Lattice Boltzmann Approach for the Modelling and Simulation of a Water Droplet Impact and Freezing

Jesús García Pérez, Jean-Yves Trépanier, Marcelo Reggio, Sébastien Leclaire

contact: jesus.garcia-perez@polymtl.ca, (514) 318-8814, Dept. of Mechanical Engineering - Polytechnique Montréal, C. P. 6079, succ. Centre-Ville, Montréal, Québec, H3C 3A7, Canada

POLYTECHNIQUE MONTRÉAL
LE GÉNIE EN PREMIÈRE CLASSE

GPS Génie par la simulation
SBES Simulation - Based Engineering Science

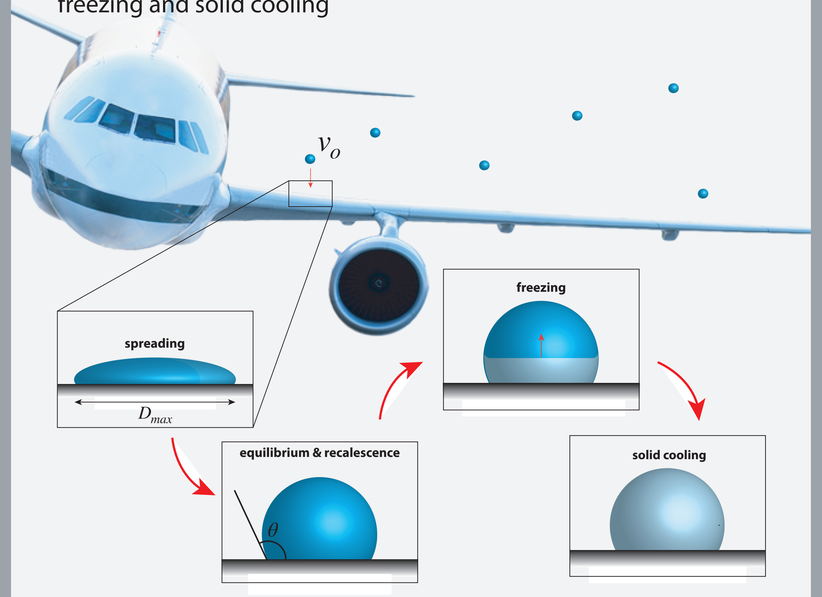
Aircraft icing

- Inflight airframe **icing** occurs when **supercooled water** freezes on impact with external surface of an aircraft
- Aviation security problems because of the **multiphase and thermal changes**

- These finally drive to **adverse aerodynamics effects** and degradation of external systems such as pitot tubes and static vents, antennas, etc.

Solidification process

- First stage of **frost** formation
- Supercooled water droplet in a metastable equilibrium which impacts with a surface and freezes
- Four stages on solidification process: supercooled, recalescence, freezing and solid cooling



Key parameters
- surface hydrophobicity
- surface temperature
- impact velocity
- droplet size
- droplet initial temperature

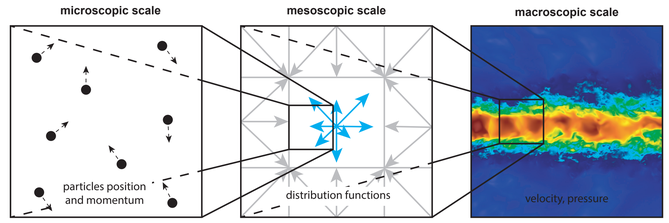
Variables of interest
- interface evolution
- freezing time
- max. spreading diameter
- temperature field

Objectives

- To better understand the impact and solidification process of a water droplet by using the **Lattice Boltzmann Method** which appears recently as a **promising digital approach** to simulate multiphase flows with phase change and complex boundary conditions.

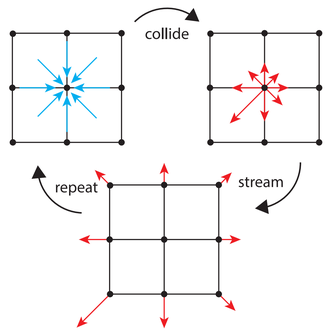
Numerical model

- Fluid is treated as a set of 'particles' (mesoscopic scale) with **probability distribution functions** on their locations and velocities. LBM allows to simulate the evolution of these distributions.



- Resolution of discretized Boltzmann equation for the particle distributions in two main steps:

$$f_{\alpha,i}(\vec{x}+\vec{e}_\alpha\Delta t, t+\Delta t) = f_{\alpha,i}(\vec{x},t) - \frac{1}{\tau_i}\left[f_{\alpha,i}(\vec{x},t) - f^{eq}_{\alpha,i}(\vec{x},t)\right]$$



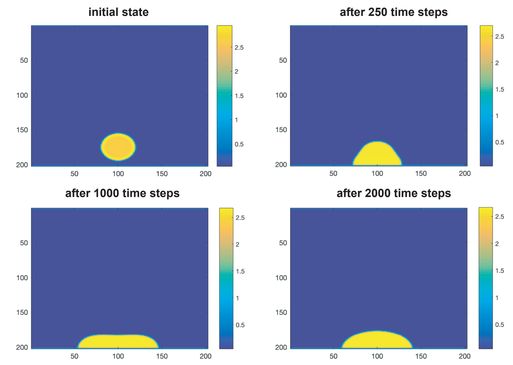
- The implementation

Basic LBM + Pseudo-potential model for multi-phase flows + Enthalpy-based model for phase change

- Advantages:
  - **Parallel** evaluation, post-processing and data analysis ✓
  - Particularly suitable to model **muliphase flow** ✓
  - Simulation of **dynamic interface** to the macroscopic scale ✓

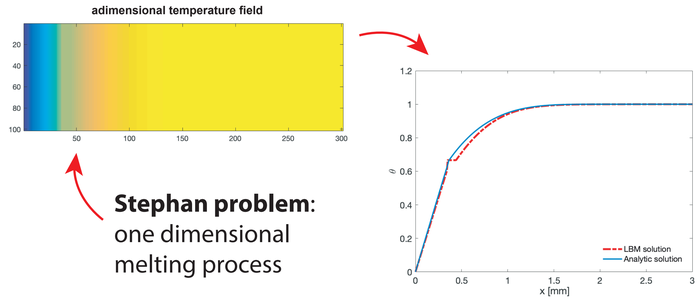
Preliminary steps

- Validated pseudo-potential model for multiphase fluid flow



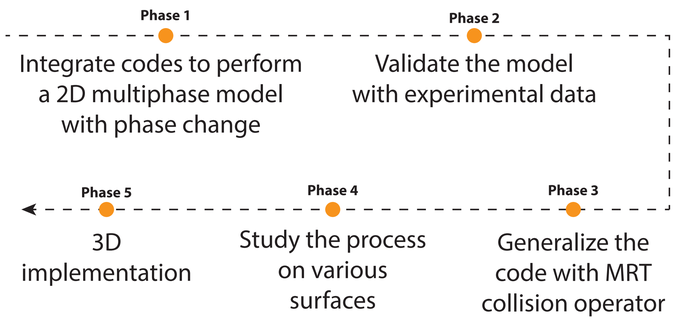
Density field for a water droplet impact on a surface at constant temperature

- Validated thermal model for phase change of a single component



Stephan problem: one dimensional melting process

Future works



Acknowledgments

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