IPW2 - Polytechnique Montréal Results

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Chapel Multi-Physics Software (CHAMPS)

Maxime Blanchet, PhD student
Mohamad Karim Zayni, PhD student
Éric Laurendeau, PhD, Professor

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Table of Contents

CHAMPS Icing Workflow - Code Summary

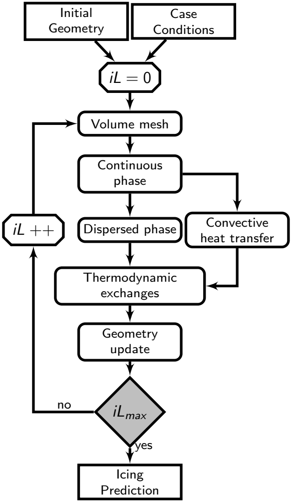


Figure 1: CHAMPS Icing Workflow

Code	**CHAMPS (Chapel)**
Grid types	Unstructured 2D(2.5D)/3D
Flow	RANS - Roe 2nd order
Turb	SA-noft2
Droplets	Eulerian - Upwind 2nd order
Thermo.	Iterative Messinger [1] - Runback with shear strength
Surf. deform.	Lagrangian at nodes Hyperbolic at nodes (PDE) [2]
Multi-layer	2D/2.5D only: Full volume grid regeneration with hyperbolic grid method

What is Chapel and why use it?

Challenges of multi-physics simulations

We have to balance

- Fidelity of multiple solvers;
- Performances → computational costs;
- Productivity → addition of multiple physical models.

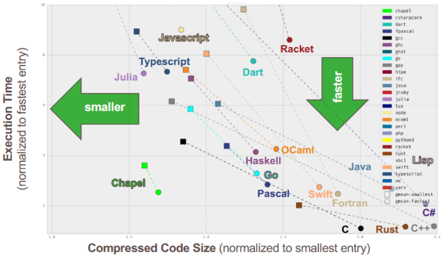


Figure 2: CLBG Cross-Language Summary.

Benefits from Chapel's features [6]

- Productivity → fast prototyping with high level syntax;
- Natively distributed → Overcome the barrier of entry of parallel distributed programming in an academic context (2 years);
- Modularity → Generic classes and records to reuse structures;
- Memory management strategies.

Stochastic Ice Accretion Model

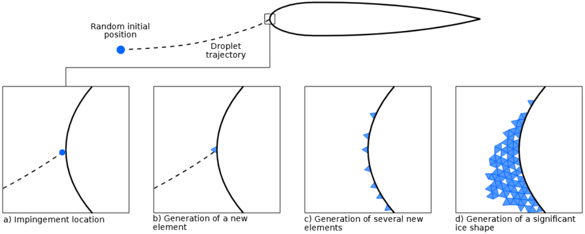


Figure 3: Advancing Front Technique [3].

Advancing Front Technique

- Droplets are released randomly from a seeding plane using a Pseudo-Random Number;
- Droplet's trajectory is extracted from the eulerian droplets velocity field;
- Upon impact, if $\mathbf{n} = 1$, the droplet freezes and a new element is generated;
- If not, the remaining mass moves downstream (runback);
- These steps are repeated until the specified criterion is met (ice mass)[a]

[a] Helene Papillon Laroche, Emmanuel Radenac, and Eric Laurendeau. Stochastic ice accretion model using an unstructured advancing front technique.International Journal of Multiphase Flow, 163:104420, 2023

2.5D Model versus 3D Model

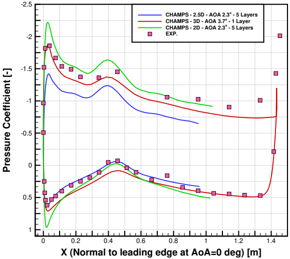
Table 1: Differences between CHAMPS' 2.5D and 3D Models.

	2.5D	**3D**
Mesh Type	2D Tunnel Mesh (editable)	3D Tunnel Mesh (IPW2)
Multi-Layer	Yes	No
Feature (s)	Sweep - No sweep	Gap - No Gap
Layer Time 6000 it. w bins	$\approx$ 1 h	$\approx$ 10 h

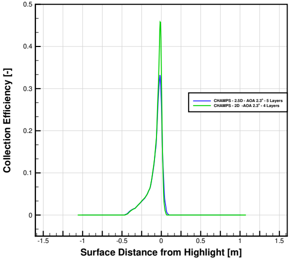
Case 1 2 - Information

- Case are computed with 2D, 2.5D and 3D grids;
- Homemade tunnel meshes are used for 2.5D and 2D cases;
- AoA of 2D and 2.5D cases are modified to match the attachment line;
- An equivalent roughness value of $k_s/c = 0.1\%$ is used for all the cases;
- Single-shot in 3D, multi-shot for 2D/2.5D cases;
- Ice density of $450 kg/m^3$.

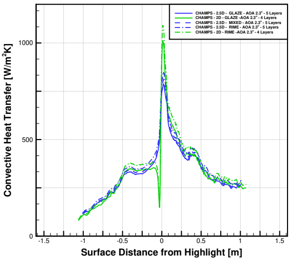
Case 1 - Pressure Coefficient - Collection Efficiency - HTC



Pressure Coefficient

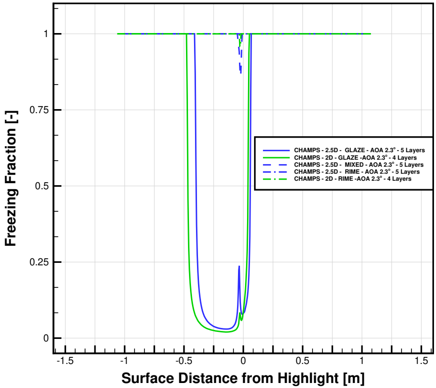


Collection Efficiency

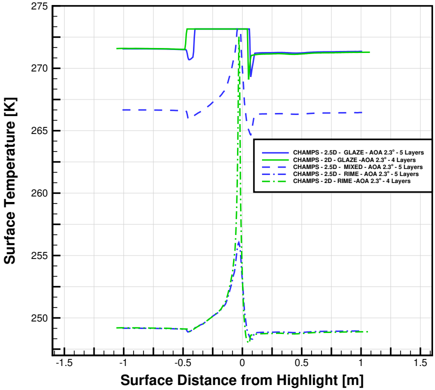


HTC

Case 1 - Thermodynamic Variables

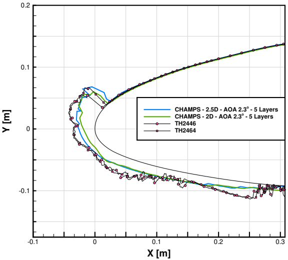


Freezing Fraction

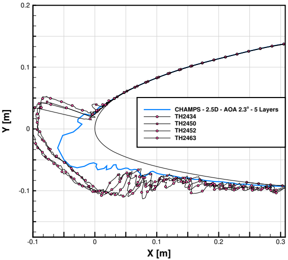


Surface Temperature

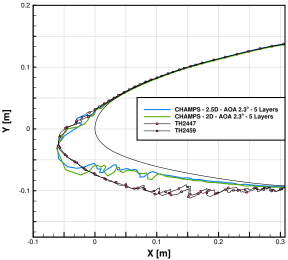
Case 1 - Ice Shapes



GLAZE



MIXED

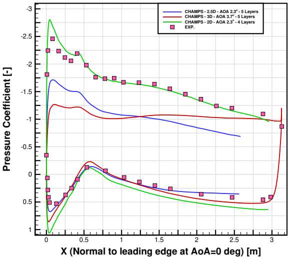


RIME

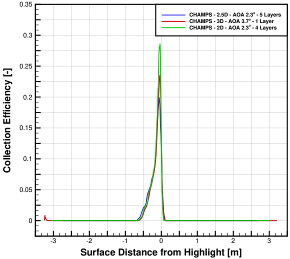
Case 1 - Overview

- Glaze ice limits are well predicted with 2D and 2.5D approaches;
- Mixed ice is poorly predicted (practically to no film);
- Rime ice matches on the upper surface but not on the lower surface.

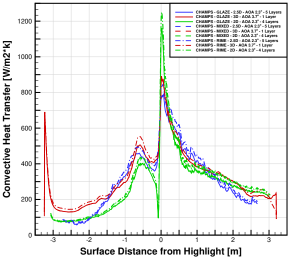
Case 2 - Pressure Coefficient - Collection Efficiency - HTC



Pressure Coefficient

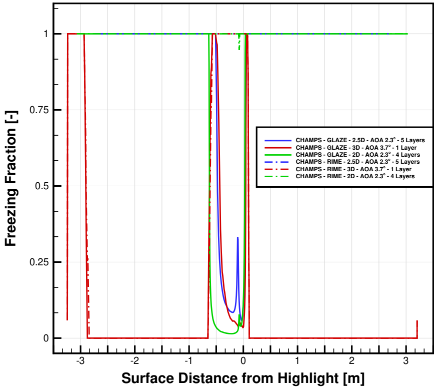


Collection Efficiency

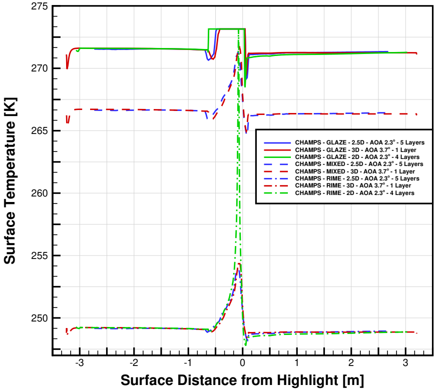


HTC

Case 2 - Thermodynamic Variables

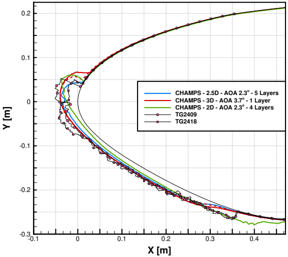


Freezing Fraction

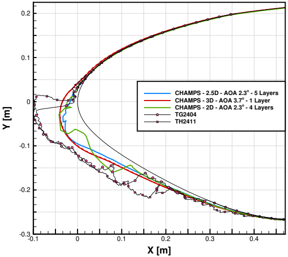


Surface Temperature

Case 2 - Ice Shapes



GLAZE



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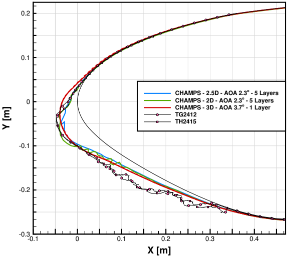


RIME

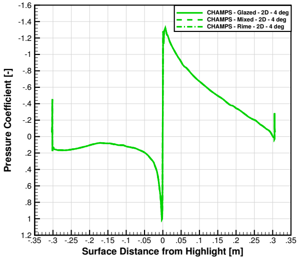
Case 2 - Overview

- Glaze ice limits are well predicted with 3D and 2.5D approaches;
- Height of the horns of the mixed ice are poorly predicted;
- Rime ice matches on the upper surface but not on the lower surface.

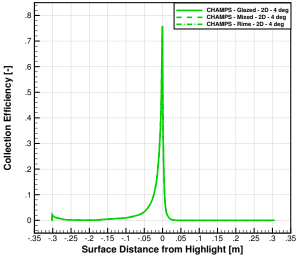
Case 3 - Information

- Homemade farfield meshes;
- Deterministic results are multi-shot (10 layers);
- Ice density of $450 kg/m^3$;
- An equivalent roughness value of $k_s/c = 0.1\%$ is used;
- Non-deterministic approach uses an ice density of $917 kg/m^3$;
- The stopping criterion for the non-deterministic approach is when the total ice mass reaches the value of the integrated impinging mass.

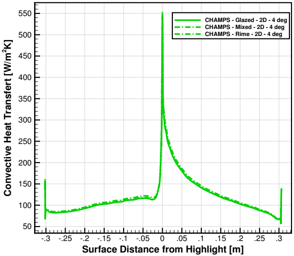
Case 3 - Pressure Coefficient - Collection Efficiency - HTC



Pressure Coefficient

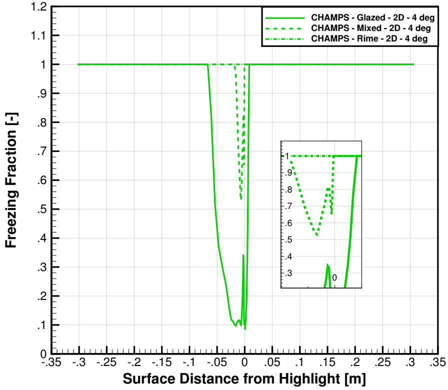


Collection Efficiency

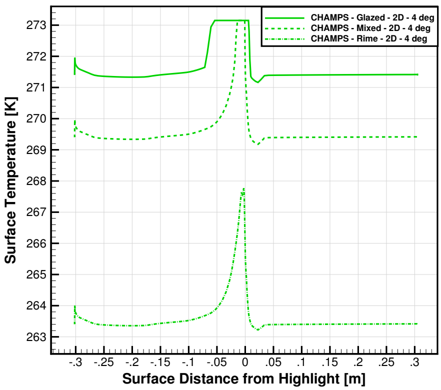


HTC

Case 3 - Thermodynamic variables

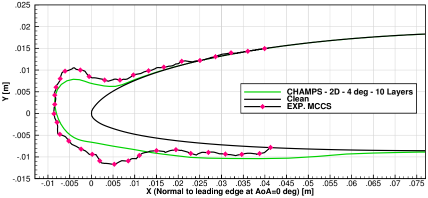


Freezing Fraction

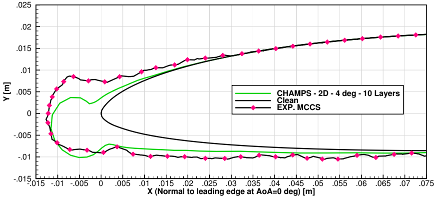


Surface Temperature

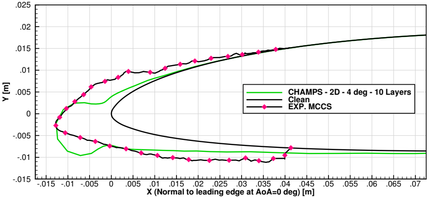
Case 3 - Ice Shapes - Multi-Layer



Glaze Case

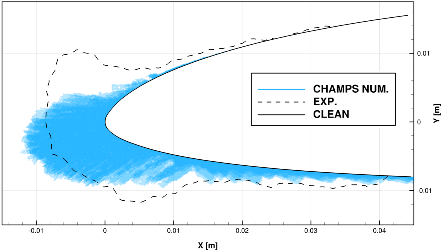


Mixed Case

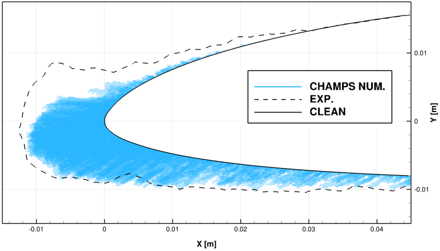


Rime Case

Case 3 - Ice Shapes - Stochastic Model



Glaze Case



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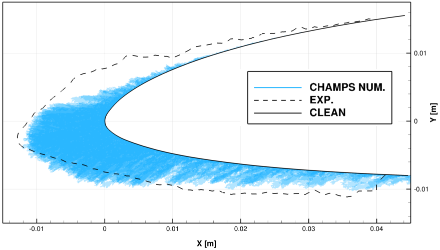

Rime Case

Conclusion

Overview of the work

- CRM cases were executed in 2D, 2.5D and 3D. Variables from the flow, droplet, and thermodynamic solvers were analyzed;
- 2.5D approach is a good compromise from the computation of the ice shapes since it allows a robust multi-layer as well as an easier match with the attachment line (change of AoA);
- Stochastic approach for the 2D case allows to capture the lower region but the upper part was not captured.

References I

[1] Tim G. Myers.
Extension to the Messinger Model for Aircraft Icing.
AIAA Journal, 39(2):211–218, February 2001.

[2] William M. Chan and Joseph L. Steger.
Enhancements of a three-dimensional hyperbolic grid generation scheme.
Applied Mathematics and Computation, 51(2-3):181–205, October 1992.

[3] Helene Papillon Laroche, Emmanuel Radenac, and Eric Laurendeau.
Stochastic ice accretion model using an unstructured advancing front technique.
International Journal of Multiphase Flow, 163:104420, 2023.

Acknowledgment

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