Automatic reliability-based control of
Iceberg towing
in open water

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Introduction

Arctic waters are becoming more and more interesting to a world looking for energy resources. According to Riska (2013, p.25), approximately 7.2% of the world oil reserves and 26.5% of the world gas reserves are present in the Arctic. As offshore operations move further north into the Arctic, icebergs pose a serious threat to offshore structures, offshore vessels and operations.

The risk of iceberg impact motivates finding ways to avoid it. All operations with the aim to avoid iceberg impact are collectively called an *Iceberg Management System*. When an iceberg is considered to be a threat, *Iceberg Handling* is required. According to Rudkin (2005, p.16), single vessel towing is the most used method for physical iceberg management. This is mostly done using a synthetic, floating towline.

Scope of work

In this thesis, the objective is to consider automatic reliability-based towing of icebergs. A literature review is performed on icebergs, previous iceberg towing and reliability-based control. Using this, a mathematical model for single-rope iceberg towing is developed. This is then simulated and tested experimentally in the MC Lab (Marine Cybernetics Lab) at NTNU.

Failure modes

When towing an iceberg, three prominent failure modes are:

- **Towline rupture**
  If the tension working on the towline reaches the rupture tension, the towline breaks. This would end the towing attempt. There is also a risk that the ruptured towline snaps back at the towing vessel, endangering both the crew and the vessel.
- **Towline slippage**
  Icebergs are slippery. For some iceberg shapes, the towline could lose its grip and slip over the iceberg. This could be a result of applying tow force, especially when the iceberg pitches/rolls.
- **Iceberg overturning**
  Iceberg overturning is the iceberg pitching/rolling such that it switches which part of the volume that is above water. As iceberg shapes are highly irregular, this could happen by itself, or when affected by a tow force. Overturning can endanger nearby operations, and would also end the tow attempt. If the tow rope does not loosen when the iceberg is overturning, this could cause a dangerous situation for the towing vessel.

By developing an automatic control method for towing of icebergs, these failure modes can potentially be mitigated more successfully than when towing manually.

Tow layout

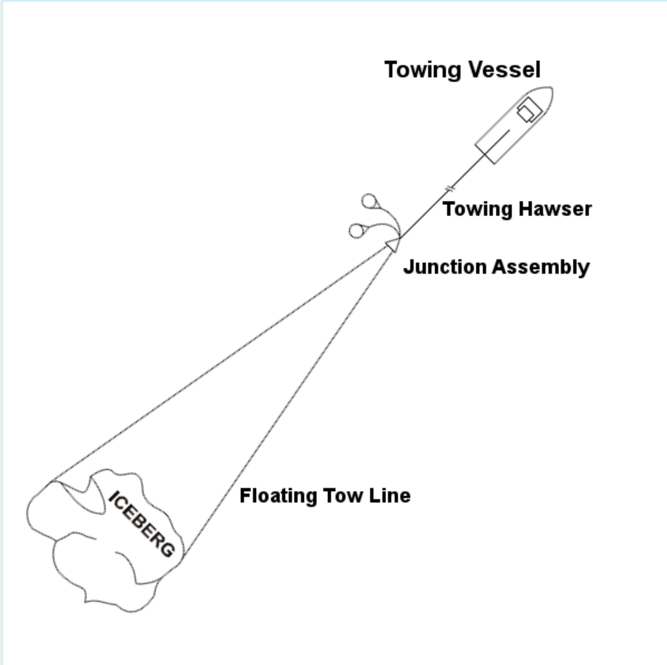

Fig. 1: Tow layout, courtesy of McClintock et al. (2007).

Iceberg LOS guidance

A Line-of-Sight (LOS) iceberg heading (α_{LOS}^{xy}) is calculated. This heading is the desired heading of the iceberg in order to follow a straight-line in the presence of an approximately constant ocean current. It is calculated in Cartesian coordinates, and consists of the geometric angle towards a desired point, and an integral term to compensate for the current-induced offset:

$$\alpha_{LOS}^{xy} = \operatorname{atan2}\left(\Delta y_{LOS} + \sigma y_{int,y}\,, \Delta x_{LOS} + \sigma y_{int,x}\right),$$

where, using Figure 2:

$$\dot{y}_{int} = \frac{\Delta y'}{\left(y' + \sigma y_{int}'\right)^2 + \Delta^2}$$
$$y_{int,x} = y_{int}\cos(\beta)$$
$$y_{int,y} = y_{int}\sin(\beta)$$
$$\Delta y_{LOS} = y_{LOS} - y$$
$$\Delta x_{LOS} = x_{LOS} - x,$$

and σ is an integral gain.

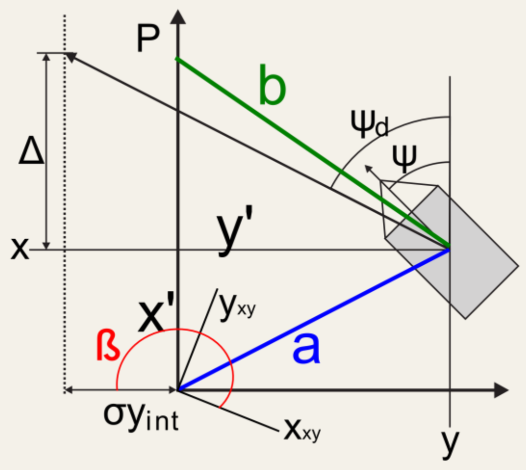

Fig. 2: Notation for transforming between Path-fixed and Cartesian coordinates. Original illustration is found in Børhaug et al. (2008).

Reliability index

In order to be able to monitor and take action based on the towline tension, a reliability index is developed:

$$\delta_T(t) = \frac{T_{b,T} - \left(\bar{T}(t) + \kappa\sigma_T\right)}{\sigma_{b,T}},$$

where $T_{b,T}$ and $\sigma_{b,T}$ are the mean- and variance of the breaking tension of the towline, respectively, and $\bar{T}(t)$ and σ_T are the mean and variance of the tension measurements, respectively. κ is a scaling factor.

In control, an action is performed to reduce forward velocity when $\delta_T(t) \geq \delta_{T,limit}$

Mathematical model

Towing vessel model (3 DOF):

$$\dot{\eta}_s = R(\psi_s)\nu_s$$
$$M_{RB,s}\dot{\nu}_s + M_{A,s}\dot{\nu}_{r,s} + D_s(\nu_{r,s})\nu_{r,s} = \tau_s - K_M R^T(\psi_s)T_{3DOF}$$
$$T_{3DOF} = [X_{TOW}, Y_{TOW}, 0]^T,$$

Where K_M is a matrix transforming the tension to apply moment on the vessel.

Iceberg model (2 DOF):

$$\dot{\eta}_i = \nu_i$$
$$\left(M_{RB,i} + M_{A,i}\right)\dot{\nu}_i + D_i\nu_{r,i} = T_{2DOF}$$
$$T_{2DOF} = [X_{TOW}, Y_{TOW}]^T$$

MC Lab setup

Towing experiments in the MC Lab are performed using the model vessel CS Enterprise I. A 25 liter bottle is filled nearly full with water to emulate an iceberg. Attached on the bottle is a rope with a 1kg mass, in order to keep the iceberg model stable during the experiments.

Fig. 3: CS Enterprise I and the iceberg model during a test in the MC Lab at NTNU.

The experiments are performed using a combination of Simulink and LabView for simulations. Position measurements are provided by the Qualisys camera system, which uses reflecting balls on each model to calculate their positions. To measure towline tension, a force ring is added in the junction between CS Enterprise I and the towline, as seen in Figure 4.

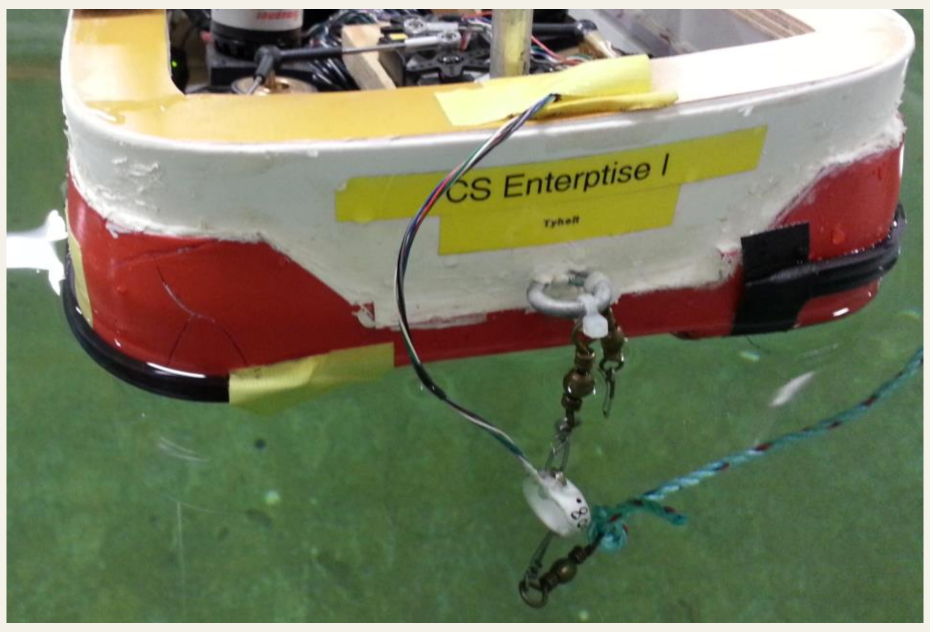

Fig. 4: The connection between the aft of CS Enterprise I, the force ring (white ring), and the towline.

Conclusion

Simulation scenarios and experiments have been performed with 2 targets: (1) To control the reliability-index never to go below a set limit, and (2) to tow the iceberg to and along a straight path in the presence of ocean current. The simulations have proved successful, and experiments in the MC Lab have shown that it is possible to achieve in a practical setting.

References

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