Numerical Simulation of Ice Ridge Breaking

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EMship+ Advanced Design

Universität Rostock

Traditio et Innovatio

HSVA

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Rostock

Goal

To develop a ***numerical solver*** *capable of simulating* ***ship breaking*** *through an* ***ice ridge***

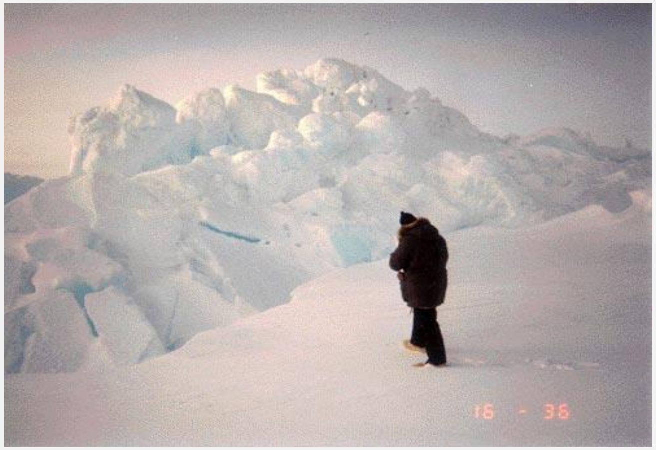
Solution Steps

- Ice ridges
- Discrete Element Method
- Software development
- Validation & Results
- Conclusions & Proposals

Ice ridges

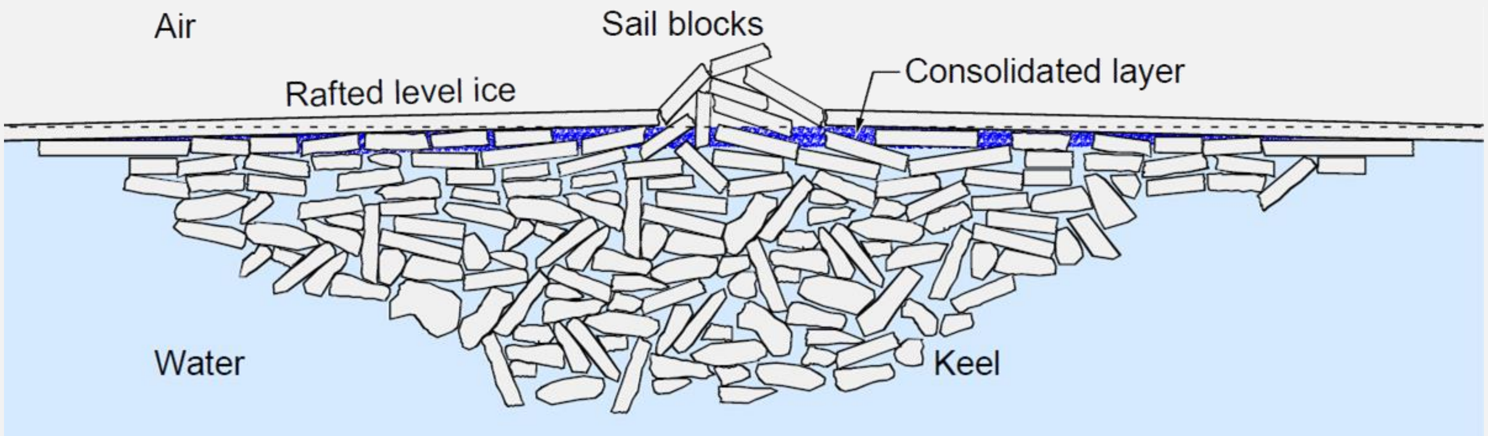
Ice ridges

- Dimensions

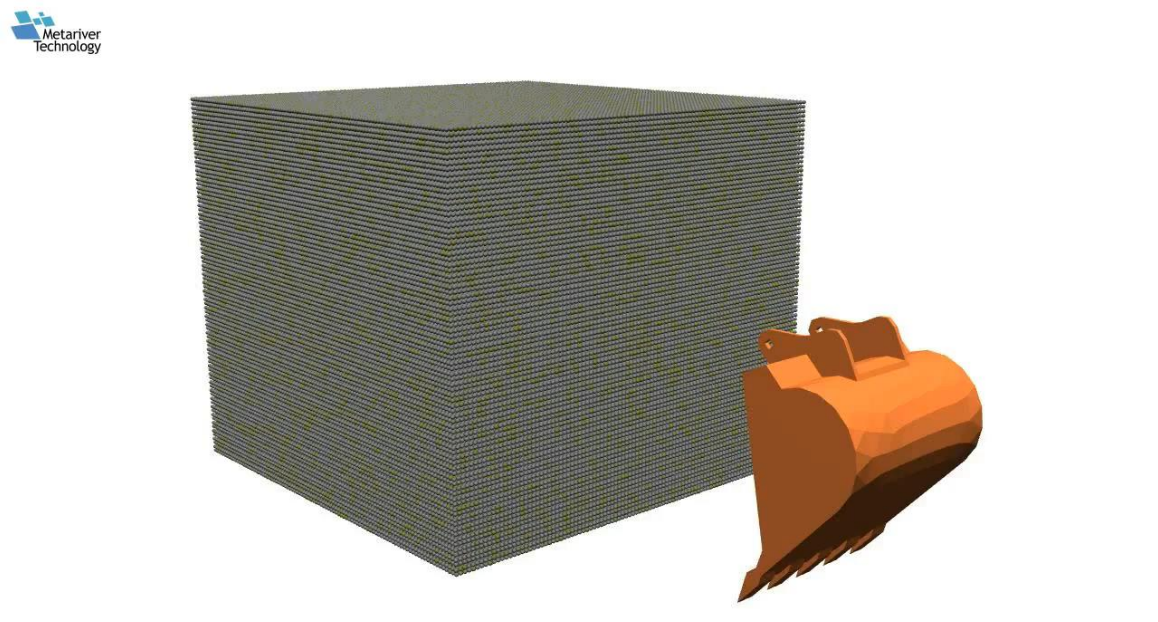


Source*: Ship Breaking Through Ice Ridges by D.Ehle*

- Configuration of ice ridge



DEM – numerical method for calculation of motion of large number of particles

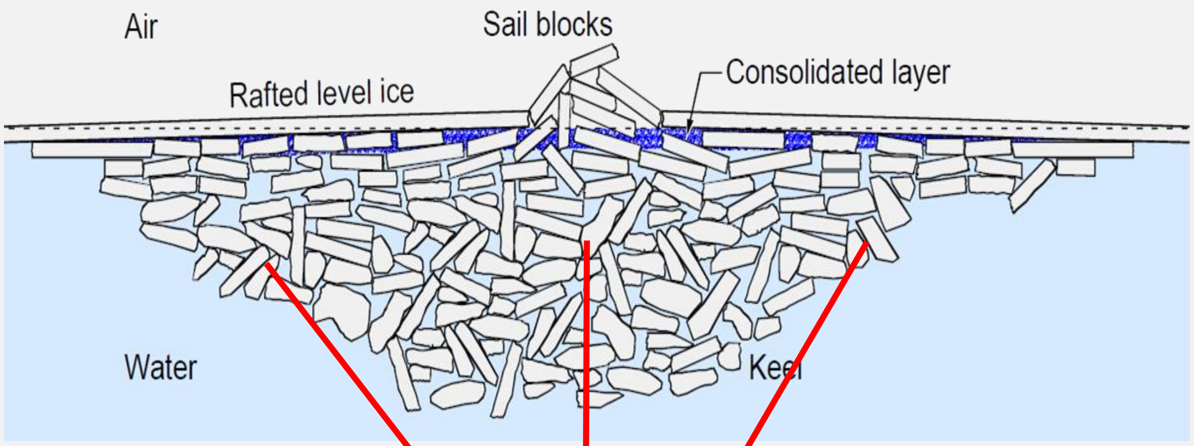


Source: *http://www.metariver.kr/*

Application in:

- Soil mechanics
- Rock engineering
- Geophysics
- Mineral processing
- Powder metallurgy

DEM – numerical method for calculation of motion of large number of particles

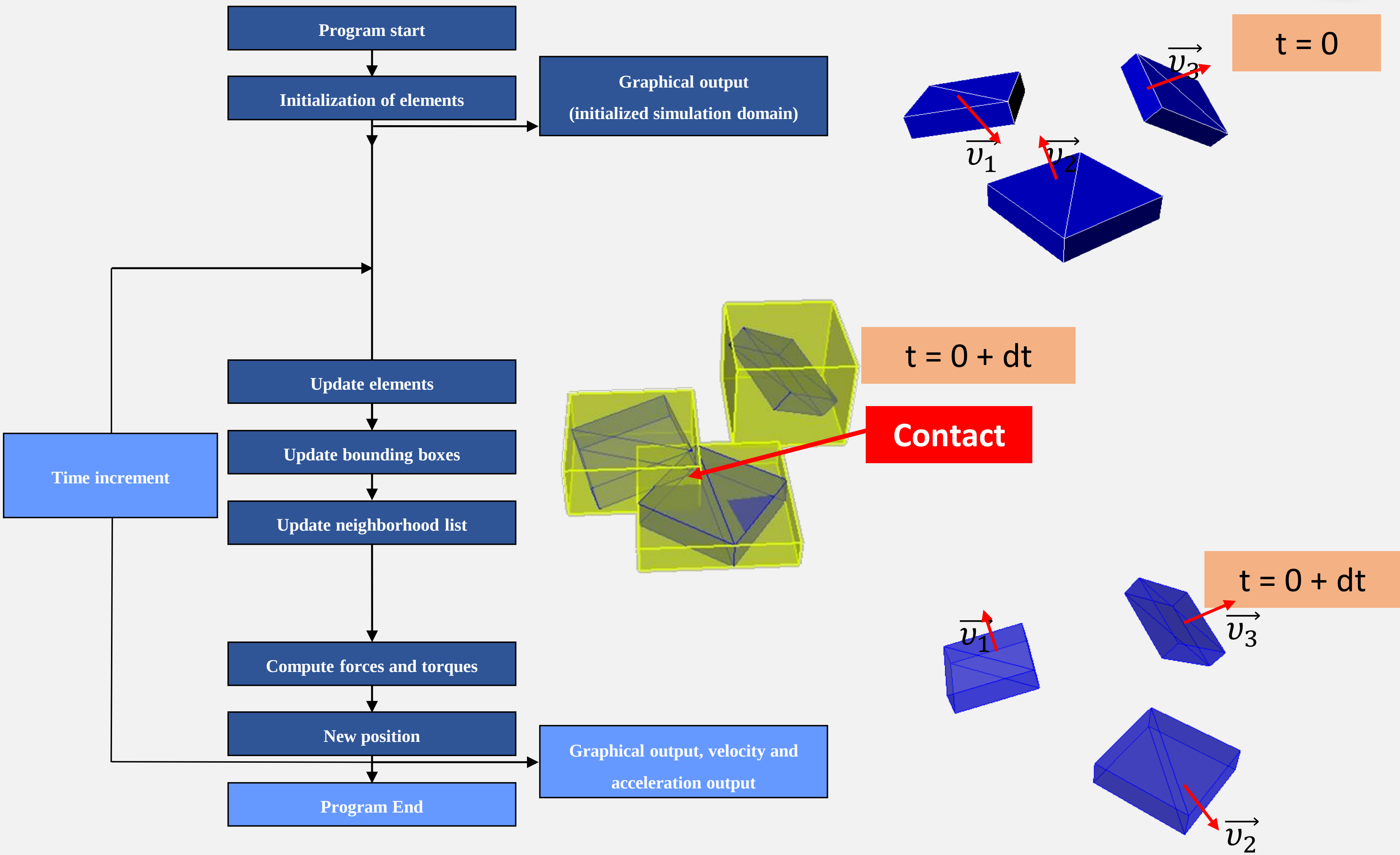


Discrete Elements

Application in:

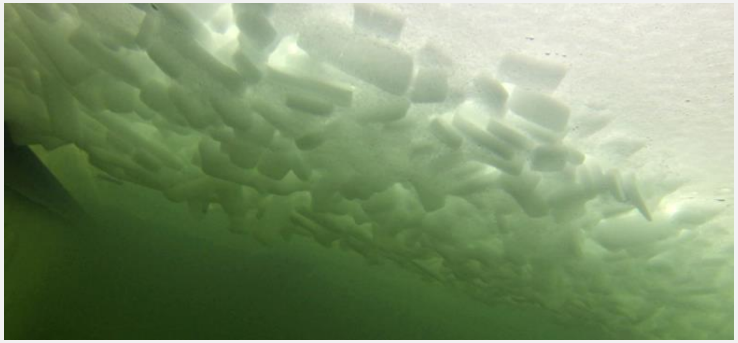
- Soil mechanics
- Rock engineering
- Geophysics
- Mineral processing
- Powder metallurgy
- Ice-related simulations?

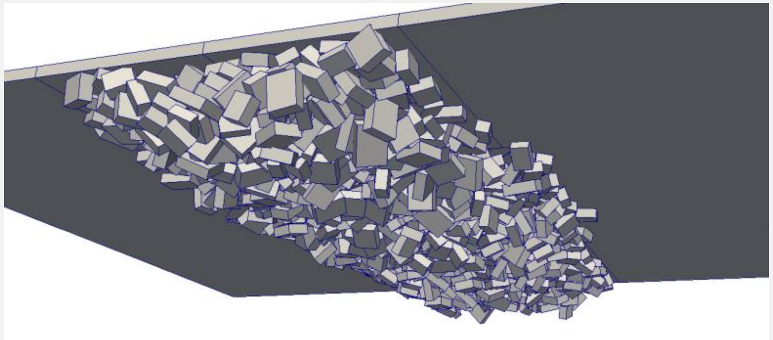
Discrete Element Method



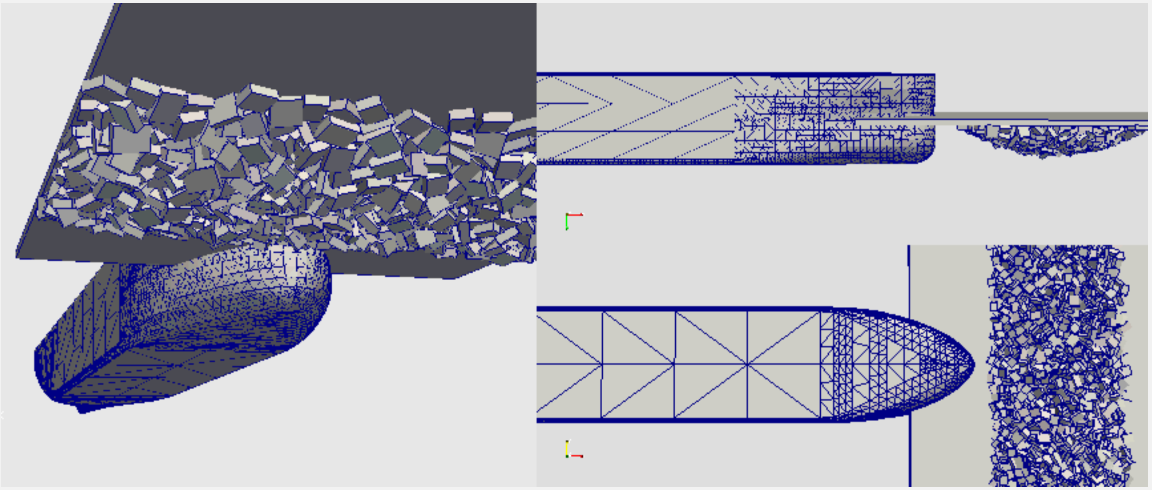
Discrete Element Method

- Ice ridge as an assembly of discrete elements





- Ship as a discrete element with special features



Introducing ship hull into simulation

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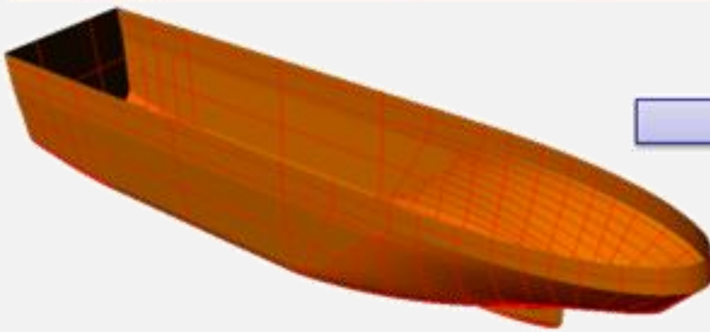
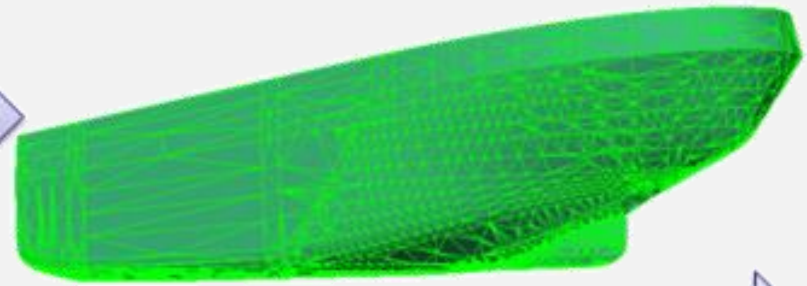
Hull Surface (NURBS, etc.)



Hull Mesh (triangular)



OBJ. file

```
# Rhino

v -0.885792 -0.345188 -0.216071
v -0.885792 -0.345188 -0.145154
v -0.885792 -0.339563 -0.0596542
v -0.885792 -0.328313 0.111346
v -0.885792 -0.322688 0.196846

f 68 63 66
f 342 340 97
f 61 50 33
f 186 155 138
f 69 31 45
```

geometry

topology

DEM data structures

VERT_COORD
vertex index 1 → 4

V_{1x}	V_{2x}	V_{3x}	V_{4x}
V_{1y}	V_{2y}	V_{3y}	V_{4y}
V_{1z}	V_{2z}	V_{3z}	V_{4z}

FACE_EQUATION
face index 1 → 4

n_{1x}	n_{2x}	n_{3x}	n_{4x}
n_{1y}	n_{2y}	n_{3y}	n_{4y}
n_{1z}	n_{2z}	n_{3z}	n_{4z}
d_1	d_2	d_3	d_4

FACE_VERTEX_TABLE
face index 1 → 4

1	1	1	2
2	3	4	4
3	4	2	3

VERT_FACE_TABLE
vertex index 1 → 4

1	1	1	2
2	3	2	3
3	4	4	4

Quaternions & Spatial Orientation

$$q = w\,1 + xI + yJ + zK$$

$$I \cdot I = -1 \qquad J \cdot J = -1 \qquad K \cdot K = -1$$

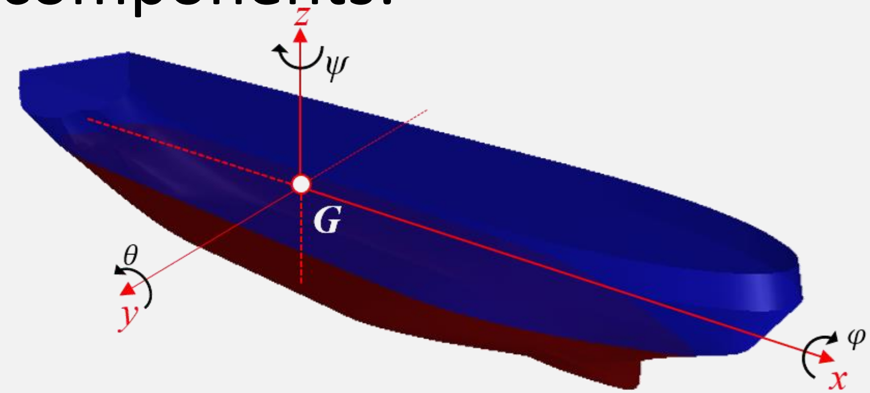
$$w = \cos\frac{\varphi}{2}\cos\frac{\theta}{2}\cos\frac{\psi}{2} + \sin\frac{\varphi}{2}\sin\frac{\theta}{2}\sin\frac{\psi}{2}$$

$$x = \sin\frac{\varphi}{2}\cos\frac{\theta}{2}\cos\frac{\psi}{2} - \cos\frac{\varphi}{2}\sin\frac{\theta}{2}\sin\frac{\psi}{2}$$

$$y = \cos\frac{\varphi}{2}\sin\frac{\theta}{2}\cos\frac{\psi}{2} + \sin\frac{\varphi}{2}\cos\frac{\theta}{2}\sin\frac{\psi}{2}$$

$$z = \cos\frac{\varphi}{2}\cos\frac{\theta}{2}\sin\frac{\psi}{2} - \sin\frac{\varphi}{2}\sin\frac{\theta}{2}\cos\frac{\psi}{2}$$

Definition of quaternion components:

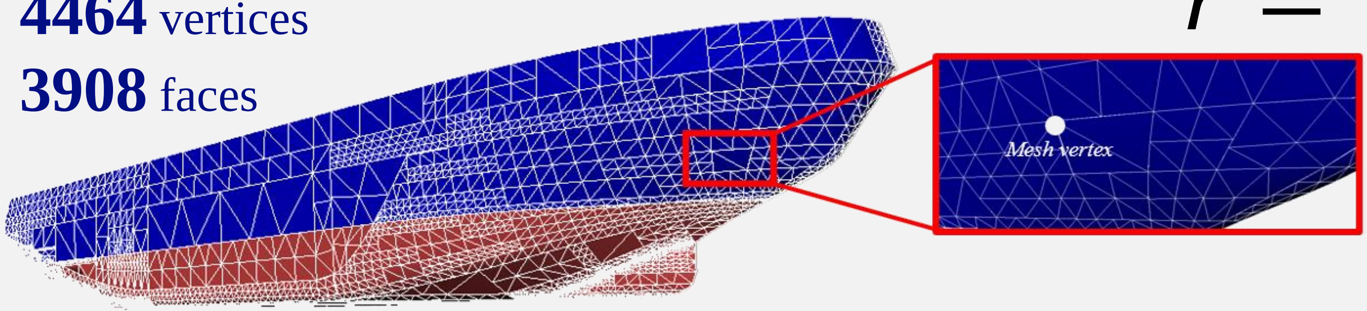


$$\tilde{r} = \mathbf{q}\, r\, \mathbf{q}^*$$

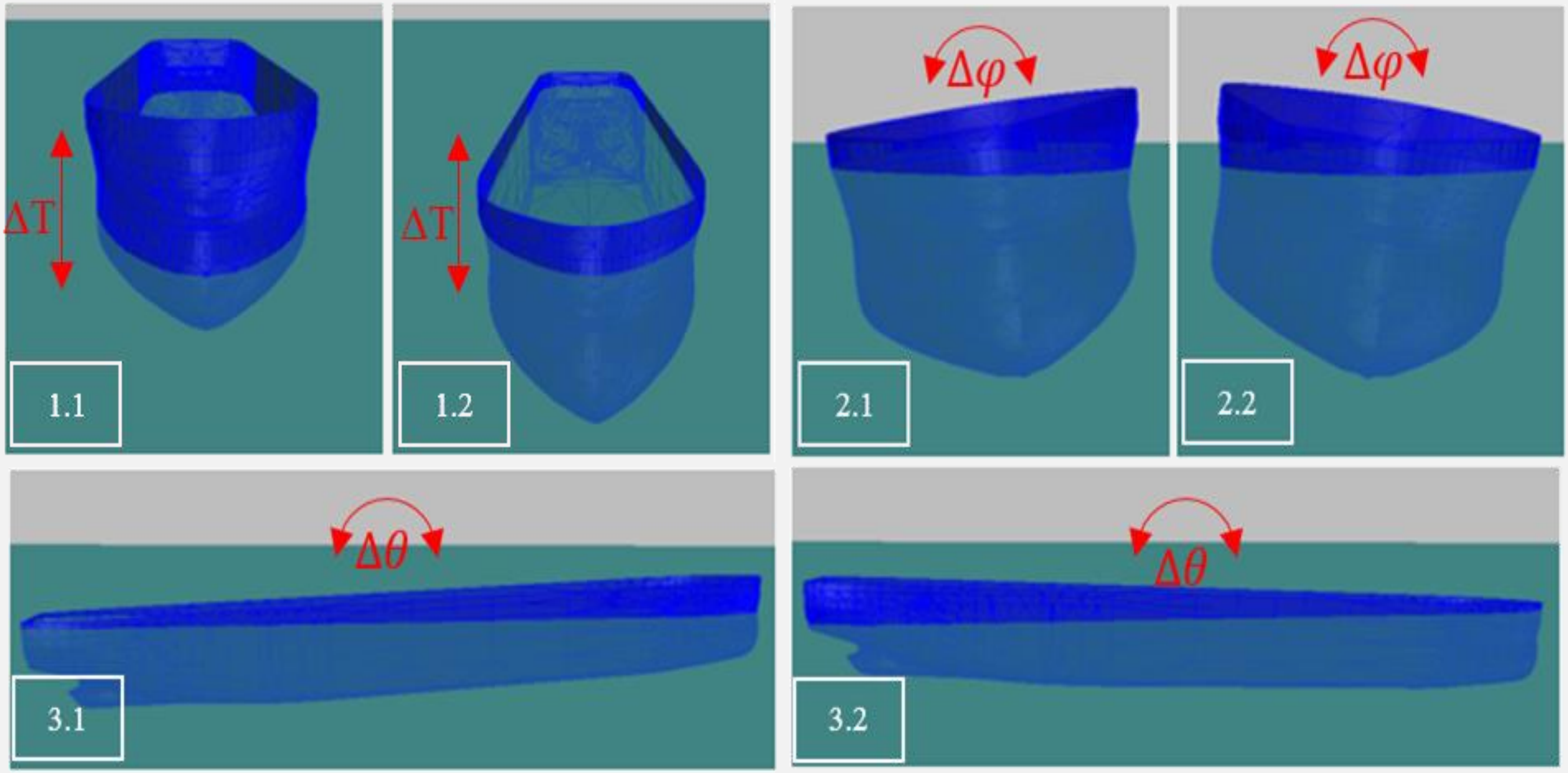
quaternion position vector quaternion *conjugation

4464 vertices

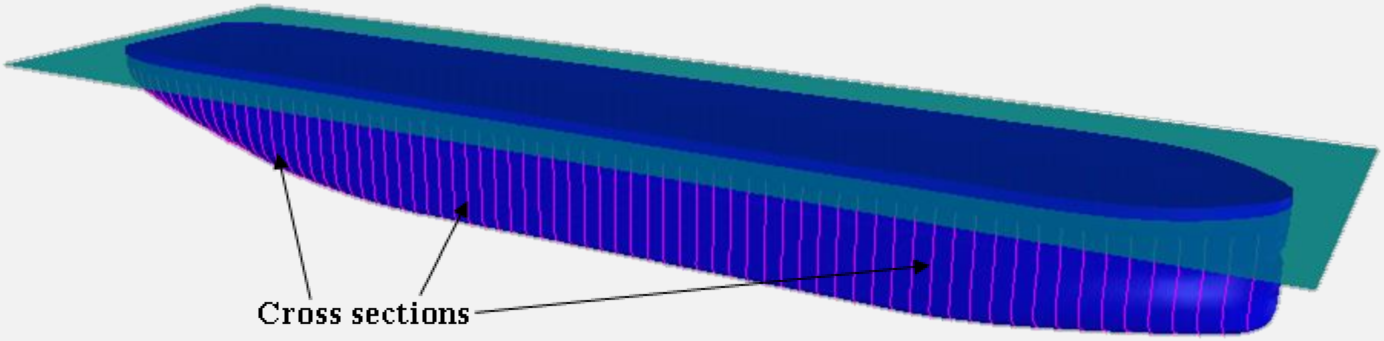
3908 faces

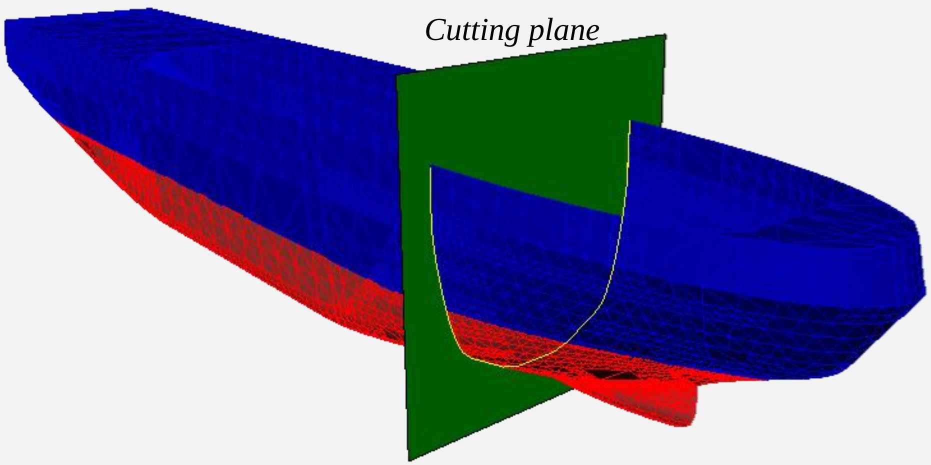


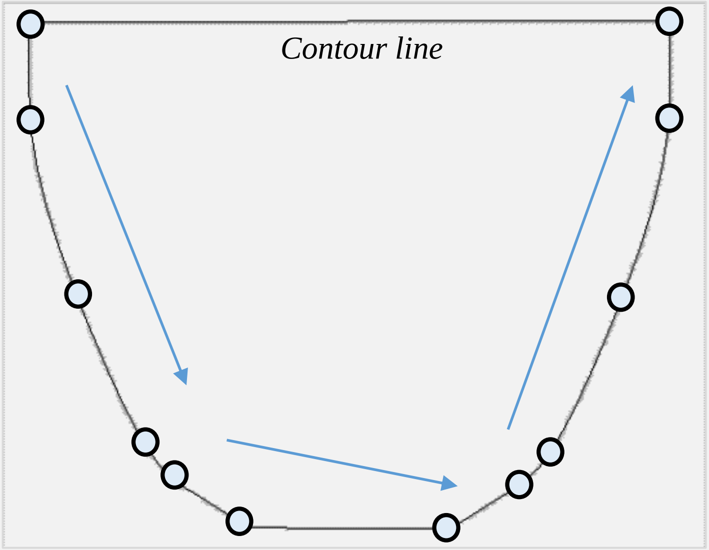
Ship Buoyancy and Propulsion



Ship Buoyancy and Propulsion

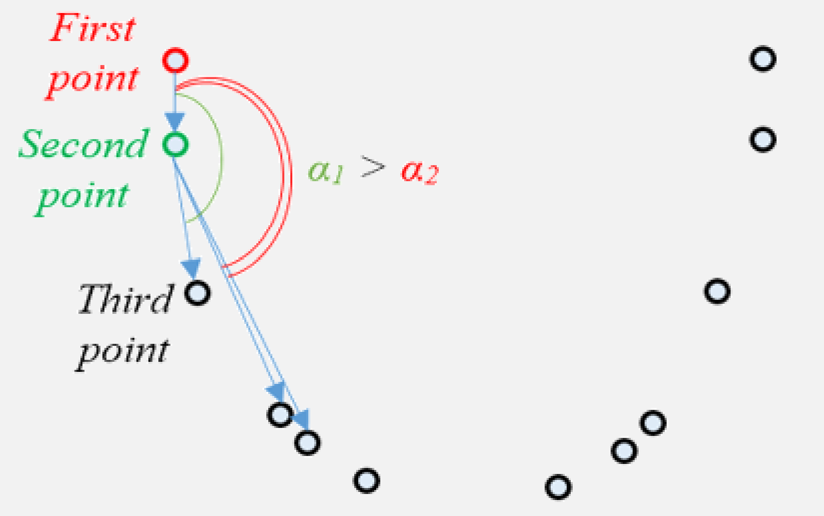




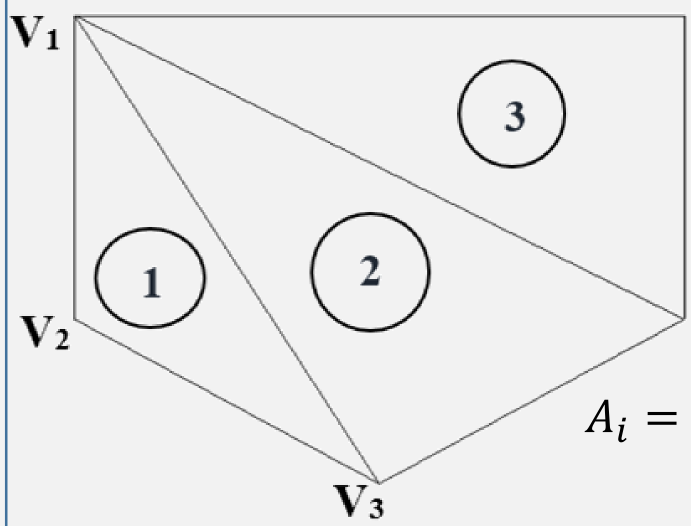


Ship Buoyancy and Propulsion

Gift wrapping algorithm



Cross sectional area

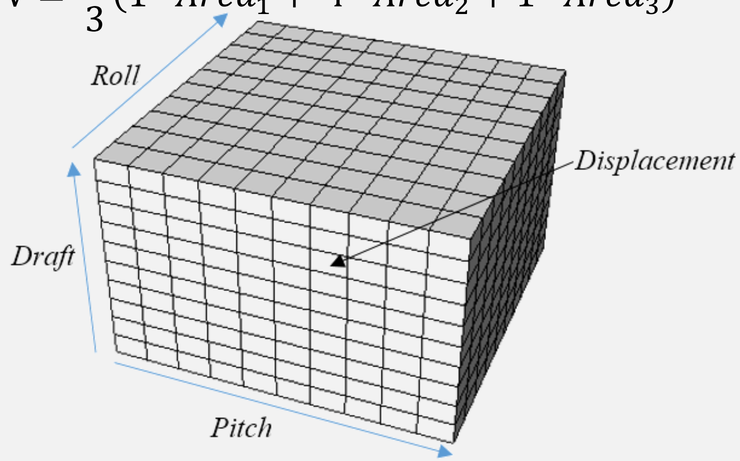


$$A_i = \frac{\overrightarrow{V_1V_2} \times \overrightarrow{V_2V_3}}{2}$$

$$A = \sum_{i=1}^{N_\Delta} A_i$$

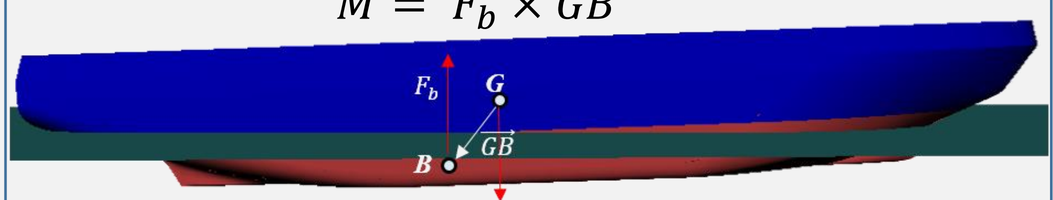
Simpson's First Rule integrator

$$\mathrm{V} = \frac{h}{3}(1 \cdot Area_1 + 4 \cdot Area_2 + 1 \cdot Area_3)$$

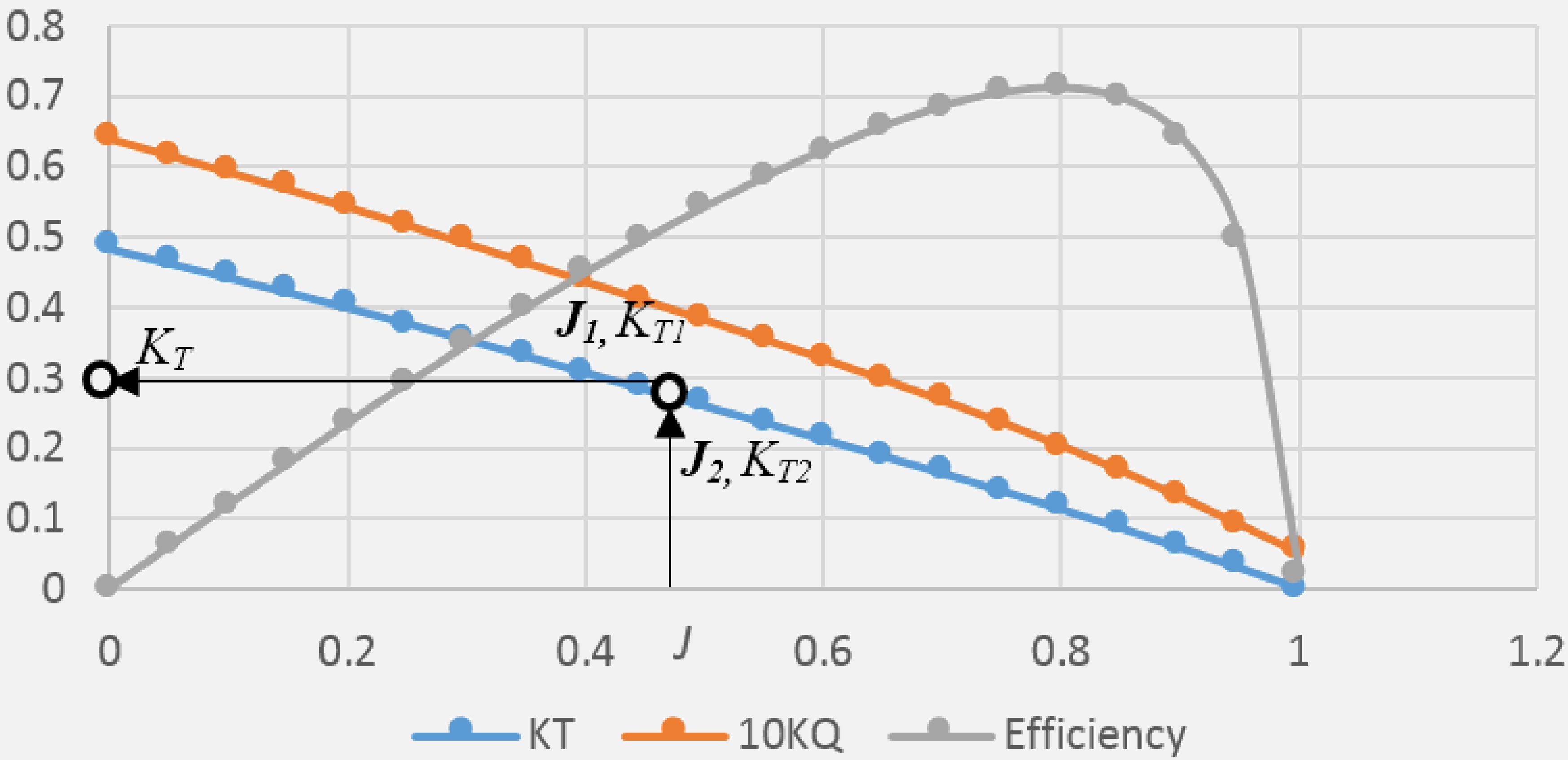


Buoyancy restoring moment

$$\vec{M} = \vec{F_b} \times \overrightarrow{GB}$$



Ship Buoyancy and Propulsion



Equations of Motions

- Rectilinear degrees of freedom

Applied forces
Mass of element
Acceleration of element

$$\overrightarrow{\boldsymbol{F}_i} = \boldsymbol{m} \cdot \overrightarrow{\dot{\boldsymbol{v}}_i}$$

- Rotational degrees of freedom

Quaternion 2nd derivative
Angular acceleration
Quaternion
Quaternion 1st derivative
Angular velocity

$$\frac{d^2\mathbf{q}}{dt^2} = \frac{1}{2}\left(\vec{\dot{\omega}}\mathbf{q} + \dot{\mathbf{q}}\vec{\omega}\right)$$

Predictor – Corrector Numerical Solver

1. Predictor step

- Rectilinear degrees of freedom

$$\boldsymbol{r} = \boldsymbol{r} + \dot{\boldsymbol{r}}\boldsymbol{dt} + \ddot{\boldsymbol{r}}\frac{\boldsymbol{dt}^2}{2}$$

$$\dot{\boldsymbol{r}} = \dot{\boldsymbol{r}} + \ddot{\boldsymbol{r}}\boldsymbol{dt}$$

- Rotational degrees of freedom

$$\mathbf{q} = \mathbf{q} + \dot{\mathbf{q}}\boldsymbol{dt} + \ddot{\mathbf{q}}\frac{\boldsymbol{dt}^2}{2}$$

$$\dot{\mathbf{q}} = \dot{\mathbf{q}} + \ddot{\mathbf{q}}\boldsymbol{dt}$$

2. Corrector step

- Rectilinear degrees of freedom

$$\boldsymbol{r} = \boldsymbol{r} + \boldsymbol{c}_0\Delta\ddot{\boldsymbol{r}}$$

$$\dot{\boldsymbol{r}} = \dot{\boldsymbol{r}} + \boldsymbol{c}_1\Delta\ddot{\boldsymbol{r}}$$

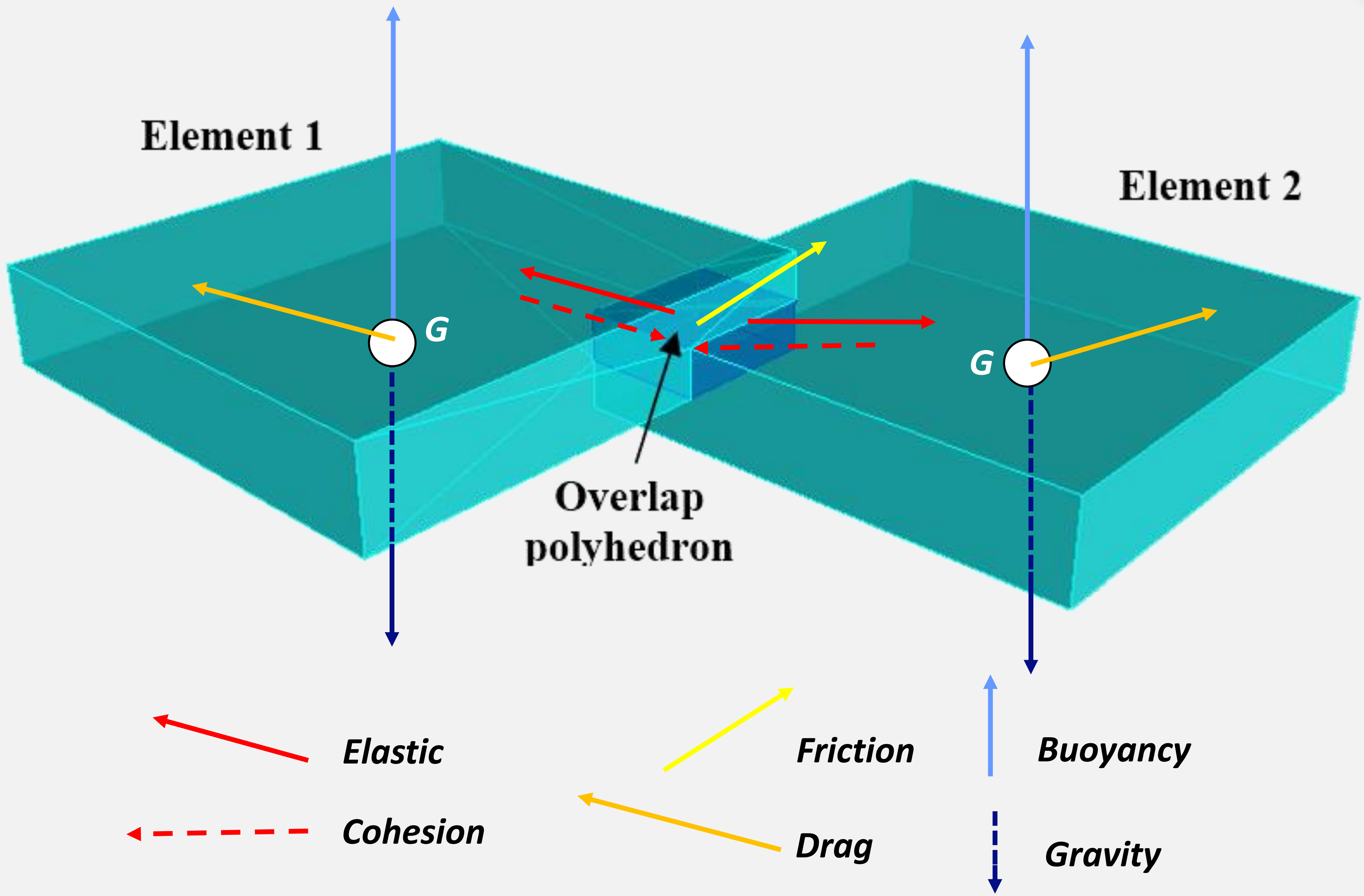
- Rotational degrees of freedom

$$\mathbf{q} = \mathbf{q} + \boldsymbol{c}_0\Delta\ddot{\mathbf{q}}$$

$$\dot{\mathbf{q}} = \dot{\mathbf{q}} + \boldsymbol{c}_1\Delta\ddot{\mathbf{q}}$$

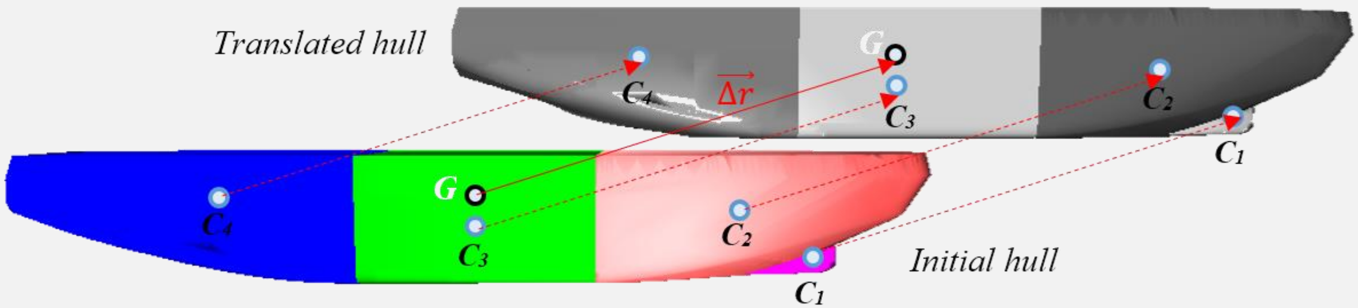
$$\ddot{\mathbf{q}} = \ddot{\mathbf{q}} + \boldsymbol{c}_2\Delta\ddot{\mathbf{q}}$$

Forces Calculation

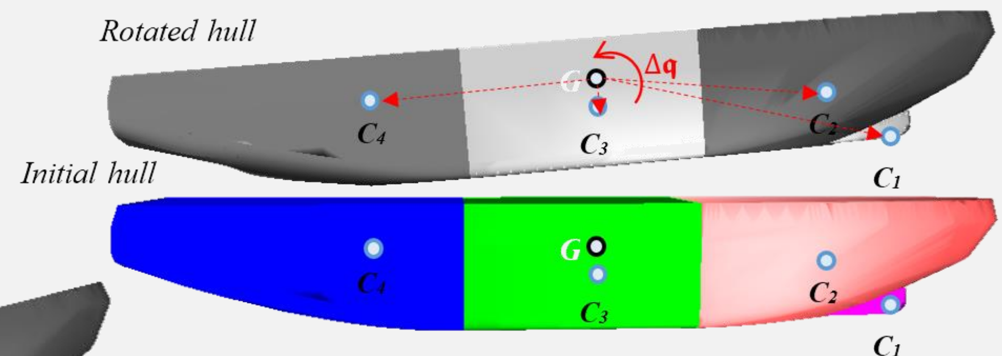


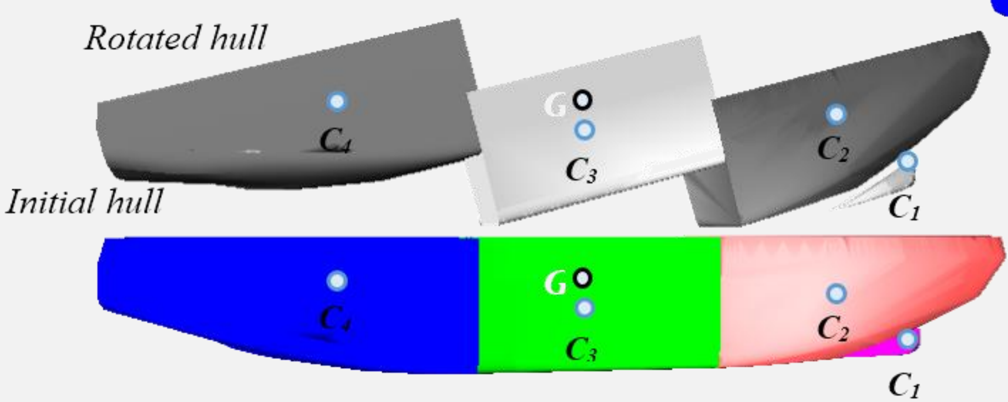
Hanging non-convex ship hulls

- **Translation**

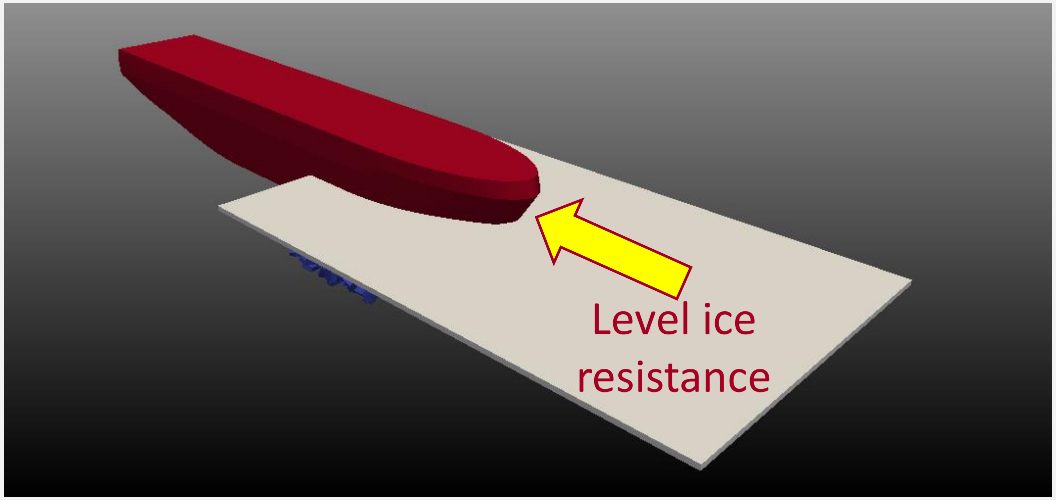


- **Rotation**

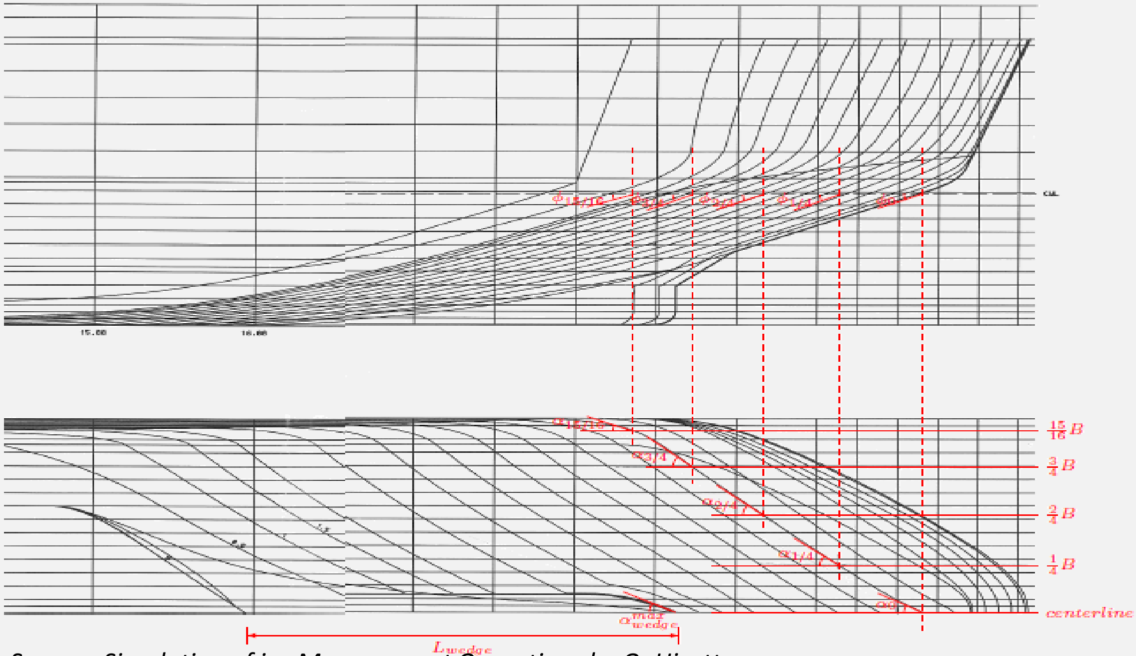




Lindqvist ice resistance theory

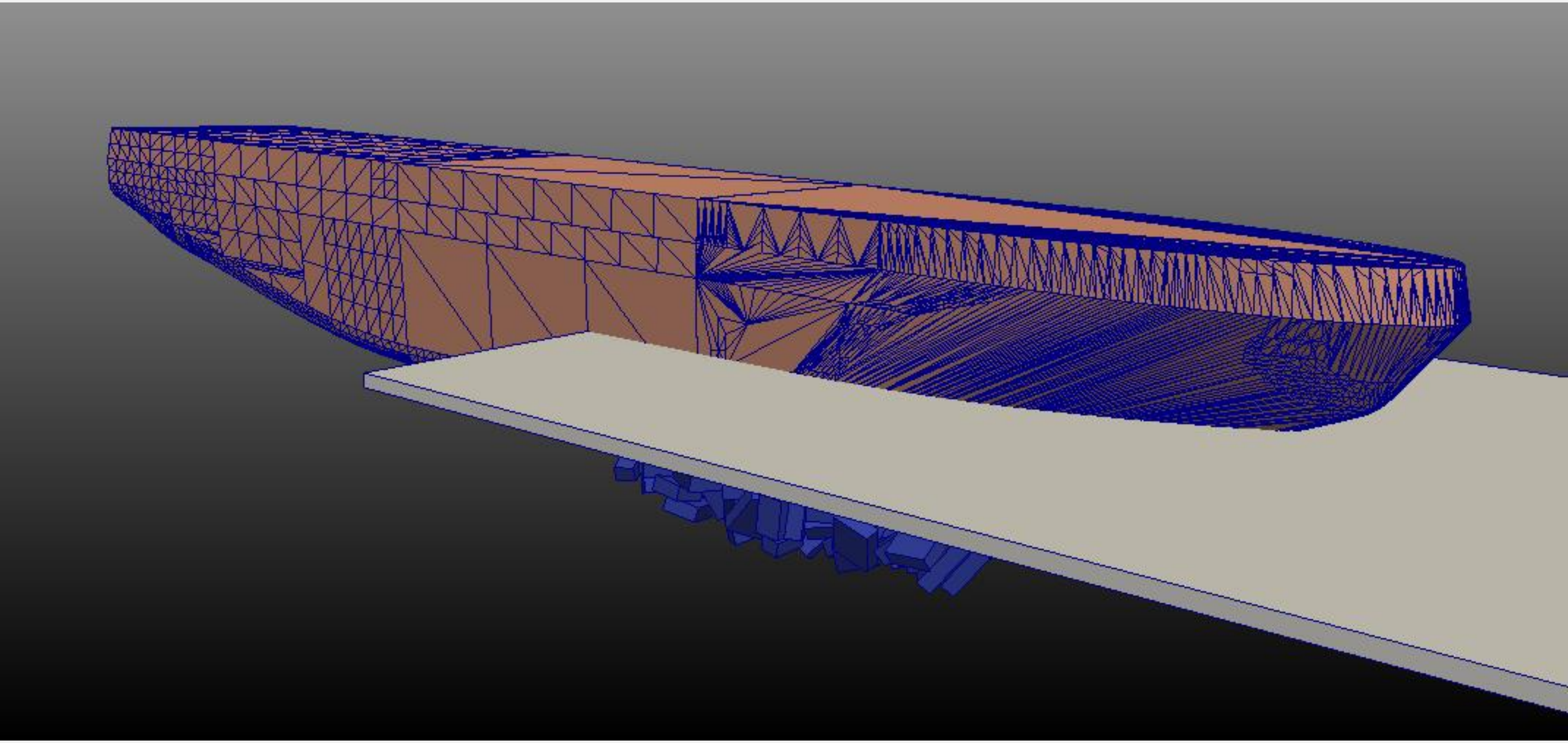


$$\underbrace{R_{ice}}_{} = \overset{\text{Crushing}}{R_c} + \overset{\text{Breaking}}{R_b} + \overset{\text{Submersion}}{R_s}$$

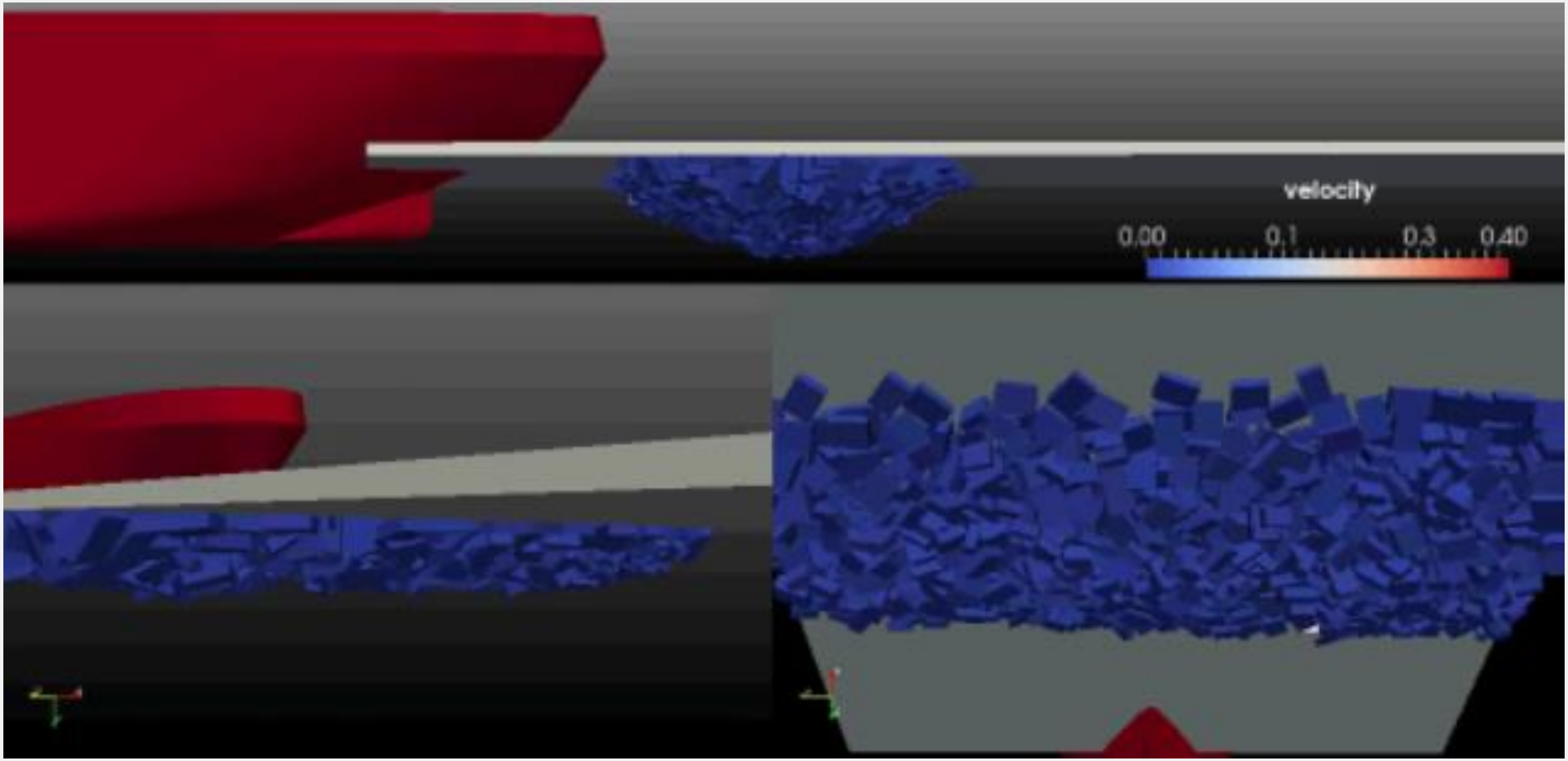


Source: *Simulation of ice Management Operations by Q. Hisette*

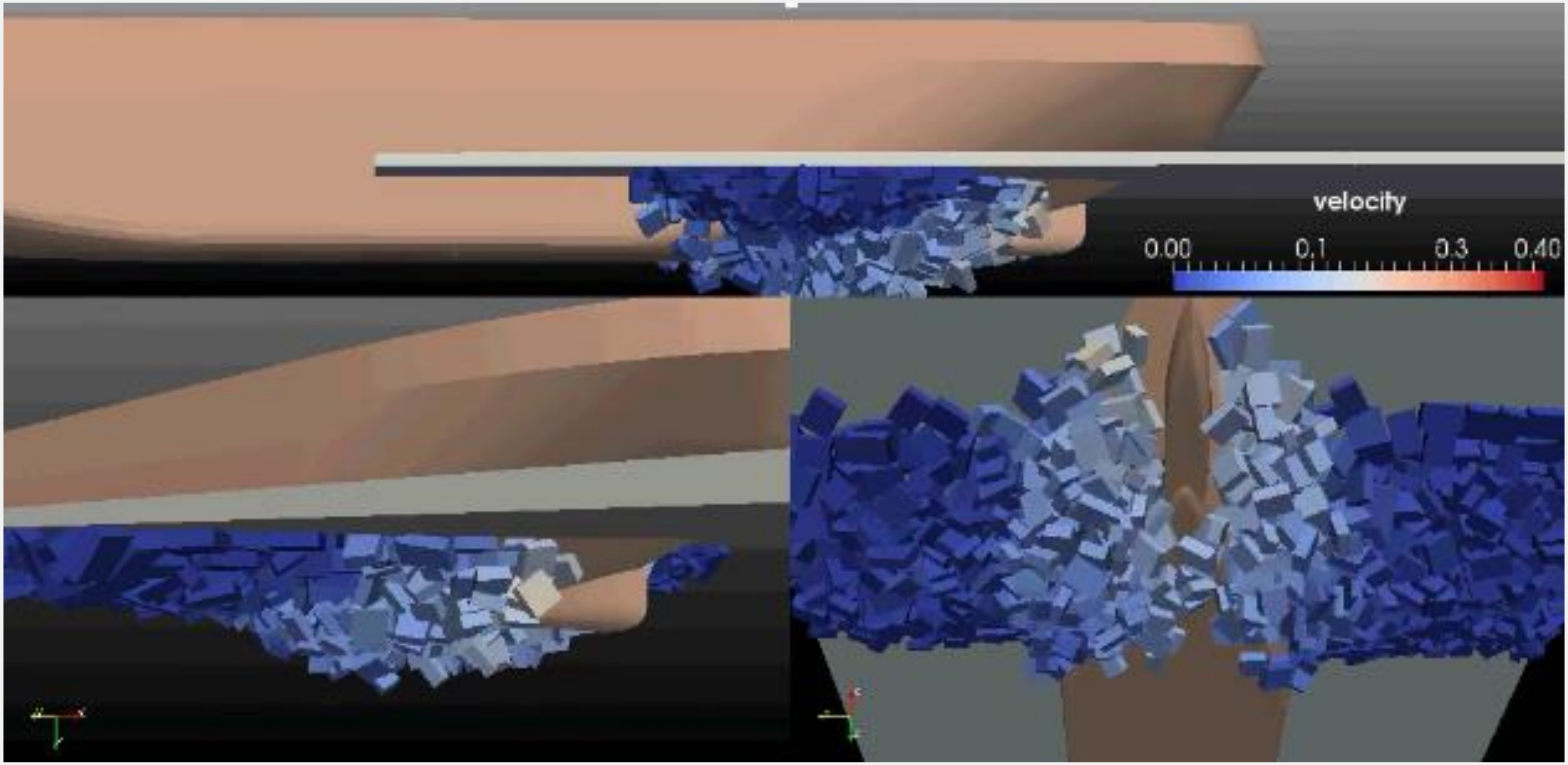
Visualization



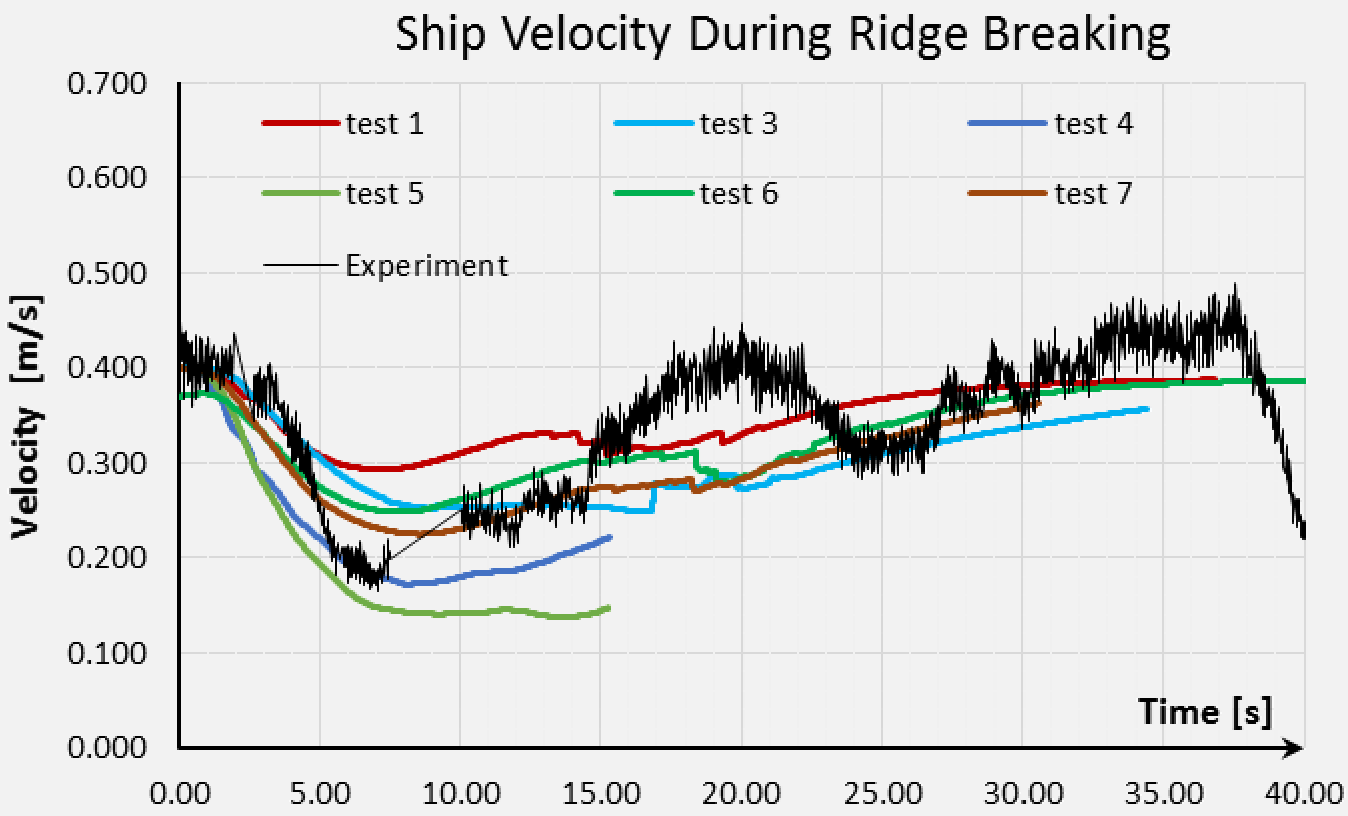
Simulation



Simulation



Validation: ridge 1



Conclusions & Proposals

Conclusions

- Flexible software for ship breaking through an ice ridge
- DEM is suitable to model ice/hull interaction
- Calibration of forces models and validation is required

Proposals

- Computational speed
- Level ice resistance
- Development towards brash ice, ice floes, etc.