



Simulation of Ship Navigation in Ice

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General

- Manoeuvring in uniform ice sheet
 - Ice breaking process
 - Crushing and bending of ice
 - Submersion of ice cusps
- Utilizing the existing ice resistance formulas
- Modular model, ice forces evaluated separately from the hydrodynamic forces

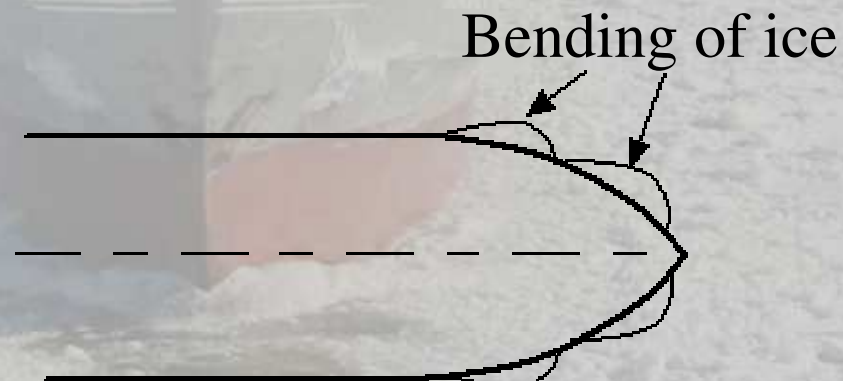
General

- Ice model is developed as a part of JavaSim-package
- Two ship models at this stage: USCGC Mobile Bay and MT Uikku
- The required input data: hydrodynamic coefficients + geometry of waterplane, the normal vector against the hull



Ice Forces

- Submersion components are determined directly as global forces
- The crushing and bending components are evaluated as pressure acting on the waterplane segments
- The geometry of ice cusps is not determined accurately in time domain but as an average size



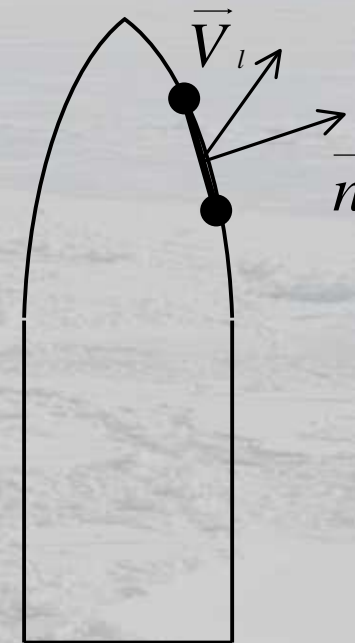


Crushing & Bending

- $\vec{V}_i \cdot \vec{n} > 0$ determines if ice has a impact with hull
- Local velocity $\vec{V}_i = (u_i = u - ry_i \quad v_i = u + rx_i)^T$
- Based on Lindqvist's ice resistance formulas

$$\vec{F}_{bending} = n_c F_n \left[\frac{1}{|n_z|} + \mu \right] \vec{n}$$

$$\vec{F}_{crushing} = 0.45 n_c l_w (\vec{n} \cdot \vec{V}_n) \left[\frac{1}{|n_z|} + \mu \right] \vec{n}$$



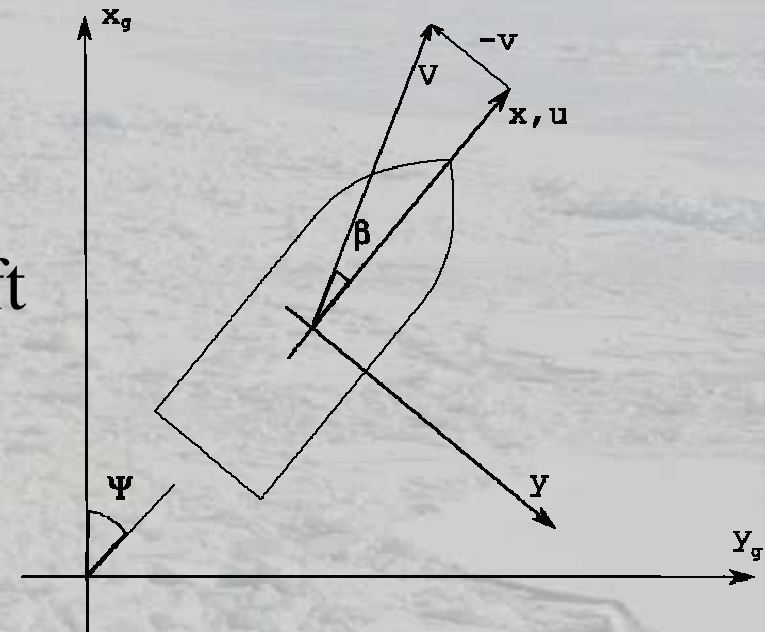


Submersion Forces

- Based also on the method of Lindqvist (potential energy)

$$R_{sub} = \partial \rho h H_{ice} \left[\frac{T(B+T)}{B+2T} + \mu (A_u + \cos \phi \cos \gamma_n A_f) \right]$$

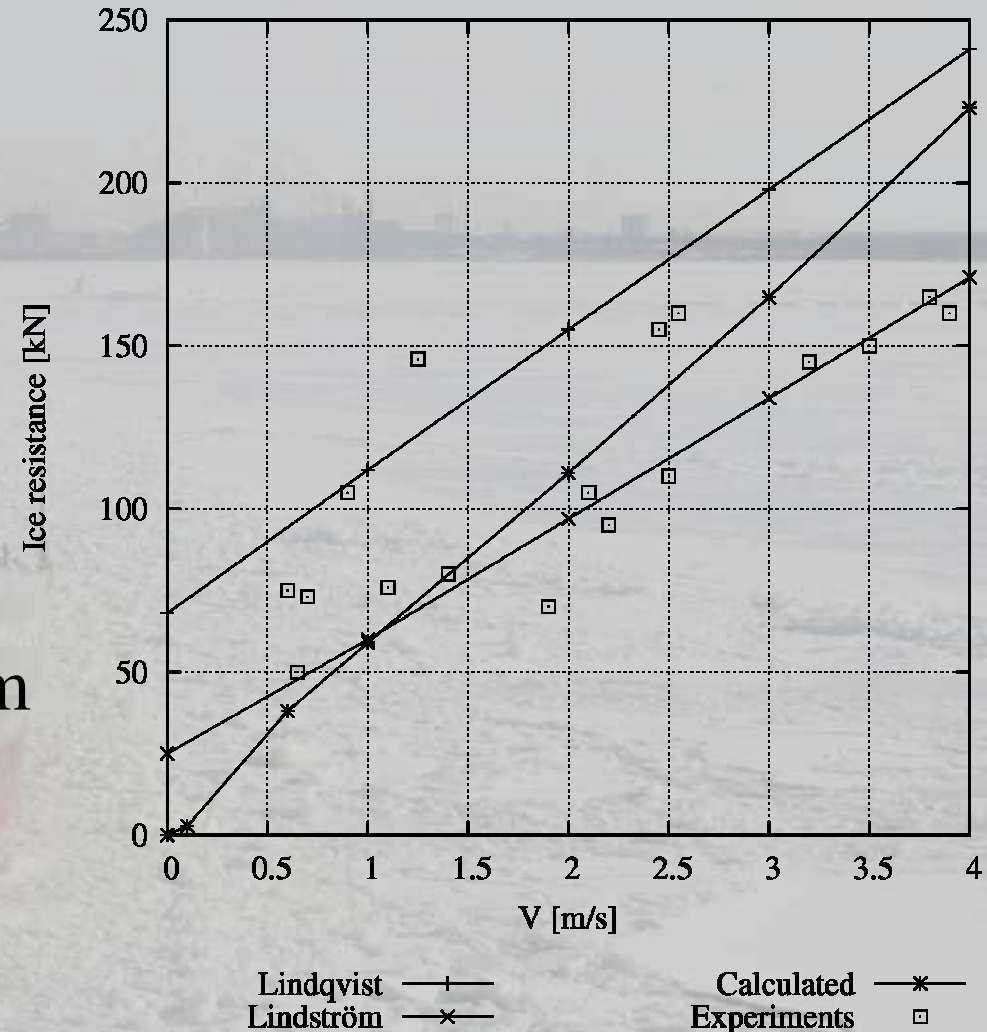
- The total global force is divided into components utilizing the instantaneous drift angle





Results: Mobile Bay

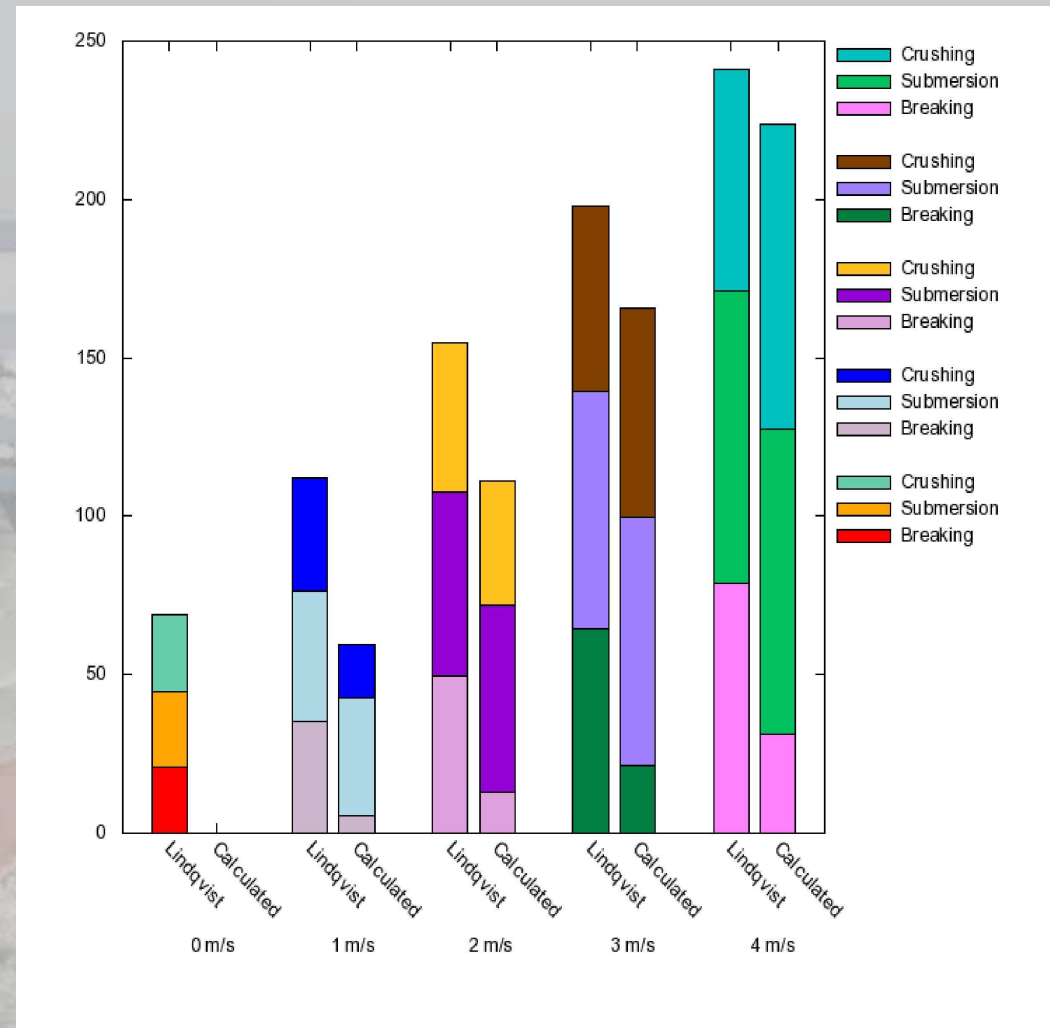
- Icebreaking tug
 - Lwl 39.6
 - Disp 660 t
- Ice resistance
 - The methods of Lindqvist and Lindström and the proposed method compared





Results: Mobile Bay

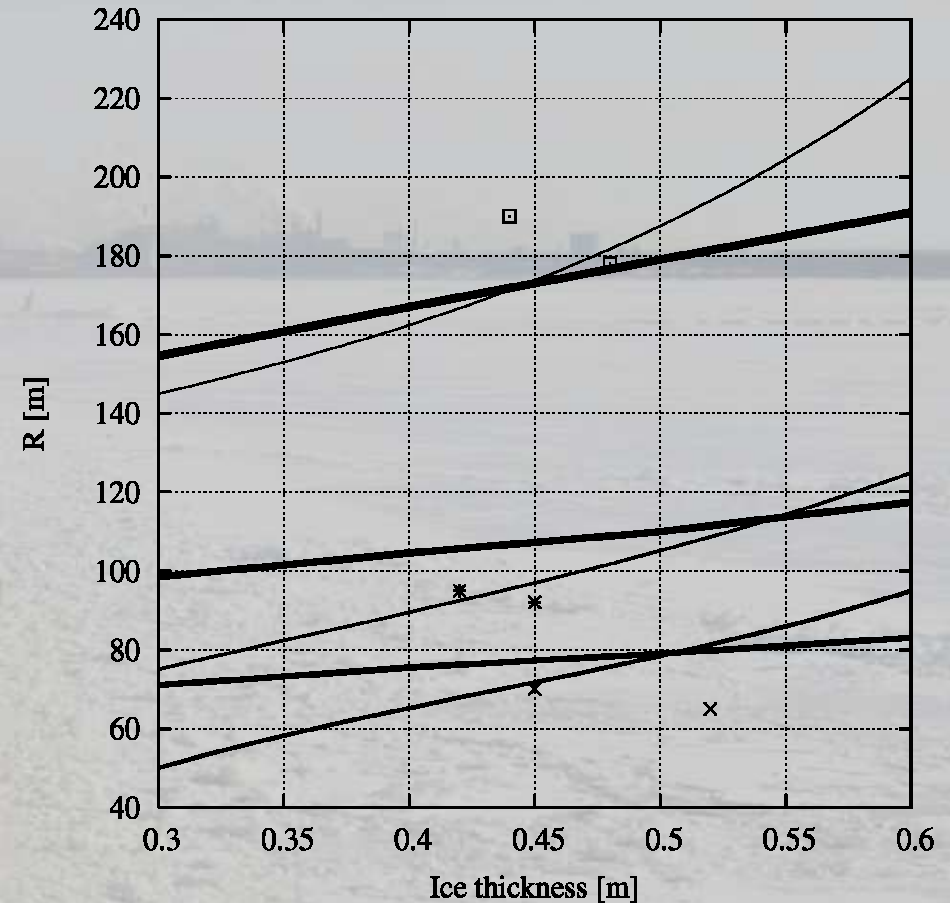
- Ice resistance components, the method of Lindqvist and the proposed method compared





Results: Mobile Bay

- Steady turning circle radius
 - Lindström's method, published experimental results and the proposed method compared



Lindström 30	—	Experiment 30	×
Lindström 20	—	Calculated 30	—
Lindström 10	—	Calculated 20	—
Experiment 10	□	Calculated 10	—
Experiment 20	*		

Model tests: Uikku

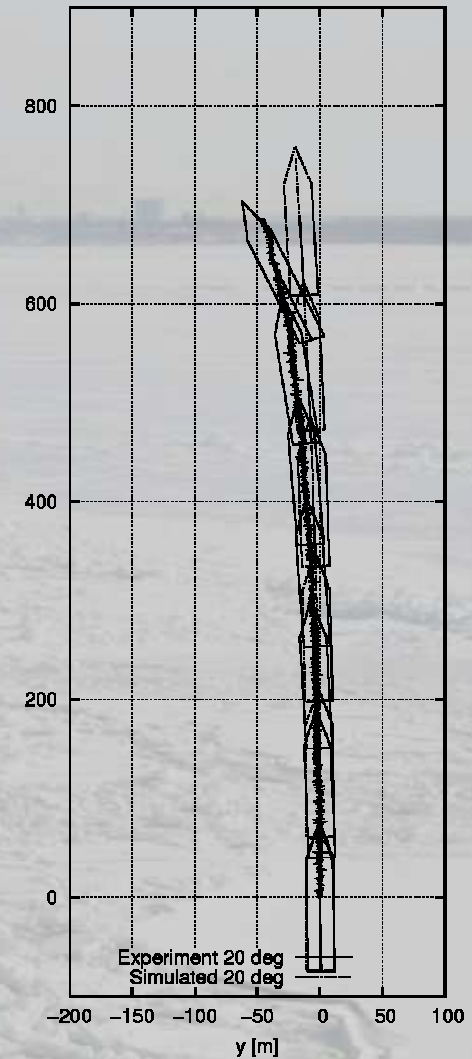
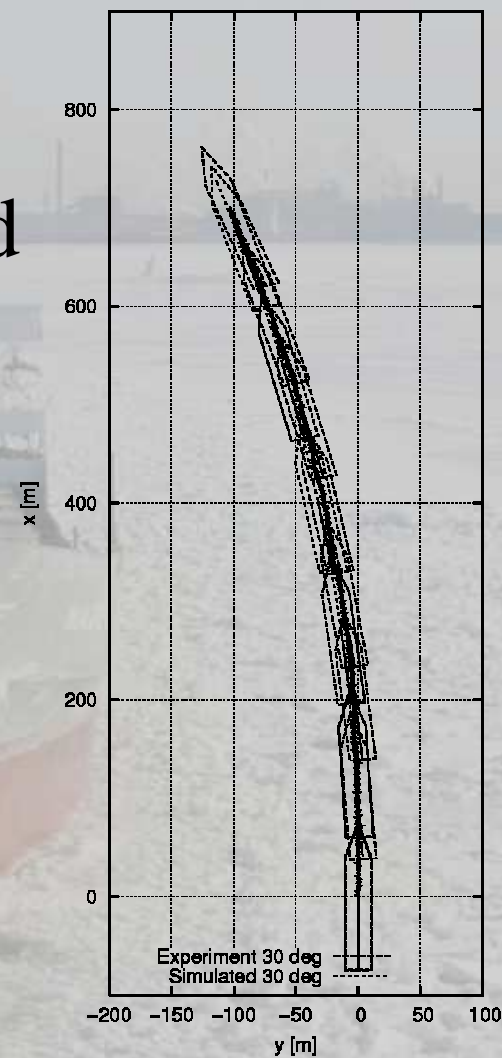
- Ice model tests using model of MT uikku
 - Self-propelled model
 - Single propeller/rudder configuration
 - Rudder angles 20 and 30 deg
 - Constant propeller revs
 - Also open water tests





Results: Uikku

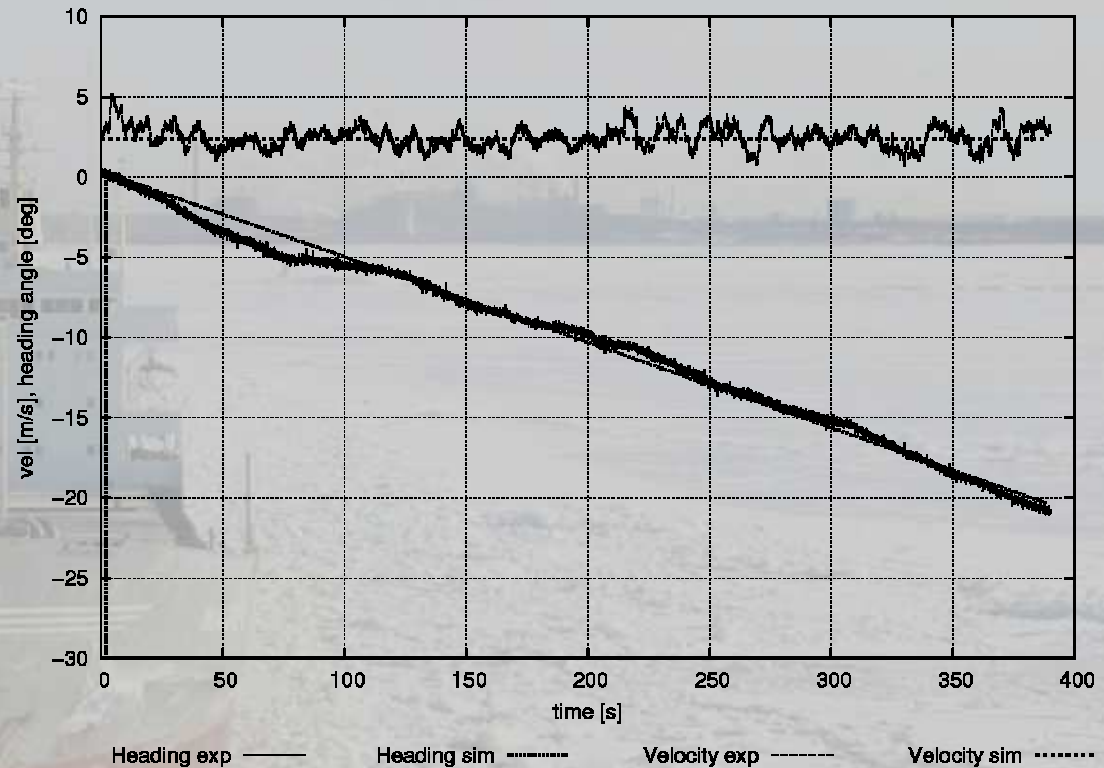
- Trajectories with rudder angles 20 and 30 deg





Results: Uikku

- Ice model tests
 - Heading angle and velocity

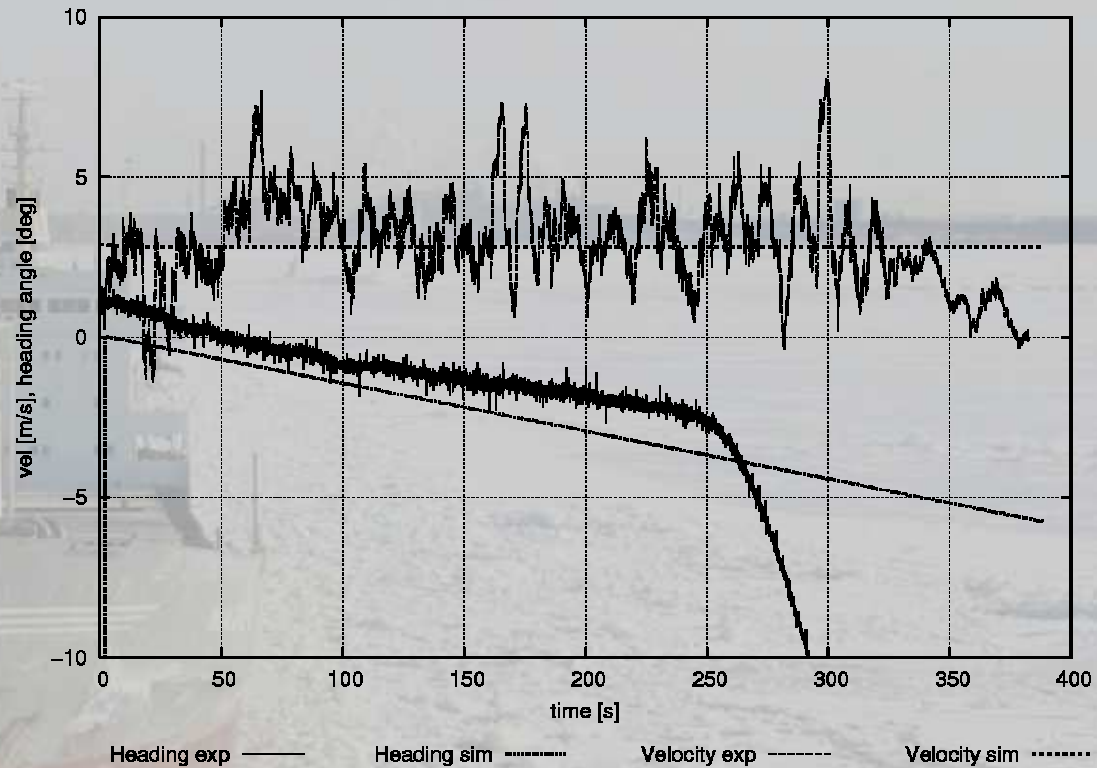


30 deg



Results: Uikku

- Ice model tests
 - Heading angle and velocity



20 deg



Conclusions

- A modular ice force model for the uniform ice conditions has been developed
- Validated using published and experimental results
- The ice breaking process is simulated utilizing the average size of ice cusps in time domain



Future

- Ice channels – data from ice field around the vessel?
- Global forces, measurements of pressure?
- Direct numerical simulation of the ice breaking process?
- Fluid-ice interaction?