Digital Twin Technology for Autonomous Operation in Harsh Environment:

CFD-DEM Coupled Method for Ship-Ice Interaction in Waves

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Contents

* Computation Fluid Dynamics - Discrete Element Method

Digital Twin and Autonomous System

"A digital twin is a digital replica of a living or non-living physical entity."*

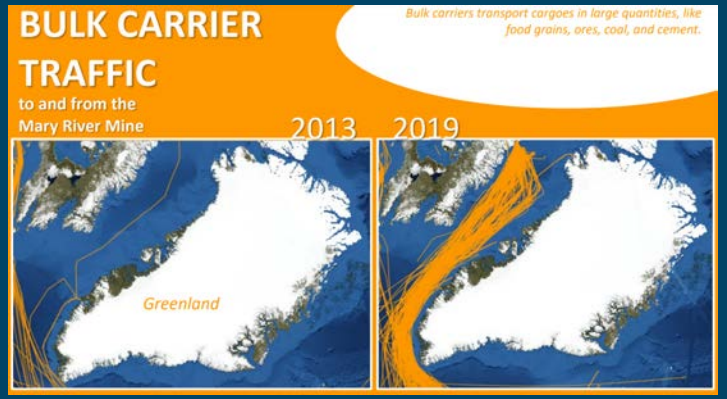
Digital twin is an *ideal testing lab* to develop an autonomous system

- **No or low risk**
- **Various operating/environmental conditions**
- **Insight on the entire process to find optimal solution**

*From Saddik, A. El (April 2018). "Digital Twins: The Convergence of Multimedia Technologies". IEEE MultiMedia. 25 (2): 87–92. doi:10.1109/MMUL.2018.023121167. ISSN 1070-986X. S2CID 51922497.

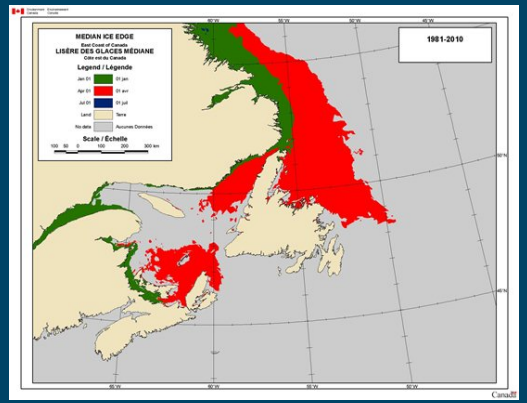
Harsh Environment Operation for Digital Twin

As increasing traffic in Arctic area (as well as considering Canadian winters), there is a need to simulate *operation in harsh environment* (i.e. ice in waves) by physics-based modelling.



Increased Arctic traffic

From PAME, "ARCTIC SHIPPING STATUS REPORTS #1", https://www.pame.is/projects/arctic-marine-shipping/arctic-shipping-status-reports/723-arctic-shipping-report-1-the-increase-in-arctic-shipping-2013-2019-pdf-version/file



Ice covered area

From CCG, "Ice navigation in Canadian waters: Chap. 4", https://www.ccg-gcc.gc.ca/publications/icebreaking-deglacage/ice-navigation-glaces/page04-eng.html

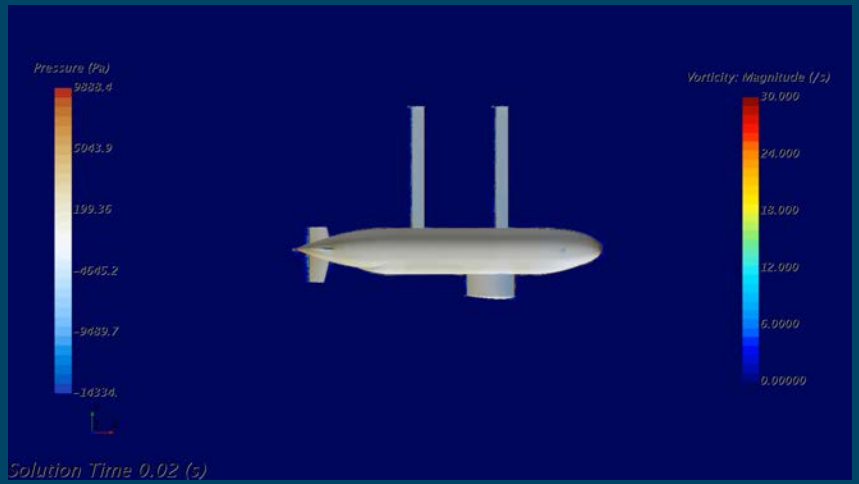
Damaged bow from ice collision

From CCG, "Ice navigation in Canadian waters Chap. 4", https://www.ccg-gcc.gc.ca/publications/icebreaking-deglacage/ice-navigation-glaces/page04-eng.html

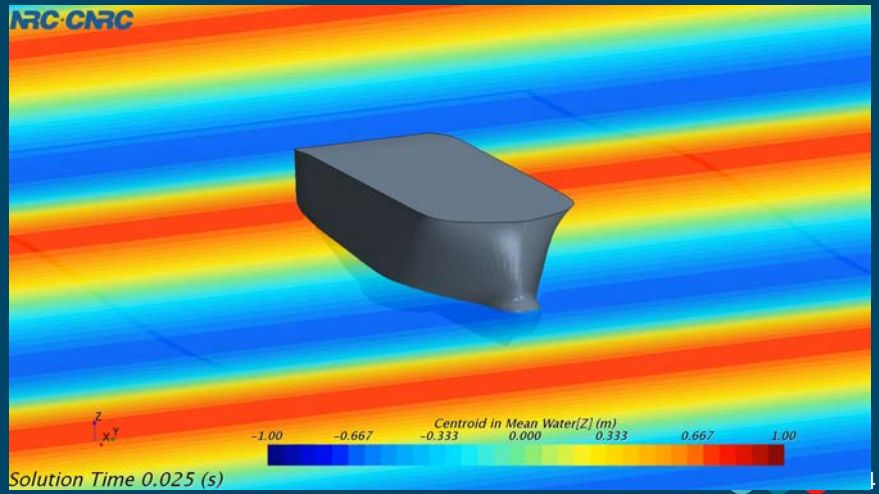
Advances in CFD

CFD has been widely used for design purposes, especially for resistance and propulsion performance estimation, and is now extending its boundaries:

- **From static to dynamic cases**
- **From pure hydrodynamic problem to *multi-physics problems* or coupled solution with other simulation tools**



Dynamic simulation for submarine testing apparatus (animation)



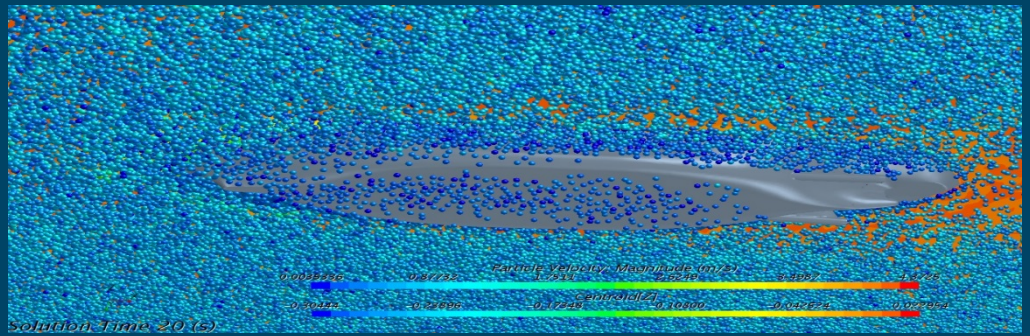
Seakeeping simulation (animation)

CFD-DEM Coupling for Ship-Ice Problems

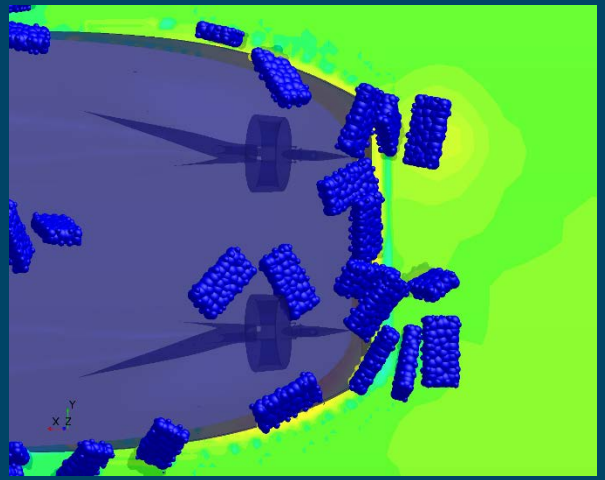
CFD solves the flow of the continuum fluid.

DEM considers the contacts between ship and ice, and between ice particles.

Hydrodynamic force on a DEM particle is based on the pressure gradient from CFD.



Ahead operation in small spherical ice particles

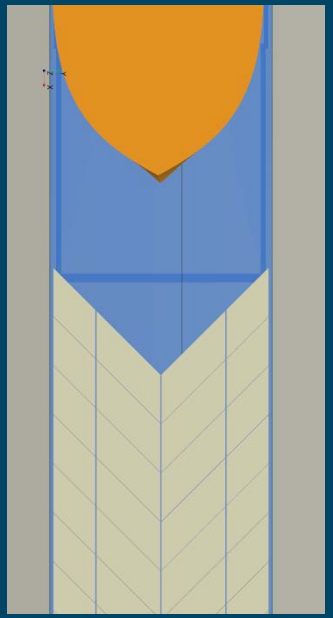


Astern operation in large composite particles

Validation Effort for CFD-DEM Coupled Approach

To reduce the uncertainties from initial ice condition (i.e. shape, size and location), pre-sawn ice is selected.

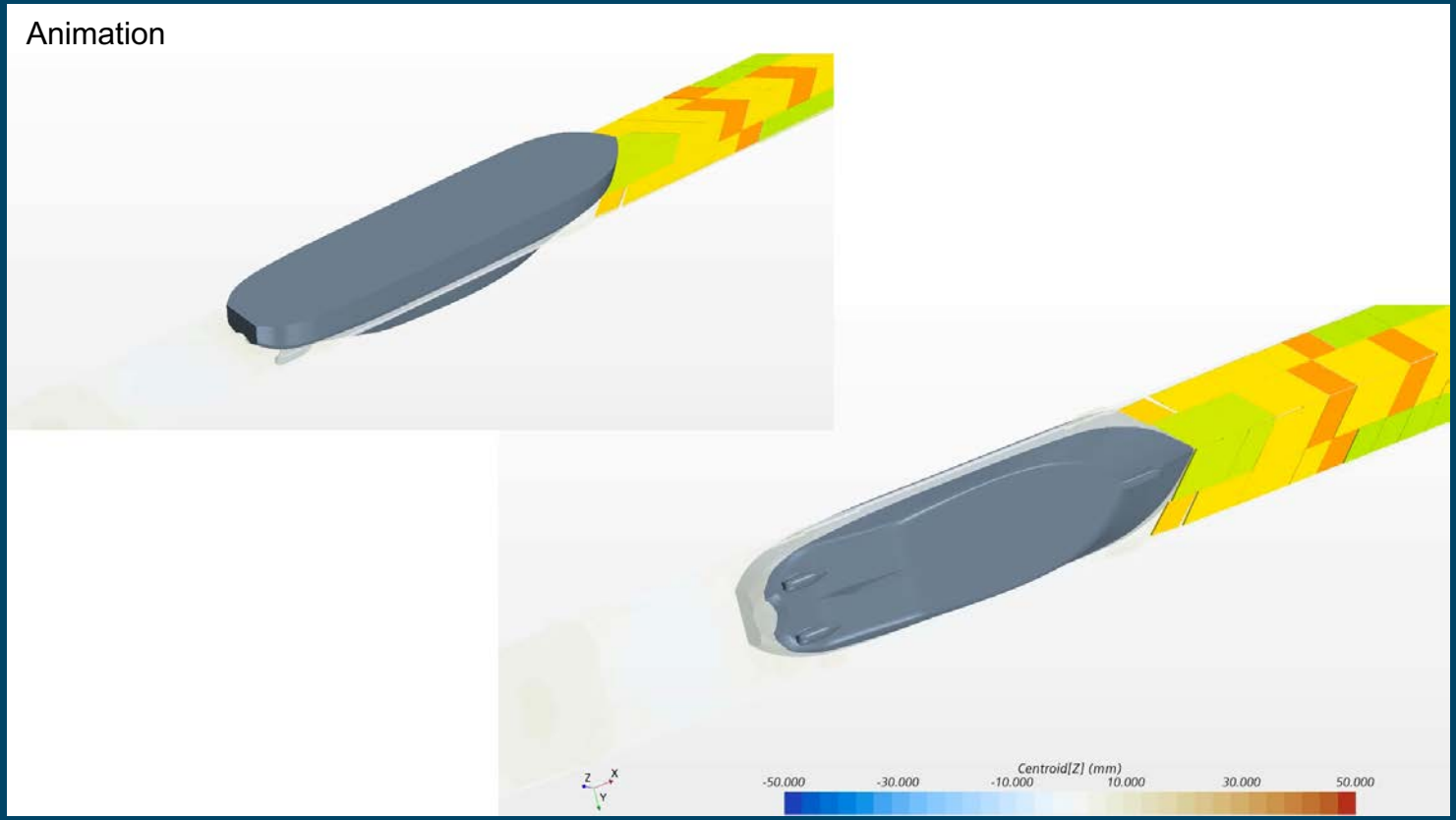
Pack ice condition



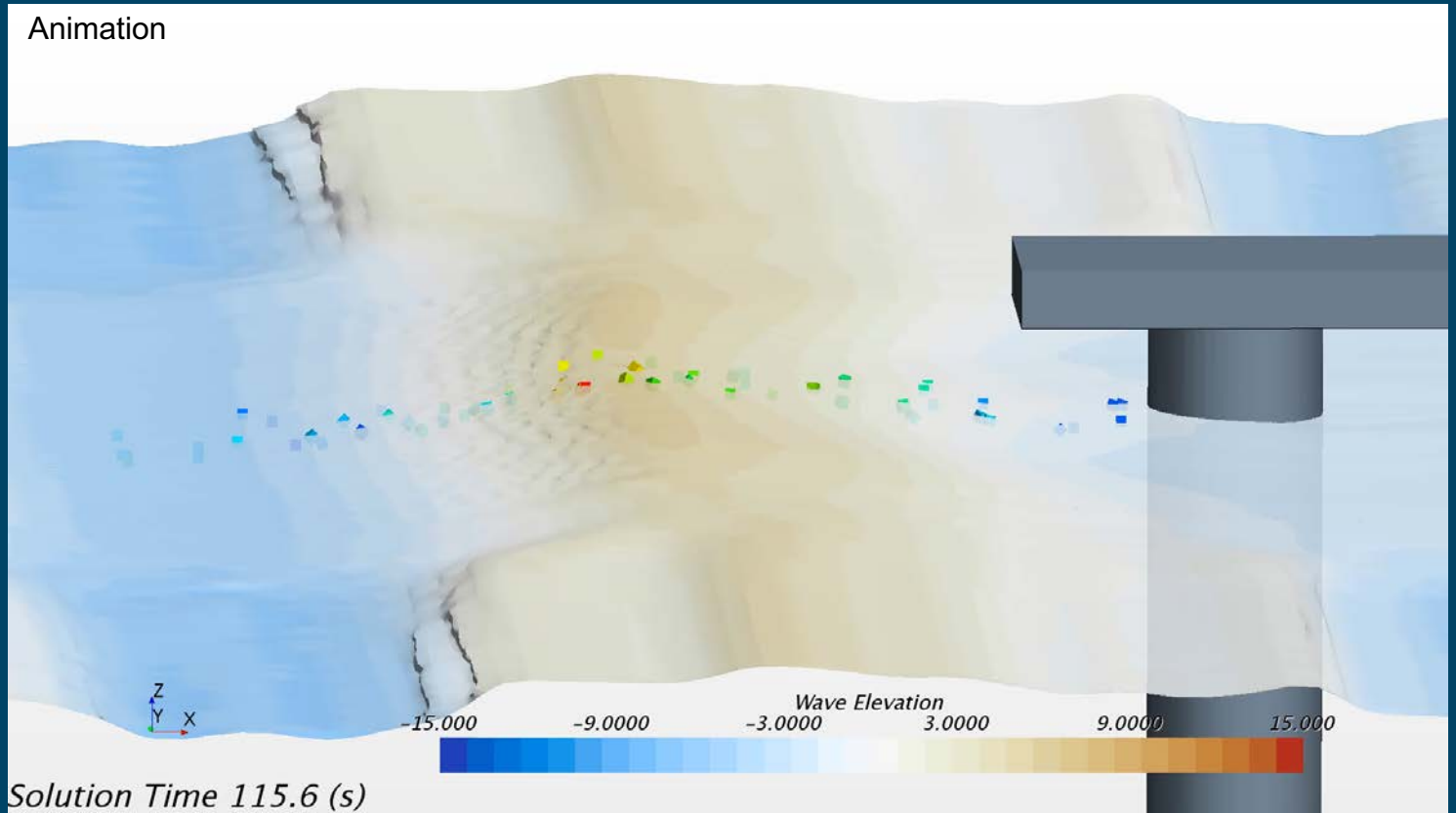
Pre-sawn ice condition (in tank and in simulation)

Simulation for Pre-sawn Ice Test

Animation



Simulation for Structure-Ice Interaction in Waves



Conclusion

CFD-DEM coupled approach is under investigation to consider operation/navigation in a broken ice field.

For reliable applications, it needs to

- Conduct more validation (e.g. ship-ice interaction in waves and maneuvering in ice)
- Find optimal simulation set-ups and modeling parameters (i.e. prediction accuracy vs. computing efficiency)