique for automatic multi-step simulations of in-flight ice accretion."* SAE Technical Paper, 2023.

PoliMIce Capabilities

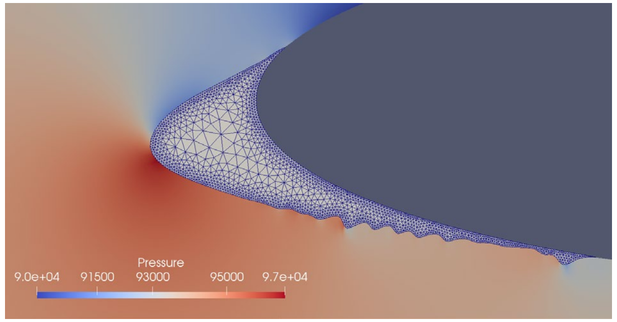
Morphogenetic approach



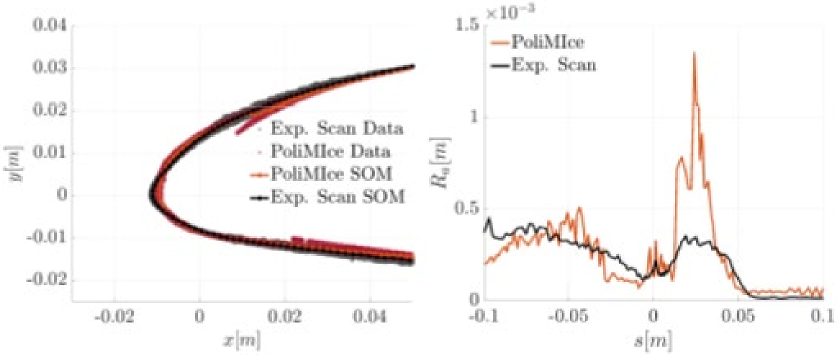
Ice accretion on rotating components

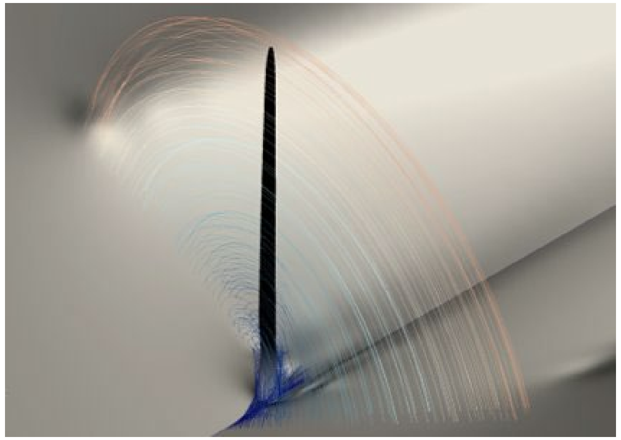


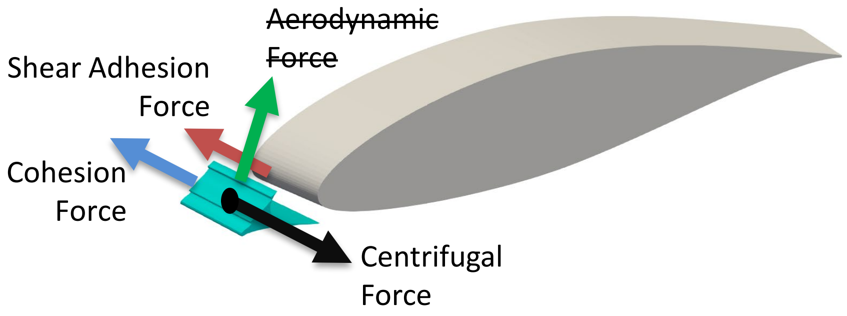
Ice shedding analysis



Roughness characterization of simulated ice shapes



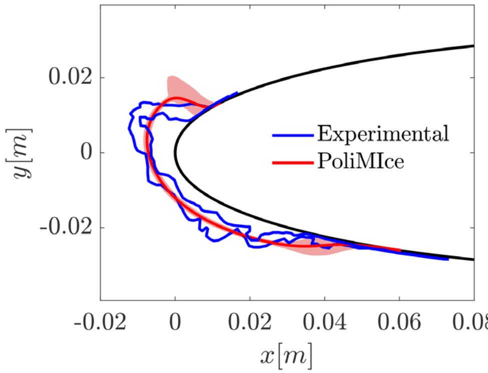


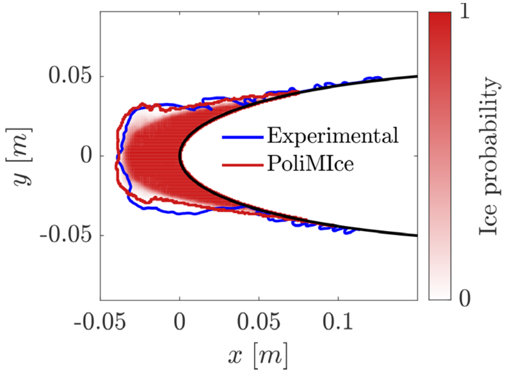


[1] A. Rausa, F. Caccia, A. Guardone. *Multi-physics simulations of ice shedding from wind turbines*. International Conference on Icing of Aircraft, Engines, and Structures, SAE Tech. Paper 2023-01-1479, 2023.
[2] A. Rausa, A.Donizetti, and A. Guardone. "Multi-physics simulation of 3D in-flight ice-shedding." *Journal of Computational and Applied Mathematics* (2023): 115226.
[3] A. Rausa, M. Morelli, and A. Guardone. "A novel method for robust and efficient prediction of ice shedding from rotorcraft blades." *Journal of Computational and Applied Mathematics* 391 (2021).
[4] Gallia M., Bellosta, T. and Guardone, A., 2023. Automatic roughness characterization of simulated ice shapes. Journal of Computational and Applied Mathematics, 427, p.115114.

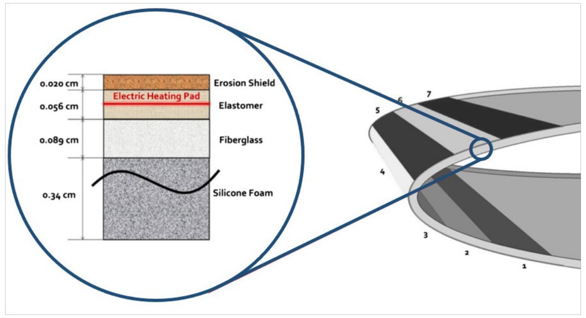
PoliMIce Capabilities

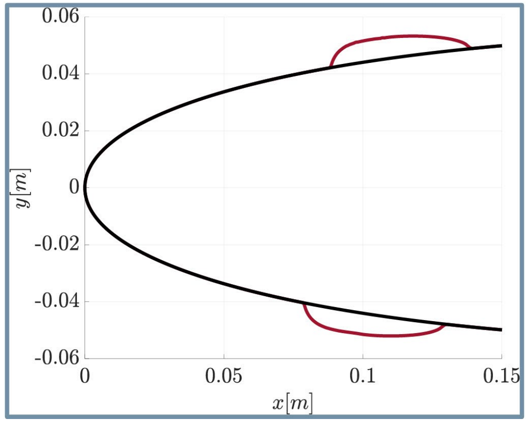
Uncertainty quantification



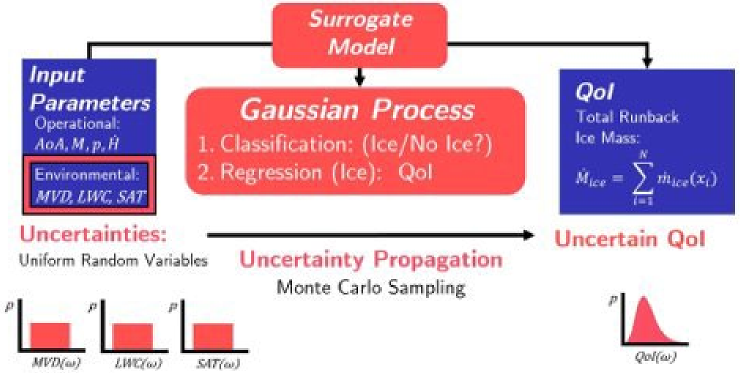


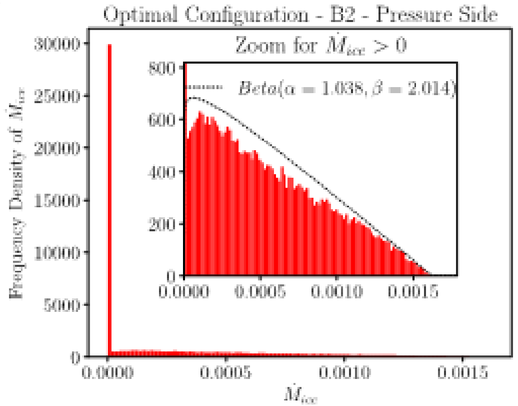
Electro-thermal IPS, anti-icing & de-icing





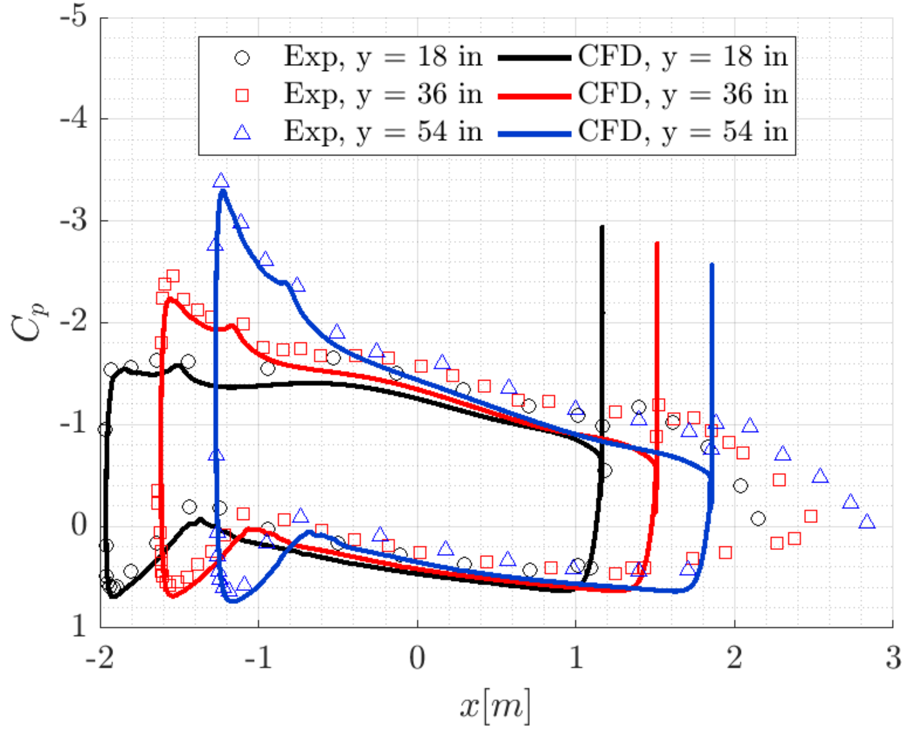
Robust optimization



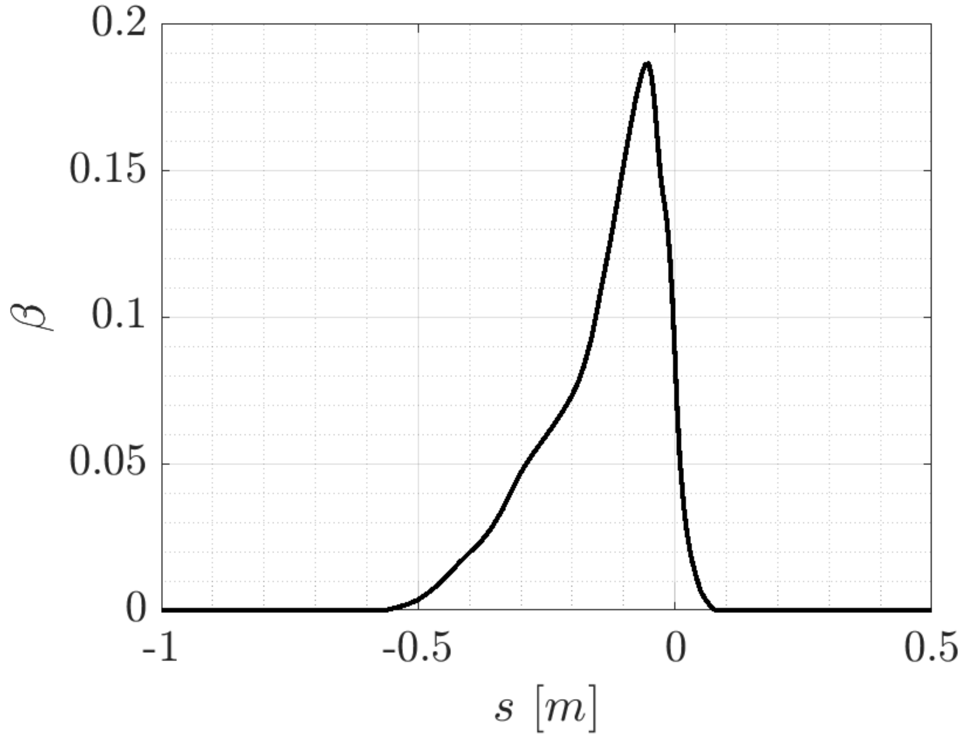


[1] Gallia M., Gori G., Guardone A. ”Numerical Optimization of Electrothermal Ice Protection Systems.” Book Chapter in: Handbook of Numerical Simulation of In-Flight Icing
[2] Gallia M., Carnemolla A., Premazzi M., Guardone A. “Optimization of a nacelle electro-thermal ice protection system for icing wind tunnel testing” Transactions on Aerospace Research (2021)
[3] Arizmendi Gutiérrez B., Della Noce A., Gallia M., Guardone A. ”Optimization of a Thermal Ice Protection System by Means of a Genetic Algorithm.” In International Conference on Bioinspired Methods and Their Applications, pp. 189-200. Springer, Cham, 2020.
[4] Gallia, M., Arizmendi Gutiérrez, B., Gori, G., Guardone, A. and Congedo, P.M., 2023. Robust Optimization of a Thermal Anti-Ice Protection System in Uncertain Cloud Conditions. *Journal of Aircraft*, pp.1-15.
[4] Gori, G., Congedo, P.M., Le Maître, O., Bellosta, T. and Guardone, A., 2022. Modeling in-flight ice accretion under uncertain conditions. *Journal of Aircraft*, *59*(3), pp.799-813.
[5] Gori, G., B ellosta, T., Guardone, A. (2023). Numerical Simulation of In-Flight Icing Under Uncertain Conditions. In: Habashi, W.G. (eds) Handbook of Numerical Simulation of In-Flight Icing. Springer, Cham.

Inboard Model

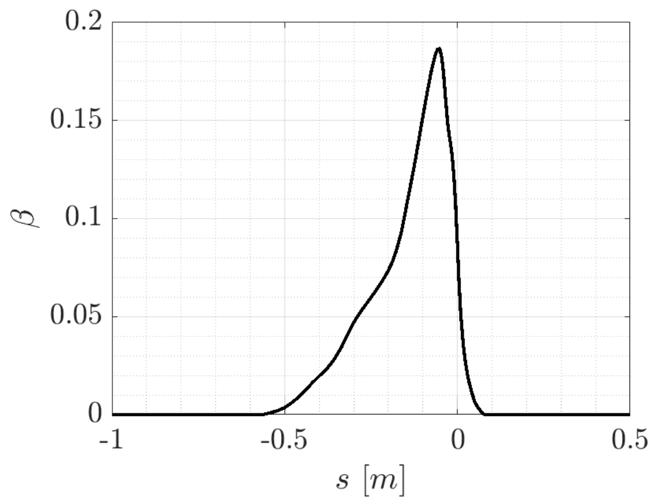


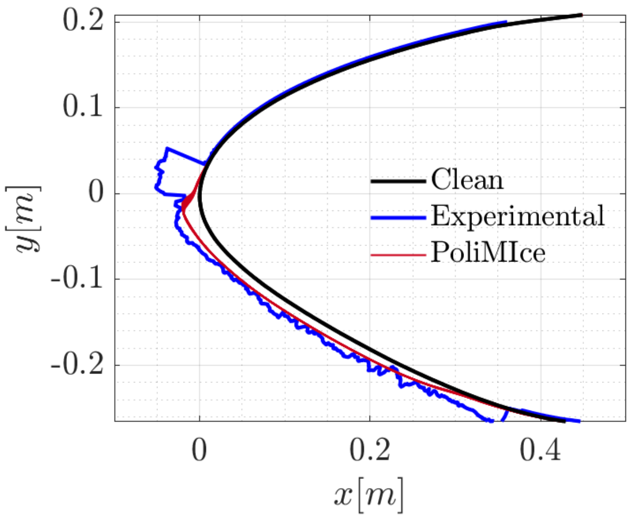
Cp distribution at different span lenghts.

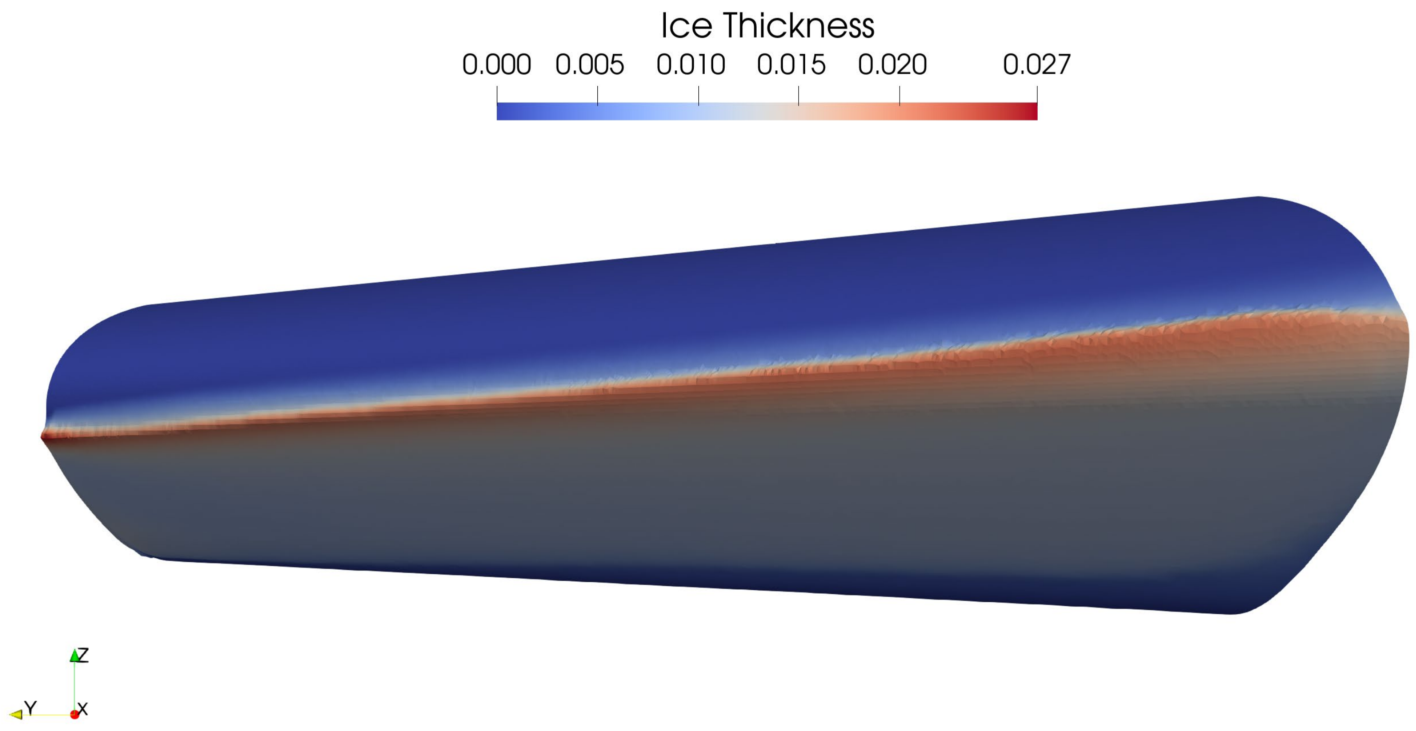


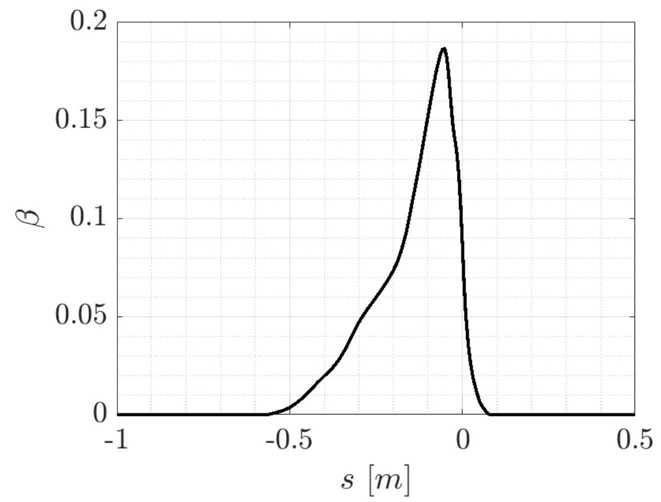
7 bins distribution.

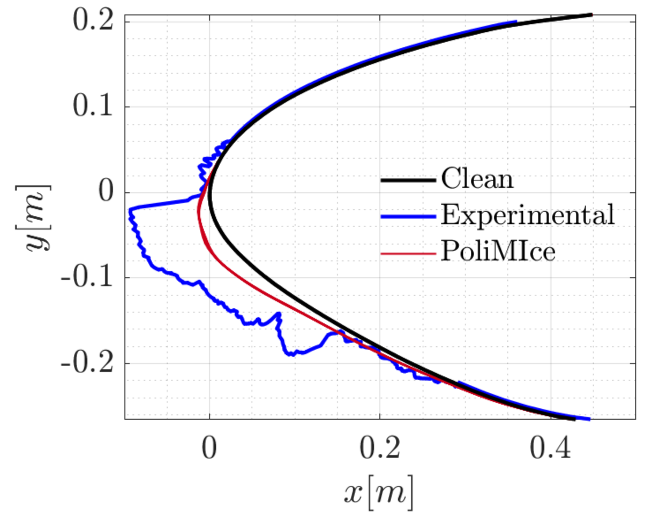
Case 2.1 Glaze

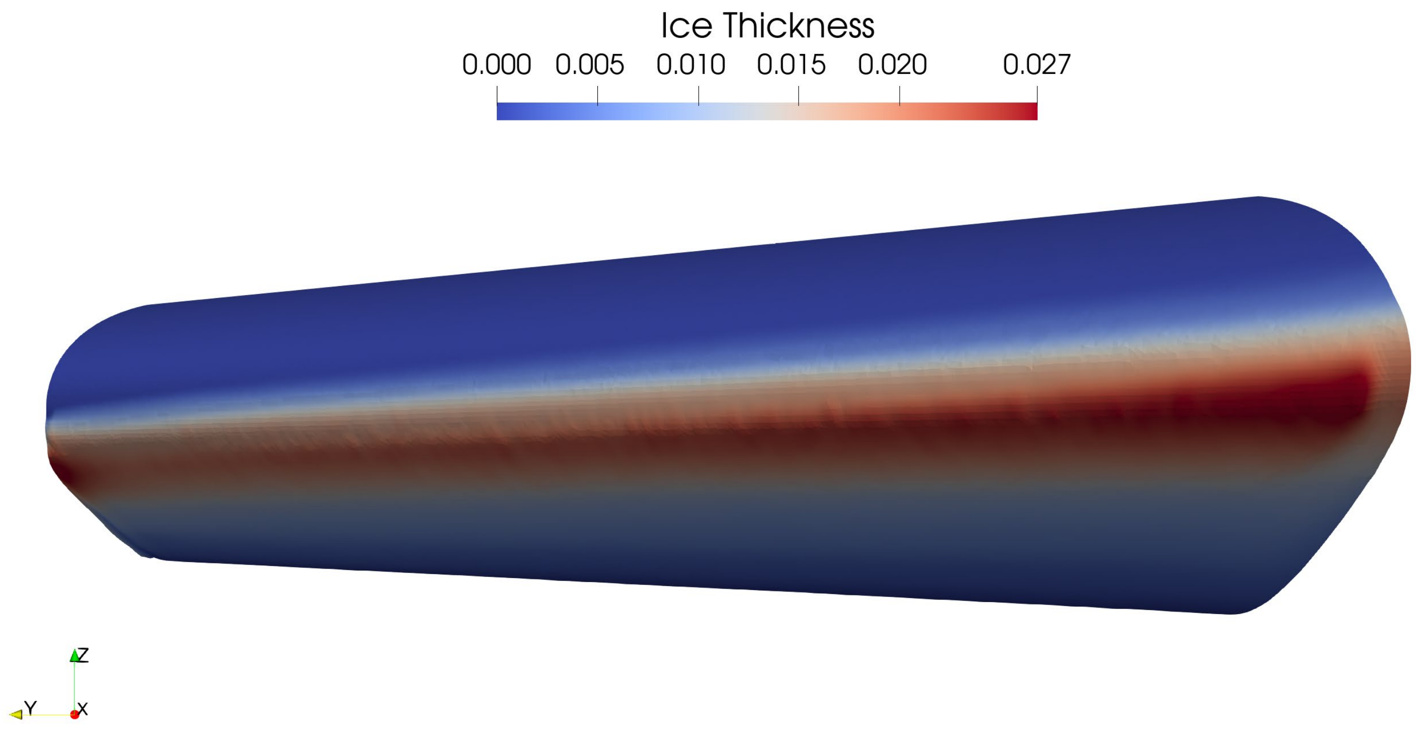




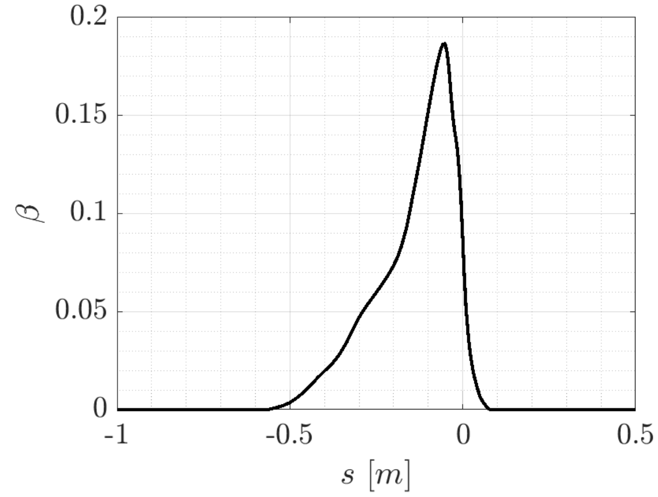



0.2
0.15
0.1
0.05
0
β
-1
-0.5
0
0.5
s [m]

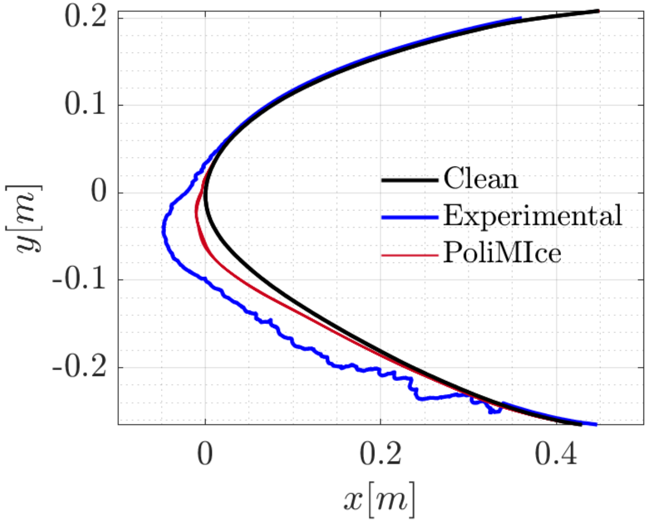

0.2
0.1
0
-0.1
-0.2
y[m]
0
0.2
0.4
x[m]
Clean
Experimental
PoliMIce


Ice Thickness
0.000
0.005
0.010
0.015
0.020
0.027
Z
Y
X

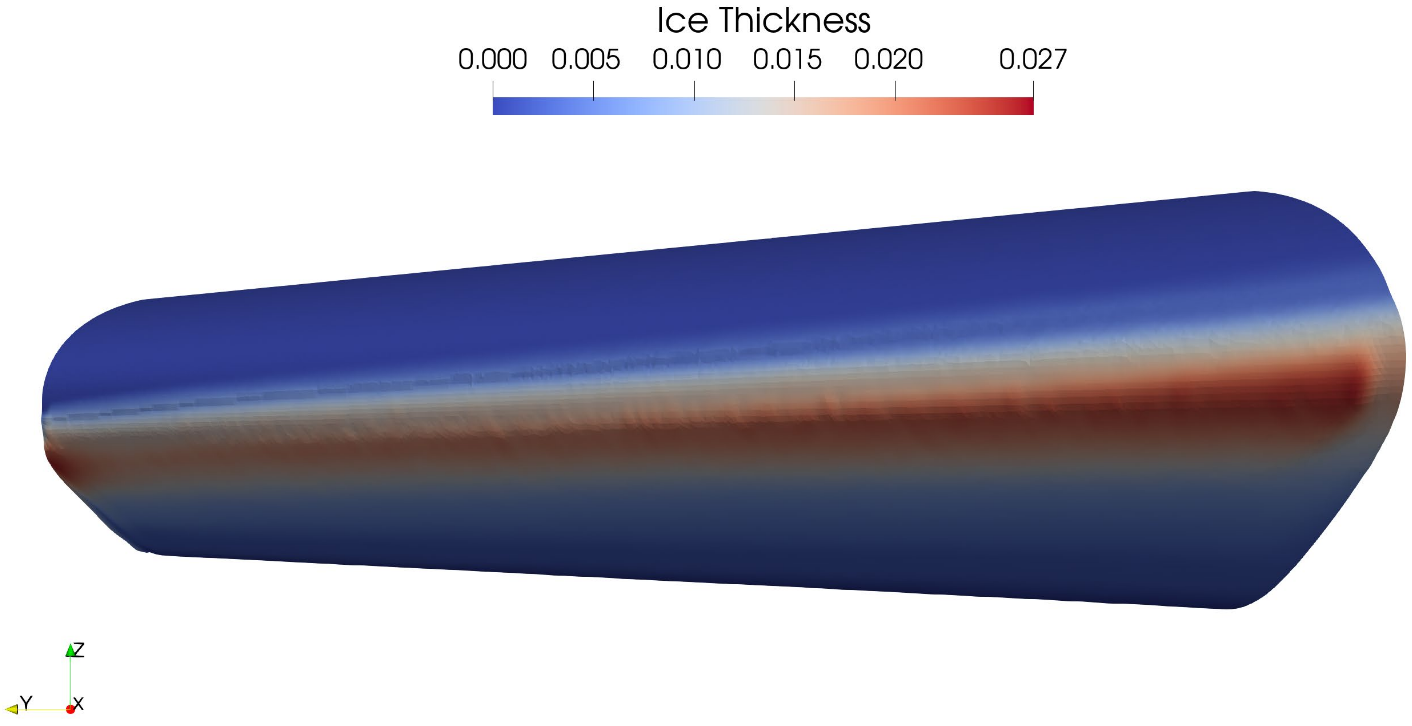
Case 2.3 Rime



0.2
0.15
0.1
0.05
0
β
-1
-0.5
0
0.5
s [m]

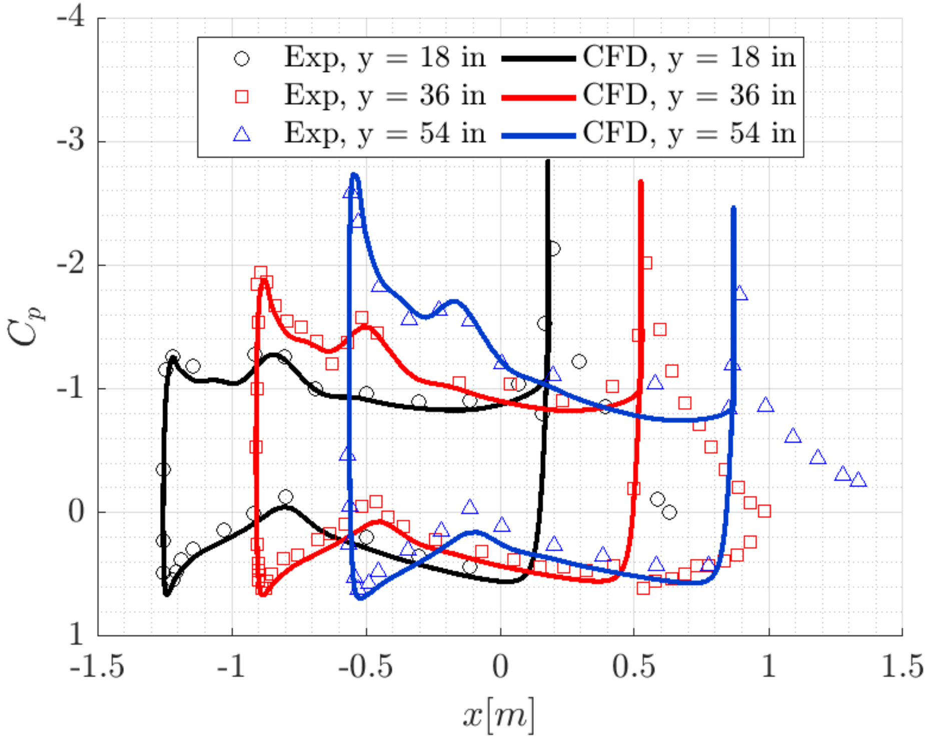


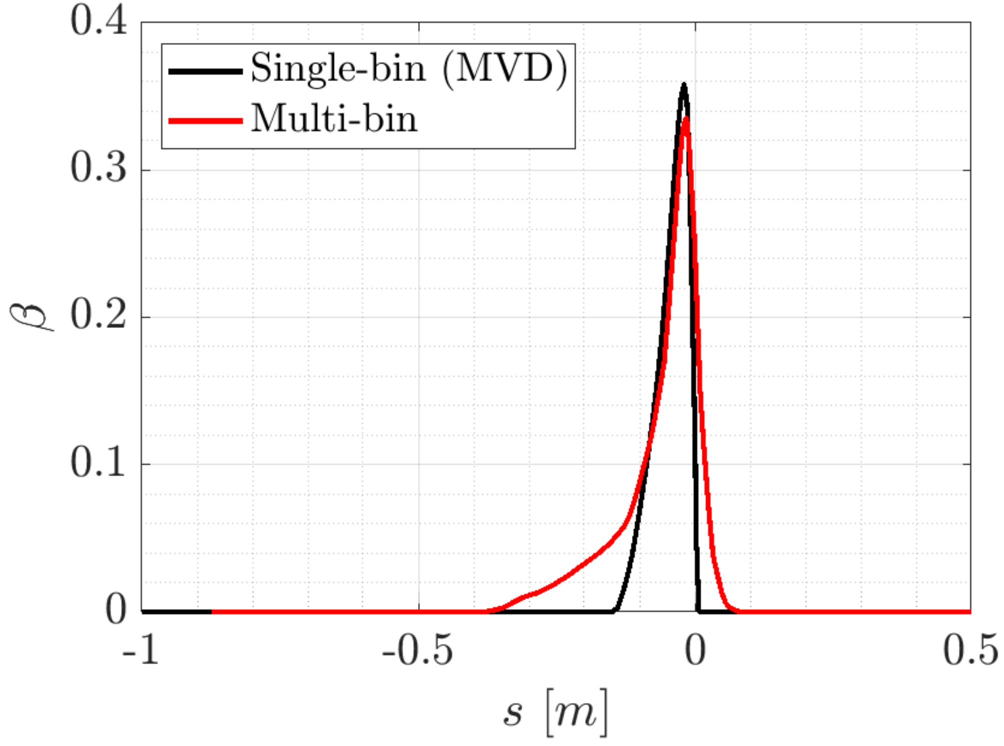
0.2
0.1
0
-0.1
-0.2
y[m]
0
0.2
0.4
x[m]
Clean
Experimental
PoliMIce



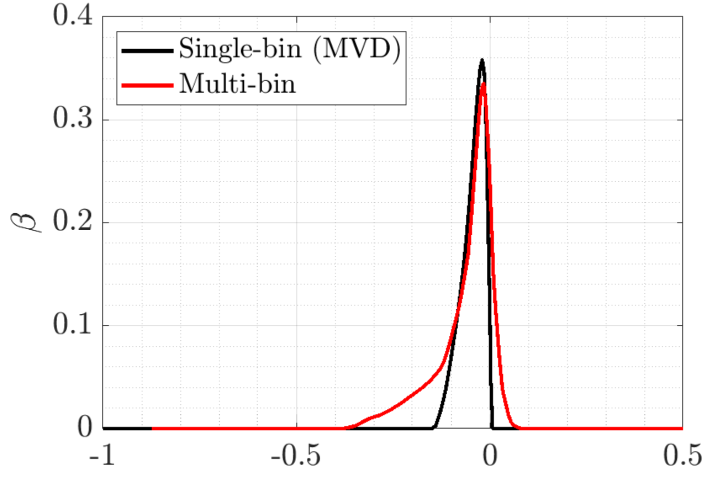
Ice Thickness
0.000
0.005
0.010
0.015
0.020
0.027
Z
Y
X

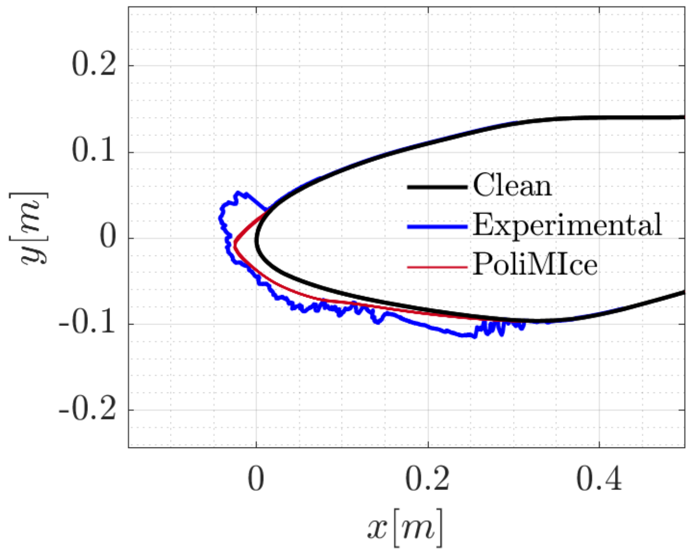
Midboard Model

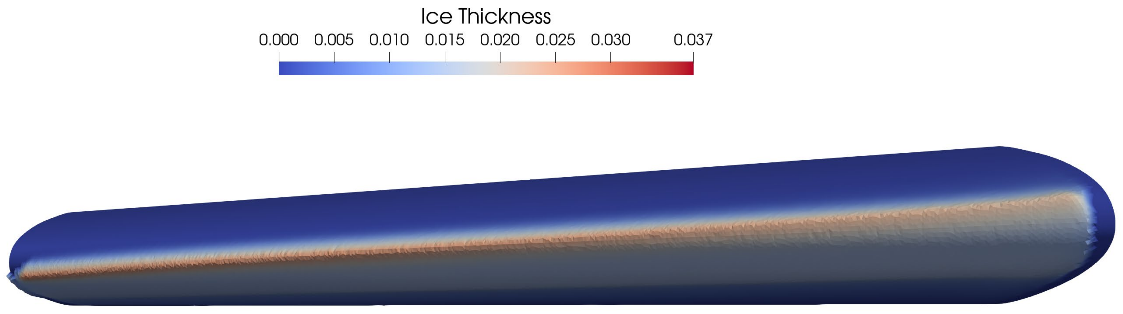




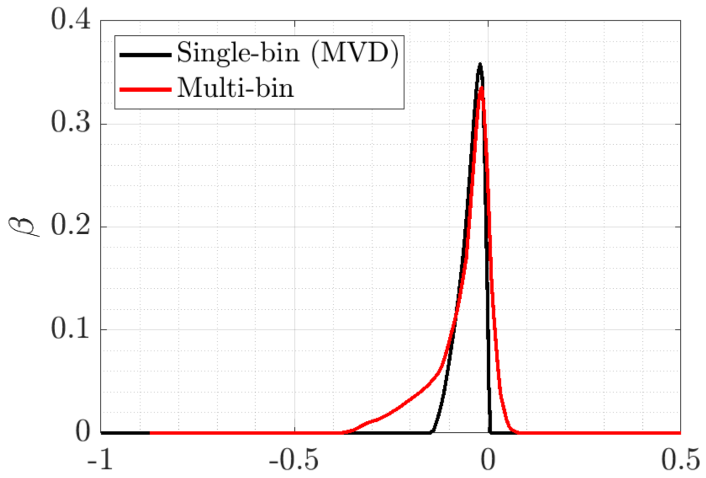
Case 1.1 Glaze: single-shot

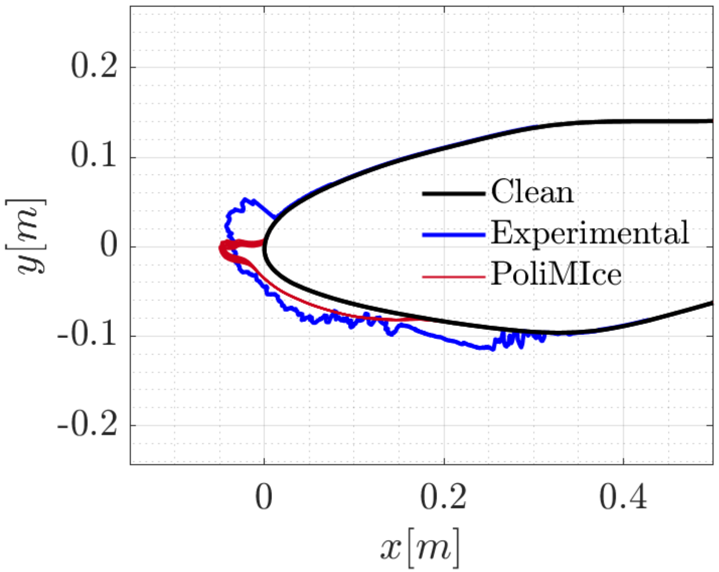


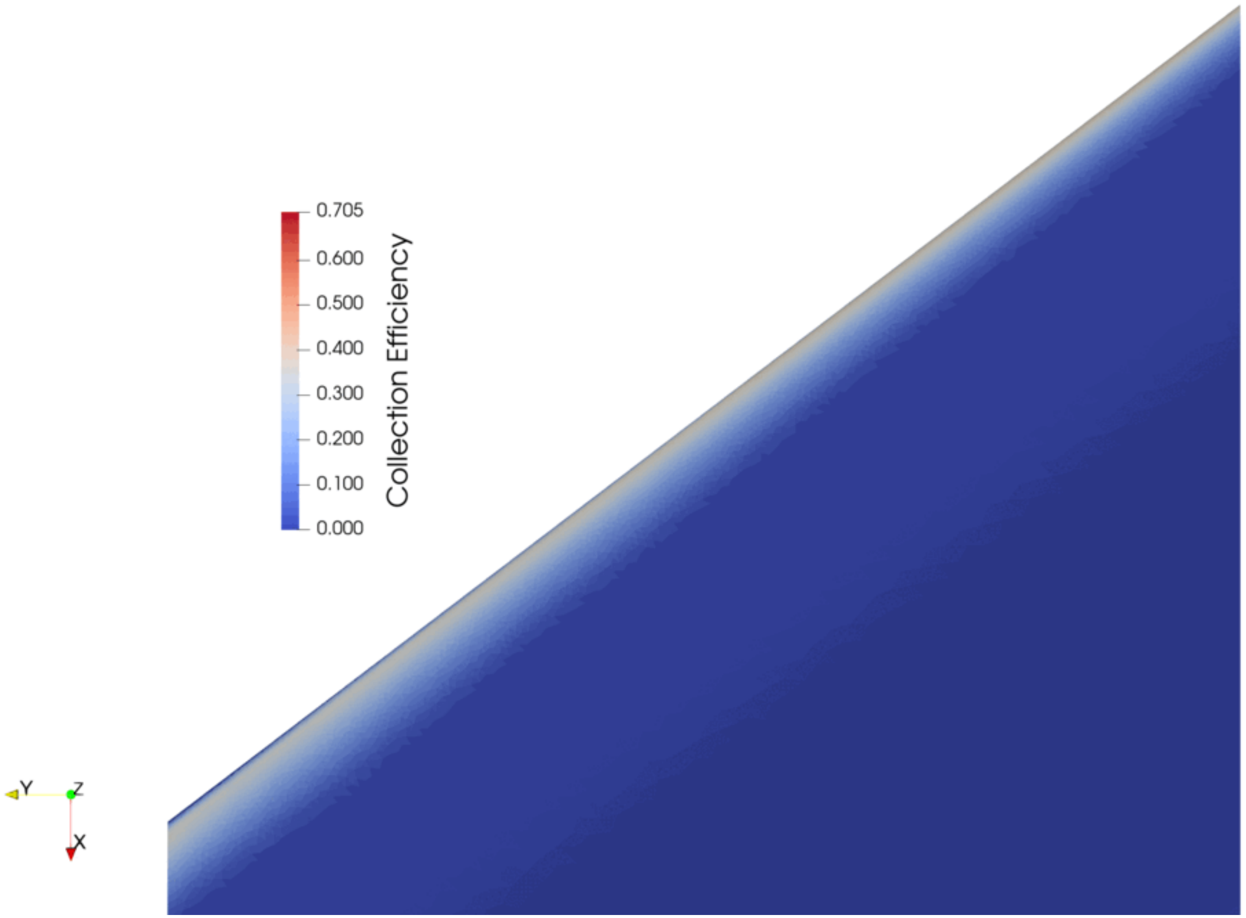




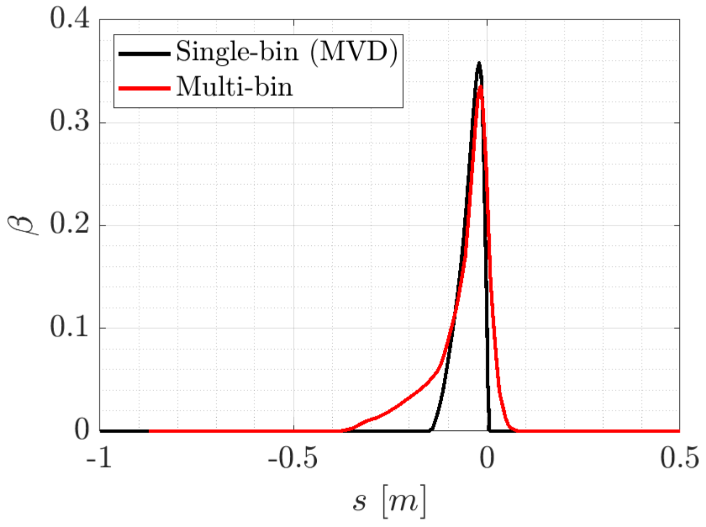
Case 1.1 Glaze multi-step (5 steps)

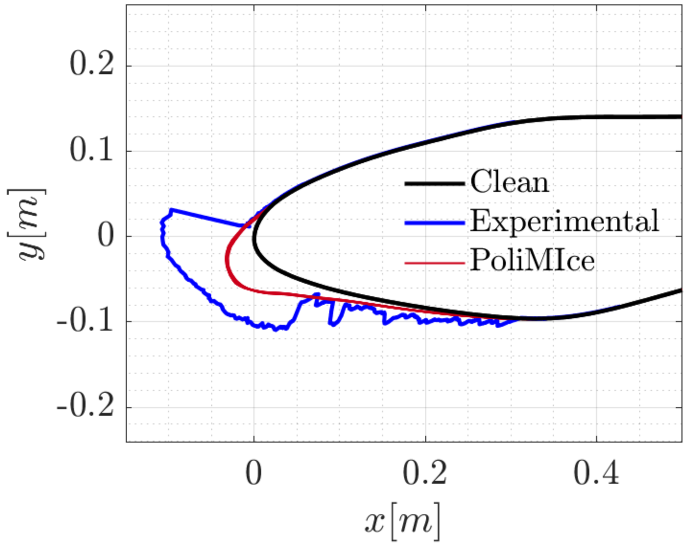


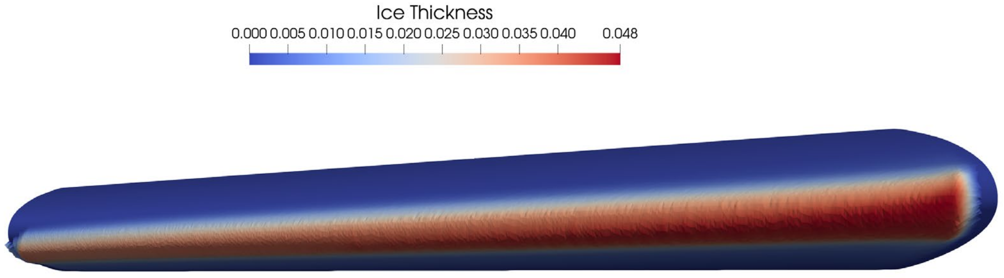




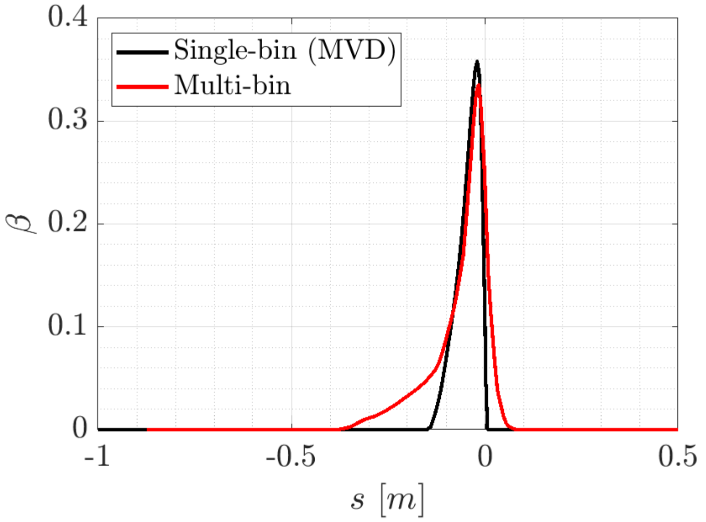
Case 1.2 Mixed: single-step

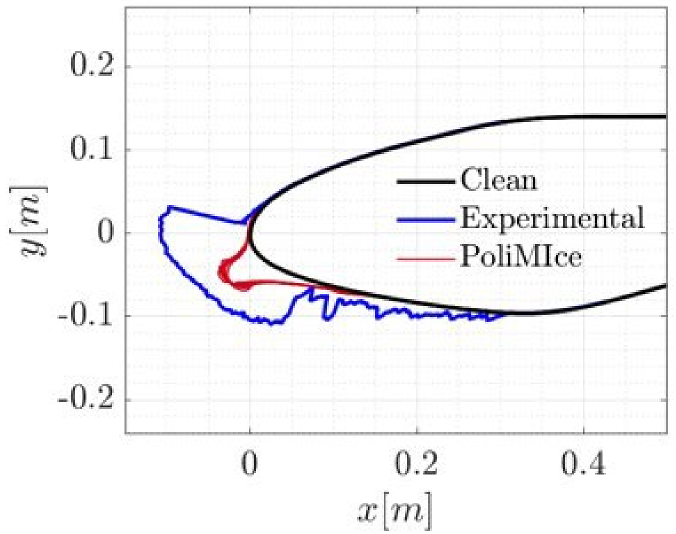


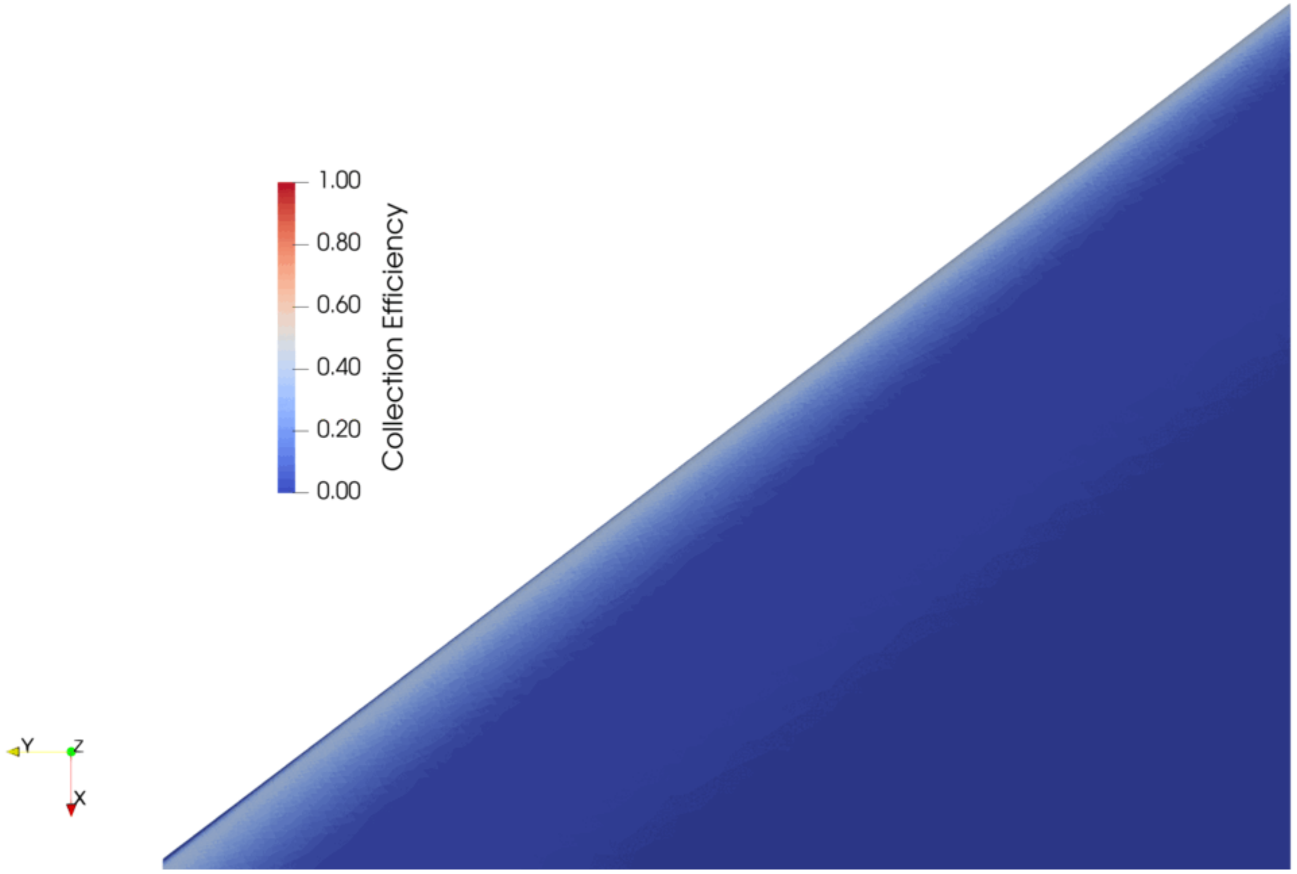




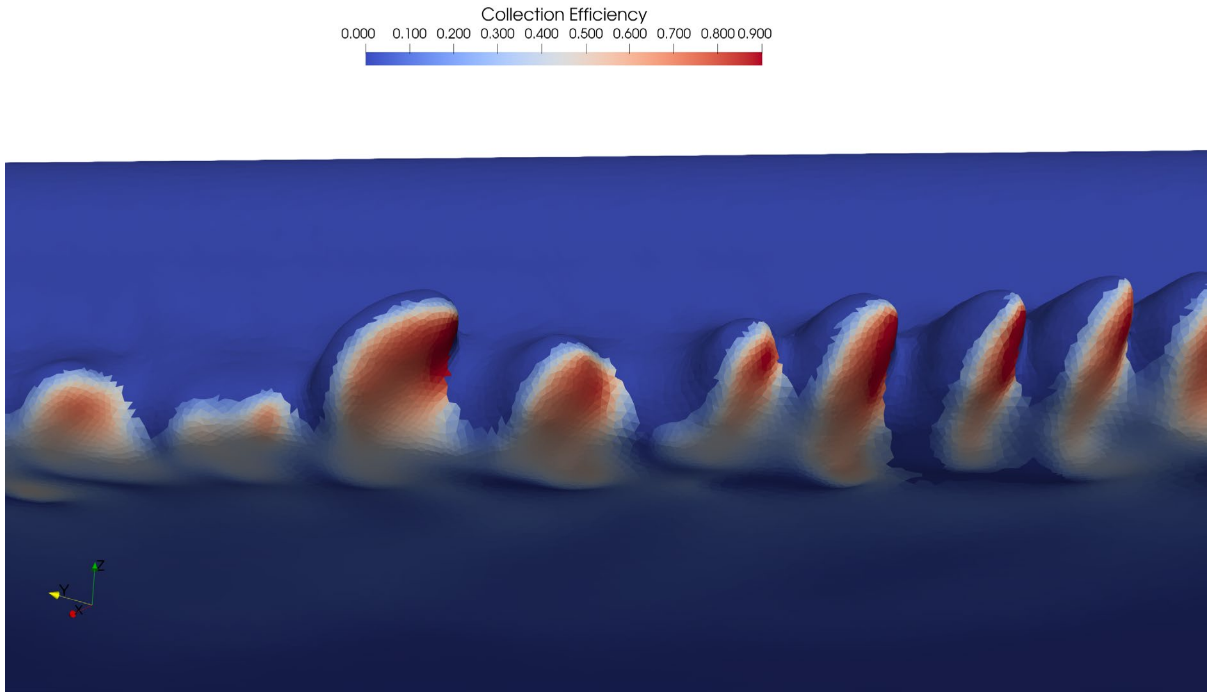
Case 1.2 Mixed: multi-step (10 steps)

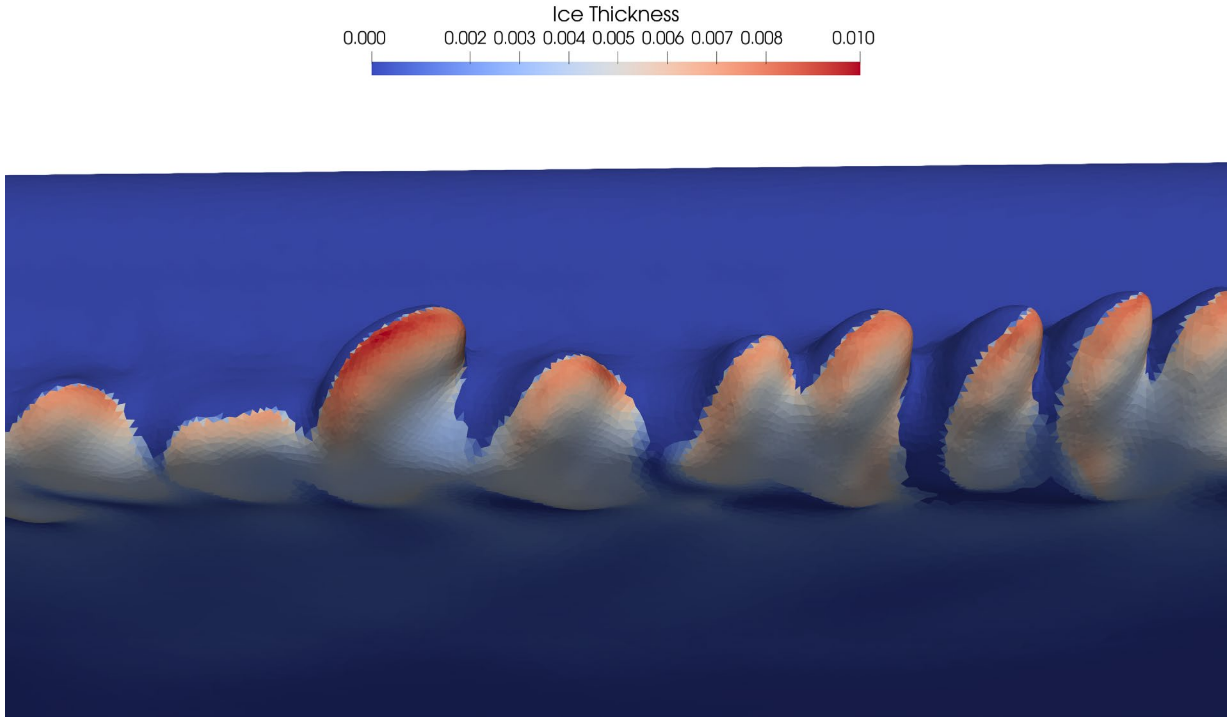




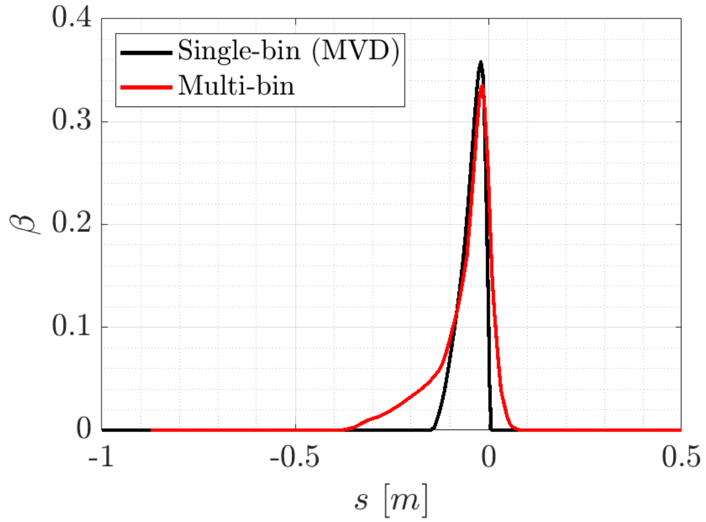


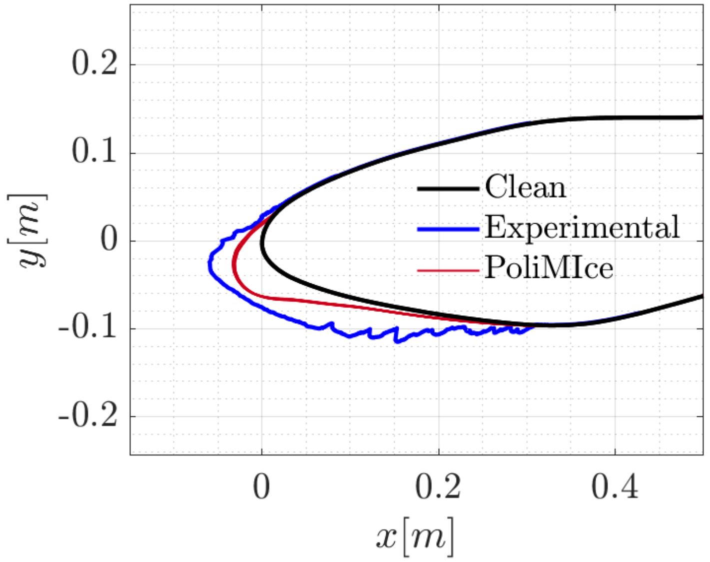
Case 1.2 Mixed Zoom

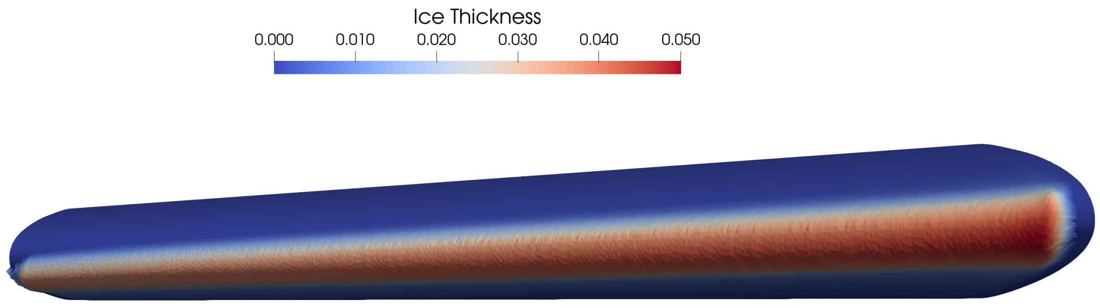




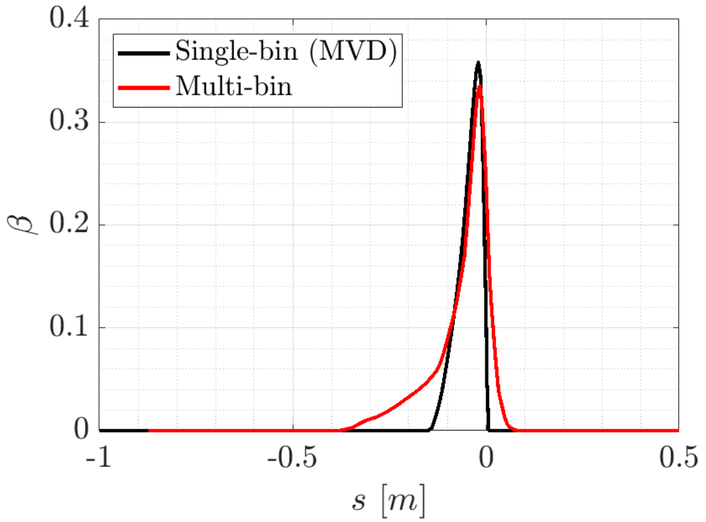
Case 1.3 Rime single-step

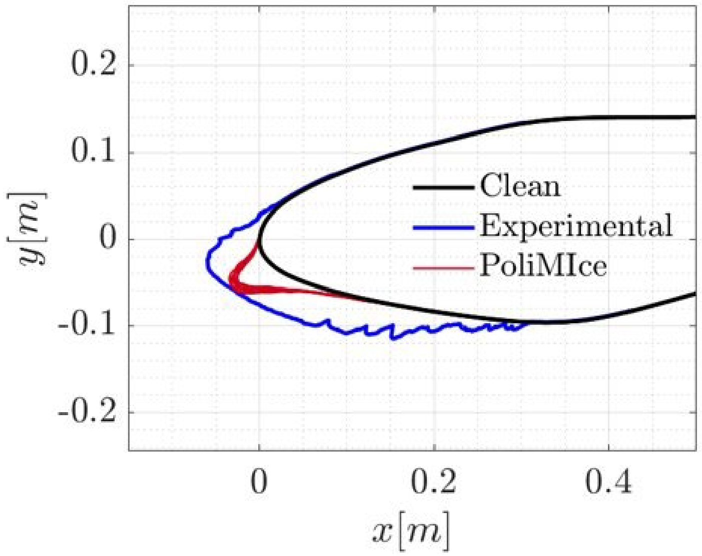


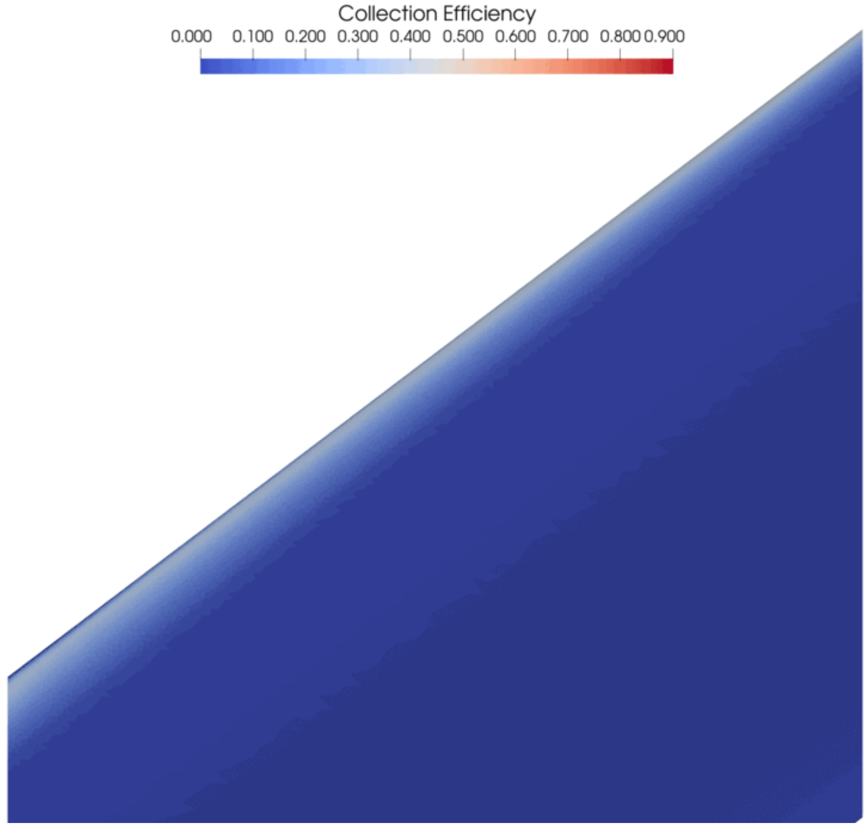




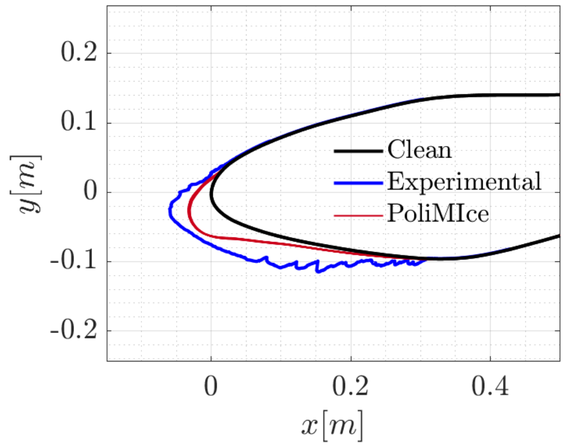
Case 1.3 Rime: multi-steps (5 steps)



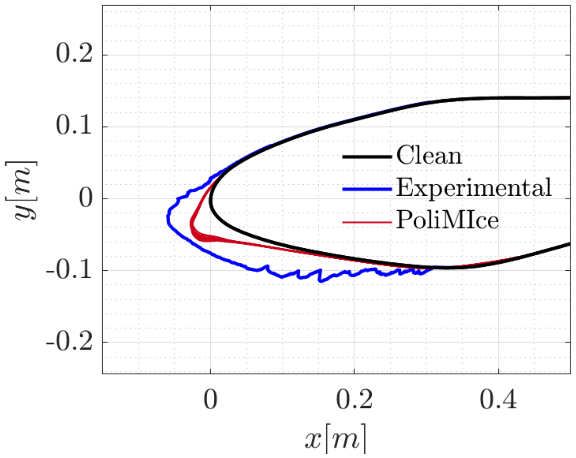




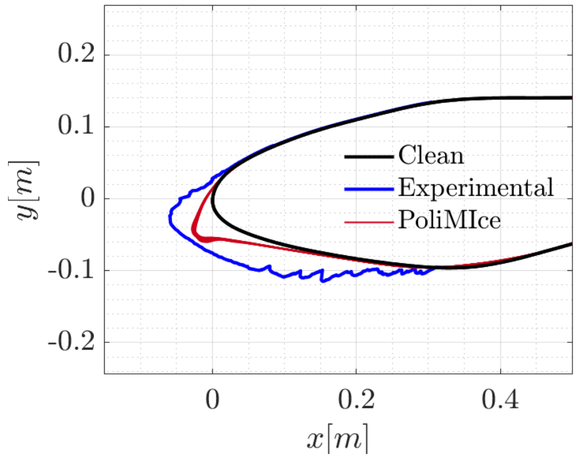
Case 1.3 Rime: multi-steps



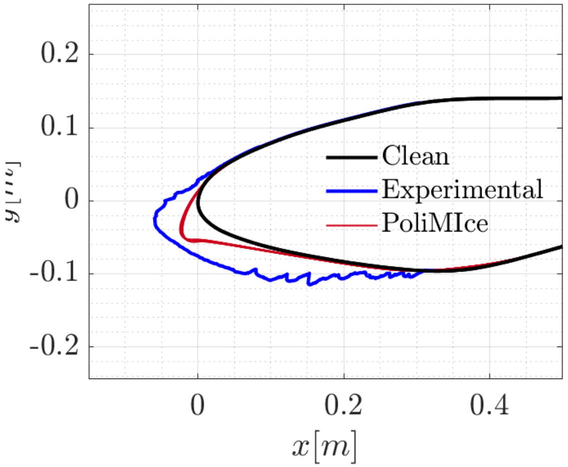
Single-step



5-steps

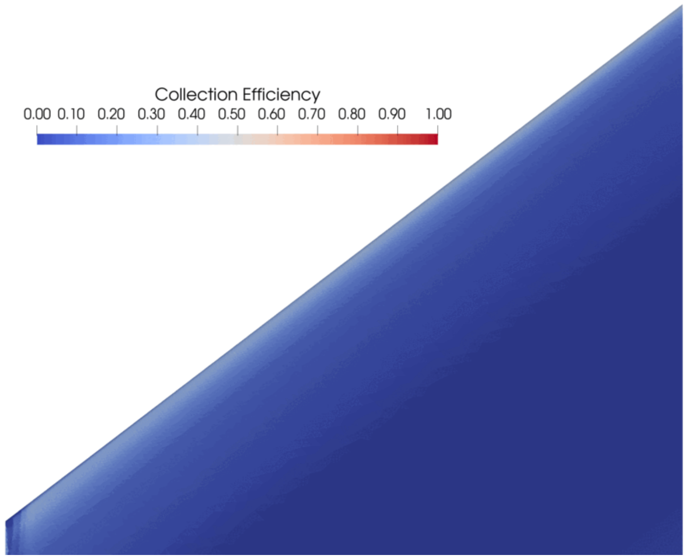


10-steps

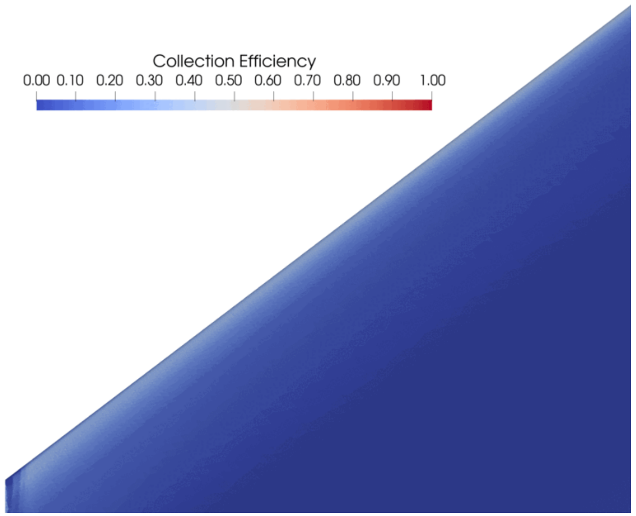


20-steps

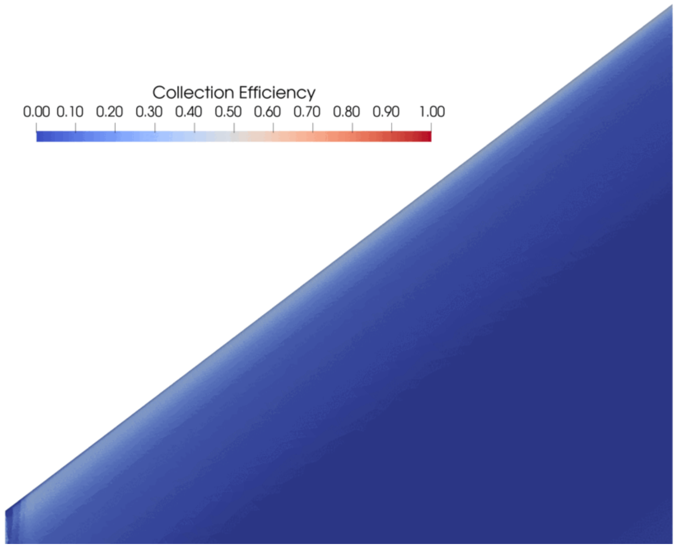
Case 1.3 Rime: multi-steps



5-steps

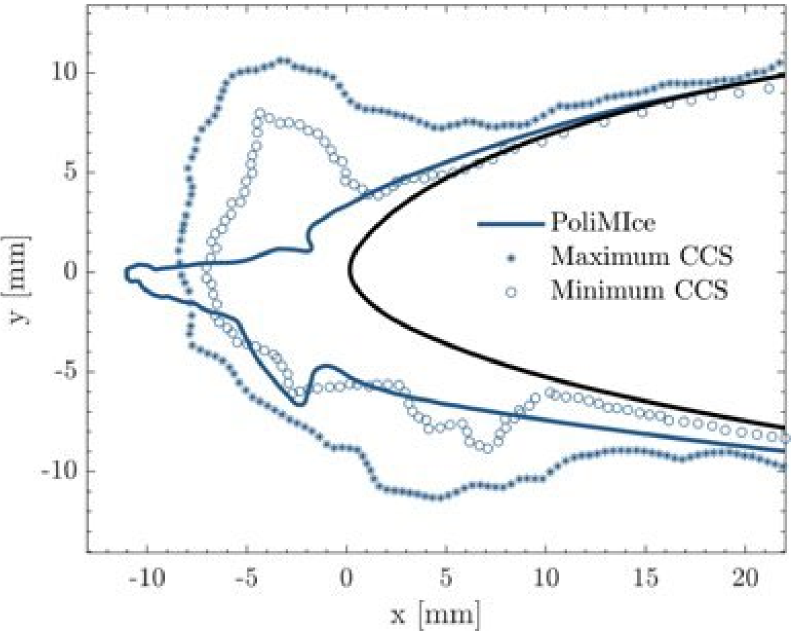


10-steps

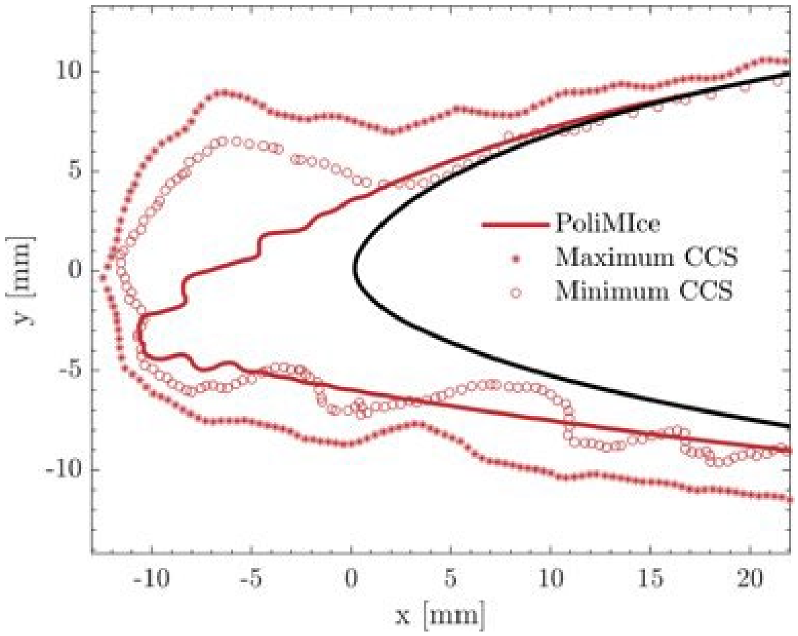


20-steps

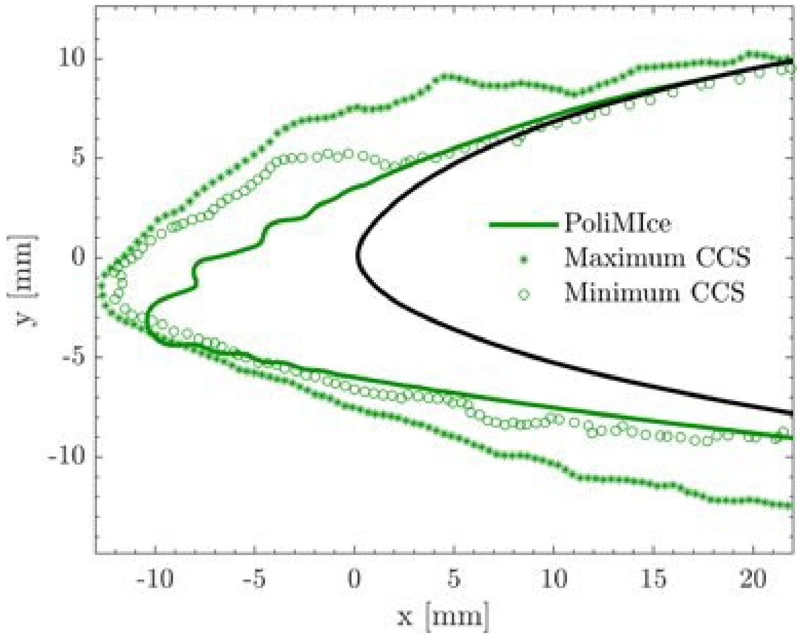
Cases 3.1 - 3.3



Glaze Ice
60 time-steps



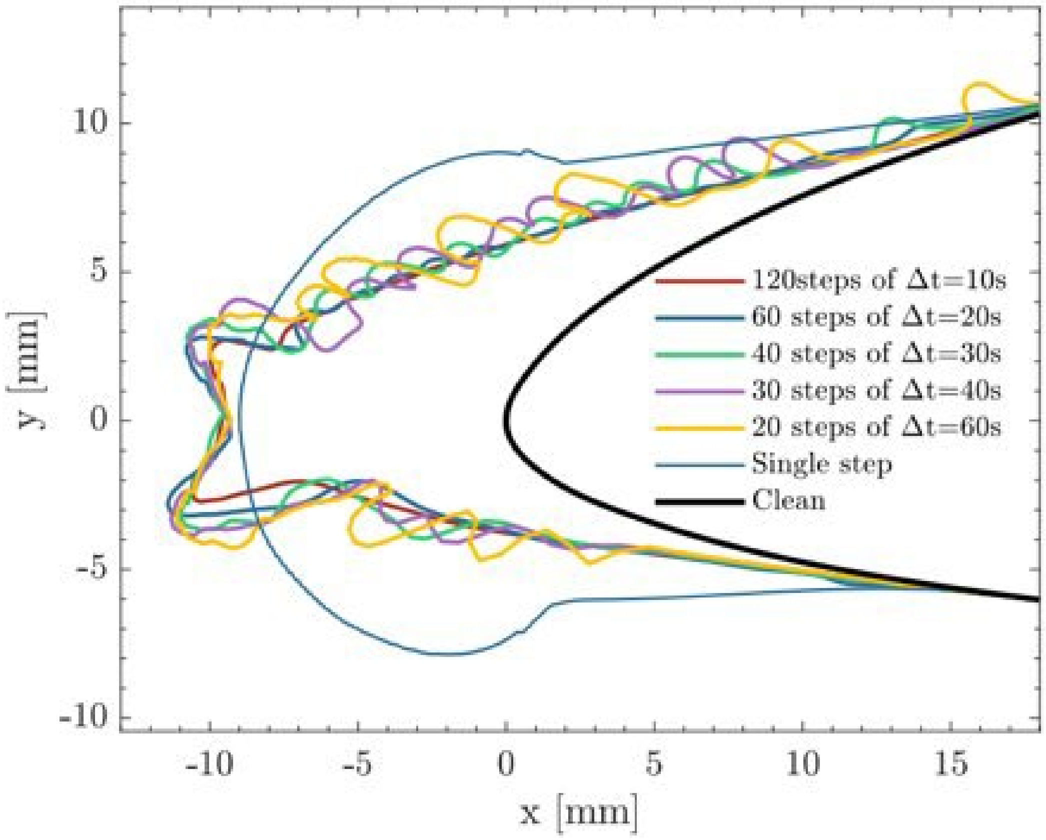
Mixed Ice
60 time-steps



Rime Ice
60 time-steps

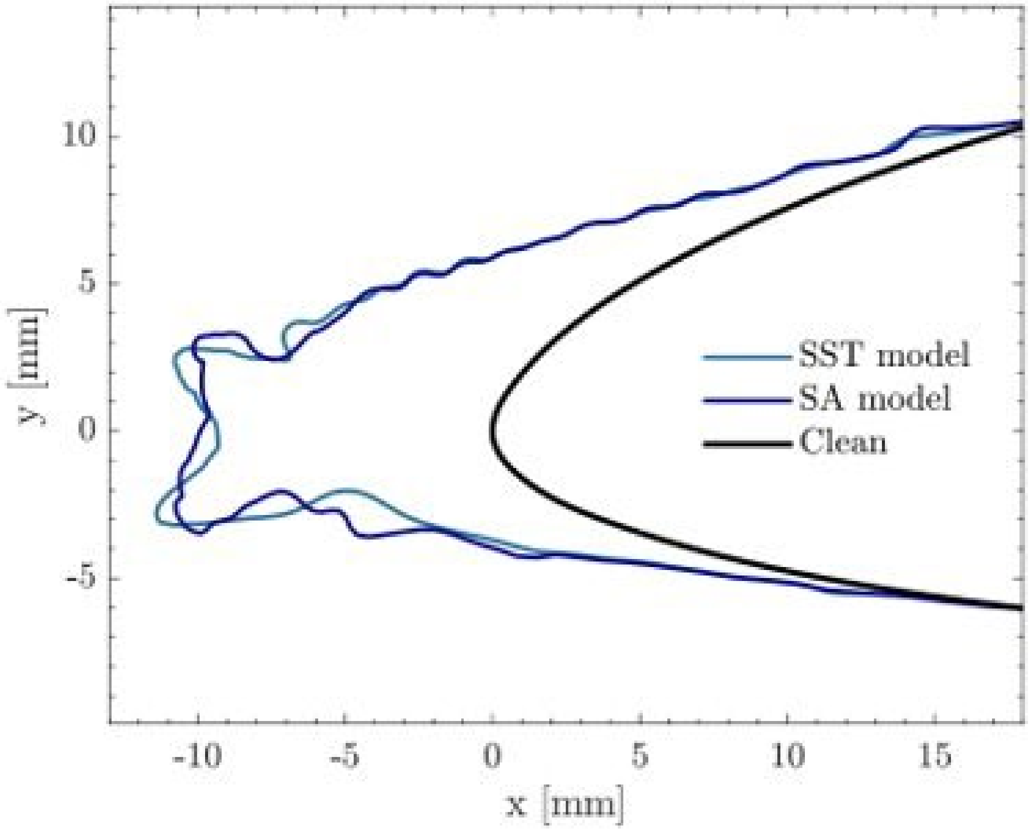
Sensitivity analysis

Time step duration.



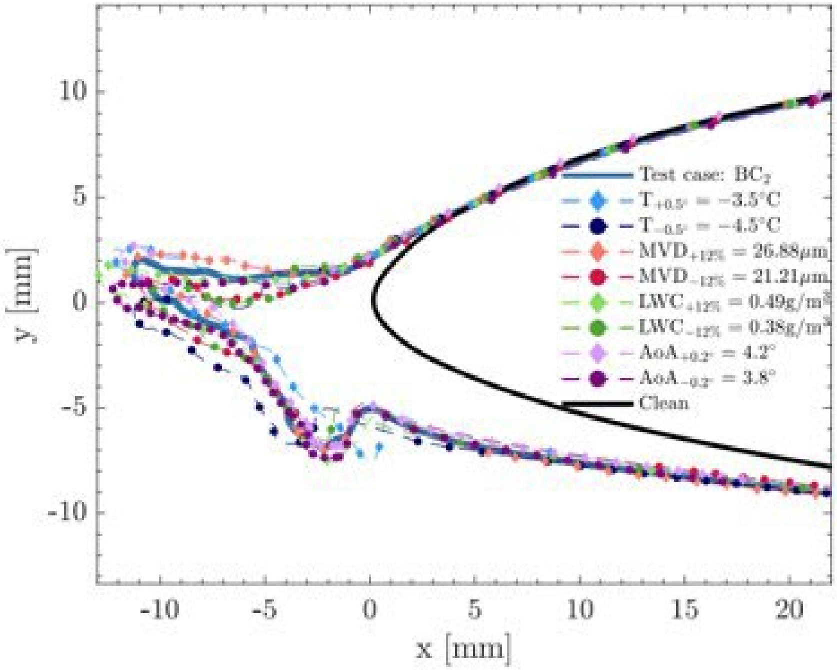
AoA = 0°

Turbulence model.



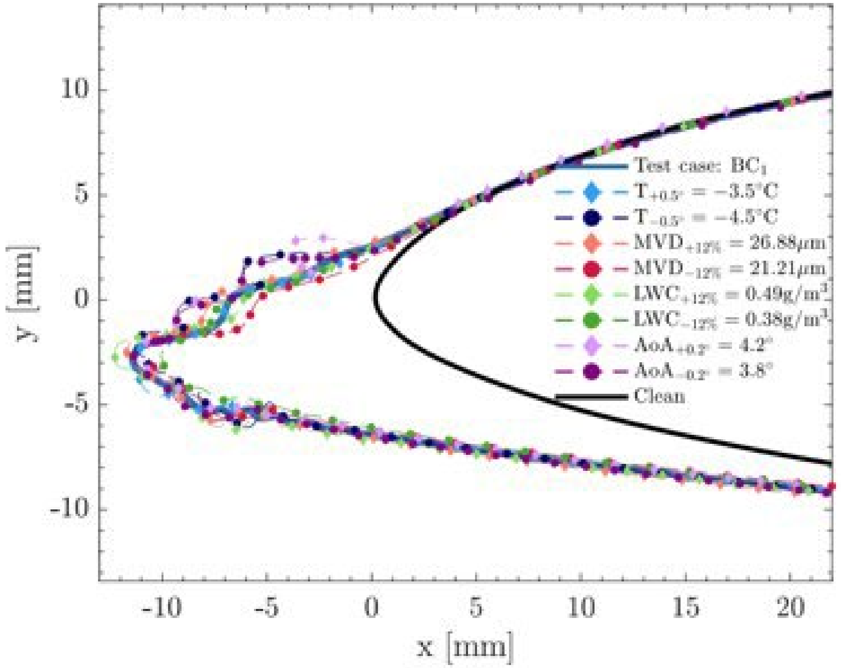
AoA = 0°

Glaze



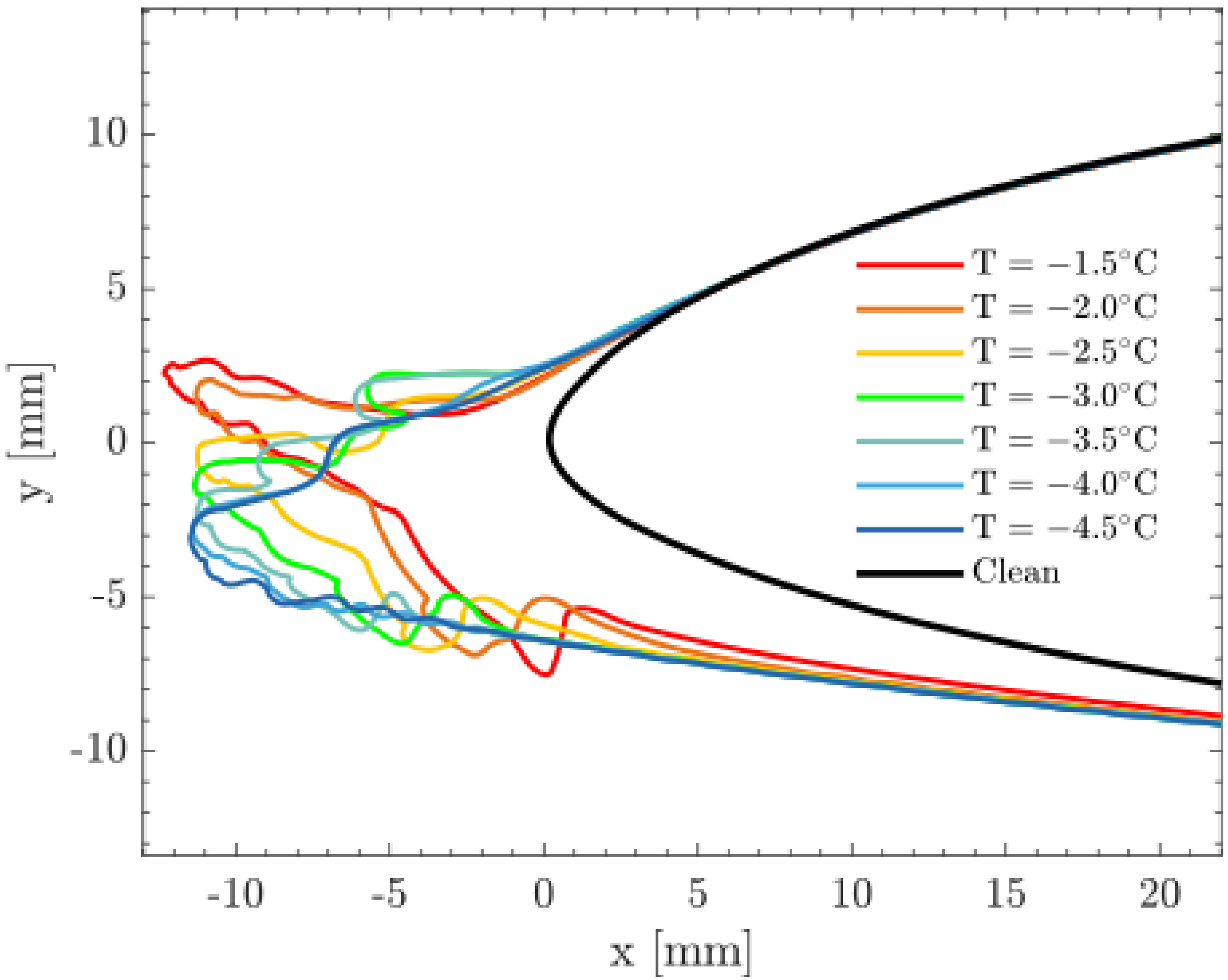
	T_∞ [°C]	MVD [μm]	LWC [g/m³]	AoA
-	-3,5	21,21	0,38	3,8°
BC_1	-4	24	0,44	4°
+	-4,5	26,88	0,49	4,2°

Mixed



	T_∞ [°C]	MVD [μm]	LWC [g/m³]	AoA
-	-1,5	21,21	0,38	3,8°
BC_2	-2	24	0,44	4°
+	-2,5	26,88	0,49	4,2°

Sensitivity analysis



Conclusions and future work

- Multi-step simulations are essential for correctly capturing complex 3D ice shape.
- Robust multi-step procedures permit to test different turbulence and roughness models and assess their influence on the ice shape evolotion.

- Improve our thermodynamic models to investigate the formation of scallops.
- 4D Scans would be extremelly usefull when comparing experimental ice shapes to numerical simulations in multi-step simulations.

Thank you for your attention!
Questions?

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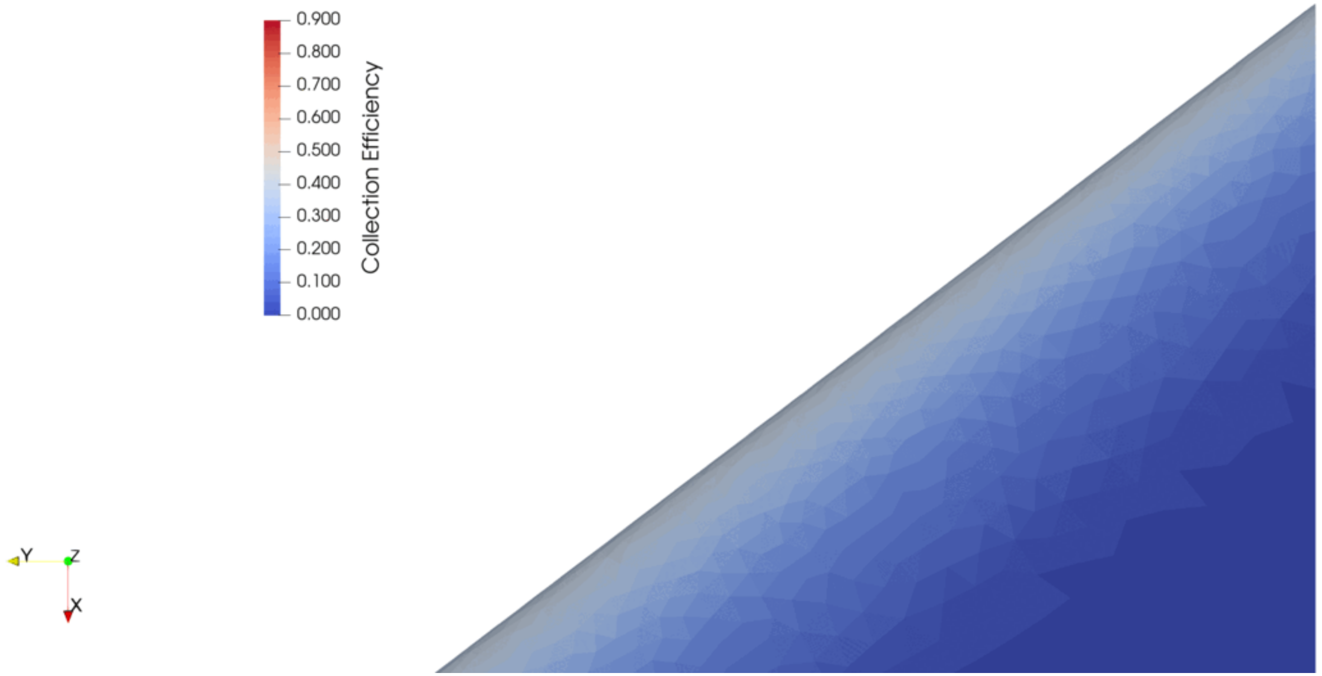
Zoom scallops



-2°C