Hull-ice friction: Correlating model hull friction to resistance in ice

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ABSTRACT
Model test results from ship resistance in ice experiments are presented to demonstrate the effect that the kinetic coefficient of friction between the hull and ice (hull-ice friction) has on measured resistance. Experiments are conducted using a 1:30 scale model icebreaker. Results show the hull-ice friction coefficient of a model hull has a significant effect on measured resistance. Total ice resistance is observed to decrease 6% to 8% for every 0.01 decrease in hull-ice friction below the target value of 0.05. For every 0.01 increase in hull-ice friction above the target value, there is a 4% to 5% increase in total ice resistance.

KEY WORDS: Ship resistance in ice, Model tests, Hull-ice friction, Regression analysis

INTRODUCTION
The hull form design of a ship operating in ice will influence how efficiently the ship breaks and clears ice. This in turn will influence the resistance experienced by the ship as it transits through ice. Hull forms that efficiently break and clear ice will experience less resistance, and thus require less power and fuel.

One of the key factors impacting the resistance of a ship in ice is the kinetic coefficient of friction between the ice and the hull (i.e. hull-ice friction). Previous studies have investigated the correlation between hull-ice friction and ship resistance and powering in ice using model test and full scale data (Spencer & Jones, 2001; Lau, 2018). The objective of the current study is to quantify the effect of hull-ice friction on the measured resistance of a ship in level ice at model scale, including individual components of ice resistance, i.e. resistance due to ice breaking, ice clearing, ice buoyancy, and open water. A 1:30 model scale icebreaker is used. Ice resistance tests are repeated with three different hull surfaces, i.e. three different coefficients of hull-ice friction. Model tests follow standard ice resistance test methods with breakdown of the resistance components (ITTC, 2017; Spencer & Jones, 2001).

Each model surface is tested in 41 mm and 61 mm thick model ice sheets. The test program consists of twelve ice sheets in total.

The remainder of the paper details test procedures and experimental results. Section 2 details the methodology of the test program, including hull-ice friction coefficients, a description of the test facilities and model hull design, and the procedure and theory of analysis for ship resistance in ice tests. Section 3 presents the results and discussion, including correlations between hull-ice friction and measured resistance in ice. Section 4 provides conclusions of the study.

METHODOLOGY
Hull-ice Friction Coefficient

The friction coefficient of a model hull is dependent on the surface finish using a specific paint formulation. The current study is separated into three phases with each phase testing a different hull surface (i.e. a different hull-ice friction coefficient). Between each phase the model hull is sanded and resurfaced. The achieved friction coefficient is measured using a standard friction test. Full details of the procedure and analysis of a friction test are described by Pallard et al. (2017), and a brief description is provided here.

The friction test is conducted on a flat 10 inch x 48 inch sheet of 3/4 inch plywood (referred to as the friction board) with the surface coating prepared in exactly the same manner and at the same time as the ship model hull. The friction board is clamped inside a metal tray with the painted surface of the board facing upward. The metal tray is driven by a lead screw actuator powered by a DC servo-motor. The motor controller can be set for constant speed or torque. An ice pan assembly secures a 16 x 16 cm sample of model ice against the painted surface of the friction board as the lead screw actuator drives the friction board underneath the ice. The normal force of the ice against the friction board is increased and decreased by adding and removing weights on top of the ice pan assembly. Knowing the applied normal force and the measured tangential force, the hull-ice friction coefficient can be determined. A diagram of the friction test apparatus is provided in Fig. 1.