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Study of composite plate traveling in water containing Ice Equivalent Objects

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ABSTRACT

An experimental study was conducted for a composite plate traveling in water containing Ice Equivalent Objects (IEO) in order to investigate the drag force exerted on the composite plate as well as its structural response. This study considered both fluid–structure interaction (FSI) as well as solid body interaction. The plate was partially submerged so as to interact with the IEO. As test parameters, the traveling speed and the orientation angle of the plate were changed, and the coverage density of the IEO was also varied. Both drag force and the strain response of the plate were measured when the plate was in either the steady-state or accelerating transient motion. In addition, a high speed camera was utilized to capture the interaction among the composite plates, IEO, and water flow. Computer modeling and simulation was also conducted for some simple cases in order to better aid understanding. The results showed that with the inclusion of the IEO, not only was there an increase in the total drag forces but also a difference in the resulting deformed shapes of the plates. As a result, strain measurements at different locations did not vary proportionally resulting from the IEO.

1. Introduction

The emergence of more navigable sea lanes throughout the Arctic region is an on-going event due to changes in the extent of Arctic pack ice. This has resulted in heavier maritime traffic looking to capitalize on more efficient shipping routes between the northern Atlantic and Pacific Oceans. With this increase in the number of vessels transiting the Arctic sea routes, it is critical that ships be properly designed and designated to operate in the Arctic region.

There are several instances in which ships can interact with ice while transiting the Polar Regions. When pack ice or fast ice of sufficient thickness is encountered, ice-breakers are required for clearing a safe passage for transit. Such cases will not be addressed herein. On the other hand, when the sea is only partially frozen, ships can and do traverse the drift ice unaided, however at the peril of the surrounding ice pieces that may affect the traveling ships. This is precisely the topic considered in the study and especially with respect to composite structures.

Considerable research has been conducted on the interaction between traditional steel hulled ships and ice [1], while almost no research has been conducted for interaction between composite structures and ice to our best knowledge. Polymer composite structures exhibit much more significant fluid–structure interaction (FSI) than do metallic structures since the material densities of such composites are very comparable to that of water [2–6].

The use of composite materials continues to become more prevalent in naval ship design and construction. In 2006, the U.S. Navy launched an experimental vessel. The 27-m long ship built of epoxy and carbon fiber is the Navy's first ship constructed entirely of composite materials and continues to serve as a ship capability demonstrator.

Another topic of interest covered in this study is the performance of different hull types as they travel thorough the water filled with drift ice. A ship hull is characterized not only by its profile but more importantly by the curvature of its sections as they pass through the design waterline. The three hull types under investigation are (1) the conventional or flared hull shape which has a negative angle of inclination with respect to the intersection of the beam at the design waterline, (2) the tumblehome hull which is found in the destroyer USS Zumwalt DDG-1000 and possesses a positive angle, and (3) a ship hull with nearly vertical sides referred to as wall-sided, commonly found in tankers and cargo vessels, where the hull exhibits no inclination throughout its depth. Three different orientation angles of test plates used in the study to approximate these hull types are illustrated in Fig. 1.

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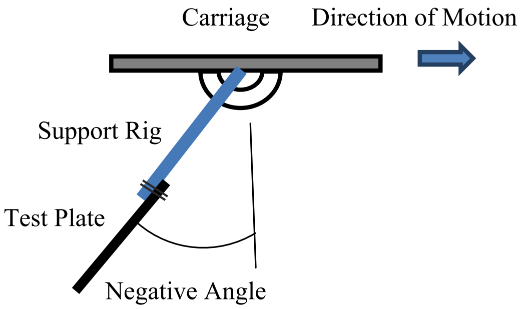
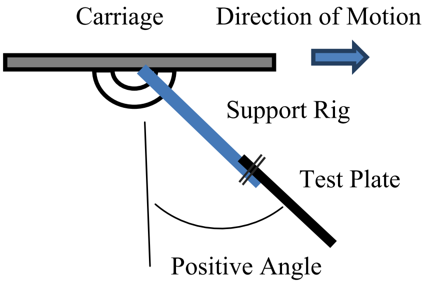
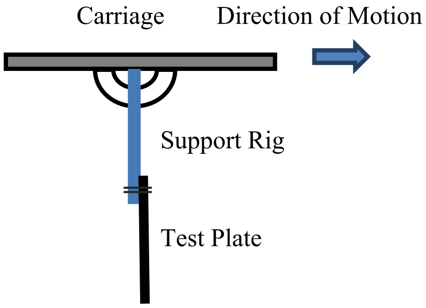


(a) Plate with negative angle



(b) Plate with positive angle



(c) Plate in vertical direction

Fig. 1. Comparison of three different plate orientation angles relative to the direction of motion.

Because composite materials are typically found in the aviation industry, the bulk of research involving the impact resistance of composite materials stems from such applications [7–12]. The aviation industry is primarily concerned with two different types of impacts; high-velocity impacts which result in penetration of the composite and low-velocity impacts resulting in visual damage to the composite structure. Low-velocity impacts can result in matrix cracking, delamination, and fiber fracture.

While the previous research has not considered the FSI effect, other studies [2–5] showed that the FSI effect on composite structures submerged in water reduces the critical impact loads for failure as well as the number of cycles for failure to occur. In addition, FSI may change vibrational mode shapes, which can result in the shift of the critical failure location.

Hydrodynamic loading or drag force on a structure has also been an intensive research topic. However, most of the research studied a rigid structure by neglecting the structural flexibility [13–15]. Of interest, one study compared the drag forces applied to a polymer composite plate and a metallic plate with the same geometry [6]. Both plates were subjected to the same flow and boundary conditions. The results showed that the drag force was greater on the composite plate due to the FSI effect.

The objective of this research was to investigate the response of various hull types as they travel through the water and impact free-floating ice pieces. To this end, an experimental work was conducted inside a tow tank using Ice Equivalent Objects (IEO). Here IEO was used instead of actual ice since the tow tank was not located within a temperature controlled environment. Hence, the ice would have continued to melt and repeatable tow tank experiments would be difficult to complete in a meaningful manner. In addition, some computational fluid dynamic modeling and simulation was undertaken to enhance the understanding of the interaction between the representative test plates and the IEO.

The next section discusses the experiments conducted in this study. Then, two sets of test results are presented and discussed; the first is for the steady-state motion of the composite plate while the second is for the constant acceleration of the same plate. Then finally, conclusions are provided at the end.

2. Experiment

2.1. Experimental set-up

This experiment utilized a tow tank as shown in Fig. 2 with its dimensions. In order to tow an object, a carriage attached to the top rails with ball bearings is suspended above the tank. This allows the carriage to translate along the length of the tow tank. The carriage is pulled using a motor that is speed controlled by adjustment of the input frequency in Hz. The relationship between the input frequency and the carriage velocity is linear as shown in Fig. 3. In order to avoid having the carriage strike the far side of the tow tank, the input speed is limited to10 Hz. Testing at higher speeds would only be possible with a much longer tow tank.

In order to tow a composite plate at a specified angle through the water, an angle selector is located on the underside of the carriage, as is depicted in Fig. 4. When the bottom edge of the composite plate is oriented toward the forward direction of the carriage motion, the angle setting is defined as positive. Otherwise, the angle is referred to as negative. At the zero position, that is when the plate is perpendicular to the primary direction of motion, there is no initial inclination of the plate.

A load cell is positioned on the front edge of the carriage. This load cell measures the force at which the pulley system tows the carriage. The other data obtained from this experiment was the strain experienced by the composite plate. The strain gauges were connected to quarter-inch bridge adapters. These adapters and the load cell were connected to a National Instruments wireless sensor network which is capable of having four channels of experimental data streamed to a laptop using a Wi-Fi connection. The four channels were occupied by the three strain gauges on the plate and the carriage front load sensor. Data acquisition for the experiment was completed via a locally written module using the commercially available Labview software. The sampling rate for this experiment was set to 100 samples per second.

The data for each trial can be divided into three stages, denoted here in Fig. 5 as phases A, B and C. The first is the acceleration stage, termed phase A. In this stage, the force peaks rapidly as the pulley system begins to move the carriage from rest. The next stage, phase B, is the steady state condition. At this point, the data is consistent and oscillates about an average value is observed. The last portion of the data record, phase C, is the deceleration to stop the motion of the carriage.