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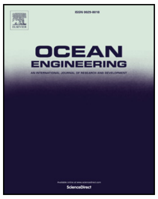

Experimental study on the wake fields of a ship attached with model ice based on stereo particle image velocimetry

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ABSTRACT

In this study, a 76000 DWT 1B ice-class Panamax Bulker attached with model ice was used as a test system for measuring the nominal wake fields based on underwater stereo particle image velocimetry. The results show that: The attached ice block adds a “virtual thickness” to the ship's stern that is equal to the thickness of the ice blocks. The interferes between ice blocks and ship's wake field results in significant expansions of the ship's axial velocity contours compared with the ice-free state, which also leads to the formation of severe velocity blockage zones (with $u/U < 0.1$) within the wake field against the incident flows of the propeller. The attachment of model ice to hull leads to interference in the stern's wake fields, and disrupts the streamlined in the vicinity of the hull. Furthermore, the non-streamlined shape of the model ice generates complex vortices that interfered with the bilge vortices of the bare hull. The level of interference varies according to the size and distribution of the model ice attachments, and the bilge vortices tends to weaken or shift outwards. Then, the test data were corrected based on momentum theory to be more close to the real phenomena.

1. Introduction

Navigation in the severe environment of icy waters is a challenging task, and the additional load caused by the attachment of ice should be taken into consideration. The hull–ice–current, ice–propeller–current, and ice–hull–propeller–current interactions are highly complex, and have a direct impact on ship resistance and wake fields in the propeller's working area in the stern. During ice-breaking navigation, level ice is broken up and slides underneath the ship along the keel, enveloping the hull before sliding into the front of the propeller plane. As the ship sails through pack ice channels and ice floe zones, most of the ice blocks floating near the free surface simply slide along the ship towards the stern, whereas pack ice or ice floes impact on the hull and slide underneath the ship, driven by its wash. Ice blocks at a certain depth beneath the free surface may also slide towards the front of the propeller's working region. Any pack ice that attaches to the front of the propeller's working region as it slides along the keel will severely impact the incident flows at the stern, and subsequently affect flow fields in the vicinity of the propeller. This degrades the propeller's wake and impairs its hydrodynamic performance, and may lead to severe noise, vibration, and cavitation.

The literature on interactions between ice-going ships with flows and ice mainly comprises studies on resistance performance and modes of ice-breaking (Aboulazm and Muggeridge, 1990; Guo et al., 2016a; Jeong and Choi, 2008; Jones, 1989, 2004; Kamarainen, 2007; Kim et al., 2013; Lewis, 1969; Spencer, 1992). In the study of propeller–ice interactions, the effects associated with the relative distance between the ice and propeller are mainly manifested as blockages, proximity effects, cavitation effects, and cutting effects (Shih and Zheng, 1992). Blockages are primarily caused by the presence of ice blocks that interfere with the incident flow of the propeller, leading to a reduction in its velocity coefficient, which in turn increases the propeller's thrust and torque coefficient. The proximity (or boundary) effect is caused by an increase in flow velocity in the gap between the propeller and the ice layer above the propeller. The interaction between ice in the vicinity and the propeller's blades then induces an unsteady load. As for the cavitation effect, the presence of ice blocks increases the local flow velocity on the surface of the propeller's blades, which reduces the local water pressure on the blades; this enhances the likelihood of cavitation, which in turn affects the propeller's thrust and torque. There have been a number of developments in mechanistic studies on the sliding of attached ice into the propeller zone at the stern and the resulting blockage of the propeller, as well as proximity and chiping interactions (Atlar et al., 2003; Kinnunen et al., 2015; Sampson et al., 2007a; Wang, 2007; Wang et al., 2007).

Measurements and analysis of the wake fields of an ice-going ship

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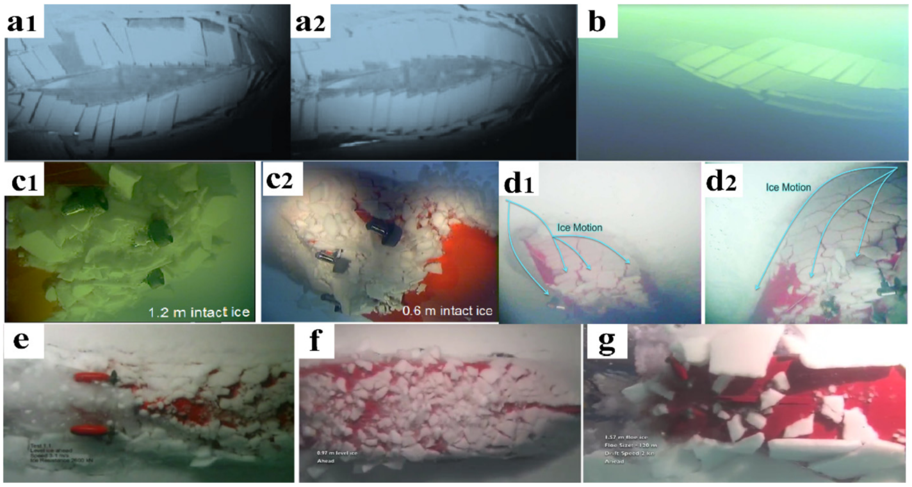

Fig. 1. Images of ice attached to hull and distribution of model ice blocks.

and flow field variations in the vicinity of the propeller during ice–propeller interactions are an important adjunct to analyses on the hull–ice and hull–propeller interactions. Walker et al. (1997) used the LDV method to measure and analyze the wake behind a blockage during propeller–ice interactions. Sampson et al. (2007b) used pitot tubes to measure the wake fields associated with propeller–ice interactions, and found that the blockage from the cutting of ice by the propeller caused changes in the propeller's wake; instabilities in the axial flows of the propeller were also identified. However, few studies have been conducted on the wake field of ice-going ships interacting with ice blocks and PIV techniques have not yet been used to measure the wake fields of ice-going ships. In recent years, the attachment of ice to the keel has frequently been observed in model experiments of ice-going ships. Fig. 1 shows hull-ice interactions (panels a1, a2, b) in the MARIN tank (Werff et al., 2015) where large quantities of artificial model ice attached to the keel. As these experiments used artificial model ice pieces of fixed shape and size, the morphology of the ice attached to the keel was highly regular. In Fig. 1, panels c1, c2 (Metrikin et al., 2015a), d1, and d2 (Metrikin et al., 2015b) show that large quantities of model ice are attached to the keel close to the propeller, and the dimensions, shapes, and distribution densities of the attached ice are different. Fig. 1-e,f,g are photographs taken during experiments performed by Aker Solutions on the navigation of ice-breaking ships in level ice. The ice in panels-e and f is densely distributed, with small pack ice fragments, whereas the ice pictured in g is more scattered, and the individual ice blocks are larger in size.

This study was inspired by the attachment of ice on ships, and the images obtained from previous studies of ice blocks attached to the keel and sides of a ship during navigation through ice floe zones. A 76000 DWT 1B ice-class Panamax Bulker was used as the test subject for SPIV experiments in the ship model tank. A towed SPIV system was used to measure wake fields of the Ship attached with model Ice. In this experiment, model ice was fixed in certain patterns to the hull based on previous experimental findings on the attachment of ice to ship. We chose this scheme out of considerations regarding the suitability of using PIV equipment in icy environments, as towed operations could result in collisions that may damage the equipment, and the movements of ice floes around the ship will interfere with the measurements. To simulate the attachment of ice to a ship during navigation in icy waters, non-frozen model ice was attached to the keel and sides of the hull. Finally, based on measurements and analyses of the nominal flow fields associated with the bare hull and with varying ice attachments (different sizes and distribution densities). We find that the wake flow of attached ice block in fixed or sliding conditions around the hull may be different. In order to get the test value be more close to the real phenomena. The test data were corrected based on the momentum theory. We display the effects of ice attachments on flow fields, and provide a reference for the design of wake-adapted propellers for ice-going ships.

2. Facility and testing model

Tests were carried out in the towing tank of Harbin Engineering University, which is 108 m long, 7 m wide, and 3.5 m deep. The main bridge and sub-bridge were installed on the towing carriage. The maximum speed of the towing carriage is 6.5 m/s and has a global speed control tolerance within 0.3%. The motion capture system and PIV system were attached to the bridge and sub-bridge for data measurement.

The model was manufactured in fiberglass. Geometric details and parameters are shown in Table 1 and Fig. 2. Turbulence stimulators were installed at 5% length between perpendiculars (LPP) away from the forward perpendicular (FP) to minimize the scaling effect induced by the conflict between Froude and Reynolds scaling. To prevent the ship motion interfering with the image acquisition, the four degrees of freedom were locked. The model was painted matte black to minimize laser sheet reflection. Two right-handed Cartesian coordinate systems were used. The origin of the global xyz-coordinate system was placed at the intersection of FP, hull centerline, and baseline, with x along the model centerline to downstream, y to starboard, and z upward. A local Cartesian coordinate system was used with the origin located at the propeller center on the station.

3. SPIV measurements

3.1. SPIV system

The SPIV system used in this study is a customized stereoscopic underwater PIV system for towing tanks (Dantec Dynamics Inc.,

Table 1
Main parameters of the 76000 DWT ice-strengthened bulk carrier.

Principal hull data	Model	Full scale
Scale	45	1
Ice class	1B	1B
Length (m)	5.00	225
Length between perpendiculars (m)	4.82	217
Breadth (m)	0.72	32.25
Depth (m)	0.45	20.10
Designed draft (m)	0.28	12.40
Designed speed (m/s)	1.150	7.716 (15kn)
Propeller radius (R)	75 mm	3.375 m

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