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Experimental drop test investigation into wetdeck slamming loads on a generic catamaran hullform

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ABSTRACT

A series of drop-test experiments was performed to investigate the hydrodynamic loads experienced by a generic wave-piercer catamaran hullform during water impacts. The experiments, which focus on the characterisation of the unsteady slam loads on an arched wetdeck, were conducted using a Servo-hydraulic Slam Testing System (SSTS) that allows the model to enter the water at a range of constant speeds up to 10 m/s. The systematic and random uncertainties associated with the drop test results are quantified in detail. The relationships between water-entry velocity and both slam force and pressure distributions are presented and discussed with a strong relationship between the slam force peak magnitudes and impact velocity being observed. In addition the three dimensionality of the water flow in these slam impact events is characterised.

1. Introduction

Over the past two decades there has been increased military and commercial interest in lightweight high-speed catamarans, with the aspiration to increase their operational speed and extend their service areas to open oceans. Structural optimisation is a key factor in achieving this, so that deadweight-to-lightship ratios can be maximised whilst ensuring resilience to wave-induced loadings. This relies on the accurate knowledge of the wave loads, which for a high-speed catamaran are generally dominated by wetdeck slamming. A catamaran experiences a wetdeck slam when the wetdeck, the exposed deck area between the two demihulls, impacts with the water surface when experiencing high relative vertical motions.

To avoid the prospect of structural damage occurring, which is a possibility even when these vessels are designed to classification society rules, as stated by Yamamoto et al. (1985), Rothe et al. (2001) and Thomas et al. (2002), it is necessary to accurately predict the wetdeck slam loading. This can be accomplished through full-scale trials, model experiments and/or numerical techniques.

Full-scale measurements can provide valuable data on the loads experienced by vessels in realistic sea conditions and allow the characterisation of the parameters that influence slam severity, as performed by Jacobi et al. (2014). However due to a range of factors such as their expense, an inability to control the test environment and the difficulty of isolating the actual slam loads from complex strain gauge records, it is generally the least common method used for estimating wave slam loads.

There are two model-scale experimental techniques which are generally used to ascertain impact loads: seakeeping tests using a hydroelastic model where the wetdeck may be isolated to measure the slamming force, as presented by Lavroff et al. (2011) and French et al. (2015) and free-fall drop tests where a quasi-two-dimensional (2-d) catamaran section is dropped into a body of water, as studied by Davis and Whelan (2007). Depending on the complexity of the test system, free-fall drop tests can be relatively simple to implement and is generally considered to be a realistic approach to characterise local slamming loads. Though there are two major weaknesses of this methodology: only a two-dimensional (2-d) catamaran section is used for the tests, therefore three-dimensional (3-d) effects are neglected, and the vertical velocity of the test section is not controlled during the impact, so the impact velocity profile may not be relevant to that experienced by vessels in real slamming conditions.

Early examples of model drop tests are found in Chuang (1966) and Ochi and Motter (1971) to predict design pressures of flat-

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bottomed models and mono-hull vessels respectively. Several references to extensive 2-d and 3-d model drop test experiments can be found in the literature presented by Djatmiko (1992), Engle and Lewis (2003), Tveitnes et al. (2008), Kapsenberg (2011), Panciroli et al. (2012), Panciroli et al. (2013), Panciroli (2013), Panciroli et al. (2015), Jalalisendi et al. (2015a) and Jalalisendi et al. (2015b). However there is very limited data for multi-hull vessels. An exception is the study conducted by Whelan (2004), where a series of 2-d free-falling drop tests was conducted to evaluate the behaviour of seven catamaran model hull forms during the water-impact phase. The limitations of assuming that the wetdeck slam event is a 2-d phenomenon were highlighted by the results of a computational study conducted by Davis and Whelan (2007) when the impact loading magnitude of the 2-d simulations was found to be significantly larger than those when the three dimensionality of the section was included.

Computational Fluid Dynamics (CFD) methods have been shown to be an accurate technique for predicting the magnitude of 2-d impact events. For example Swidan et al. (2014) successfully validated the use of CFD against the two-dimensional experimental results of Whelan (2004) and Lewis et al. (2010). However to date no three dimensional water impact tests of catamaran hull forms have been conducted and as such it has not been possible to validate 3-d CFD predictions for these hull forms.

This work was therefore motivated by the lack of non-proprietary data suitable for benchmarking catamaran vessels impacting water in 3-d flow regimes. The controlled-velocity water impact experiments reported here therefore focus on the characterisation of local slamming loads for a generic hull form of a wave-piercer catamaran during water entry. Direct measurements of hydrodynamic forces and pressure distributions are provided on an arched semi-closed wetdeck impacting water for a range of speeds and the three dimensionality of the water flow during the impact events is characterised.

2. Model and experimental setup

2.1. The test system

The water impact experiments were conducted using the Servo-hydraulic Slam Testing System (SSTS). This system was originally developed at Callaghan Innovation, Auckland, New Zealand, and is now located at the Centre of Advanced Composite Materials, University of Auckland. This controlled-speed water impact facility consists of a circular polyethylene water tank measuring 3.5 m in diameter and 2.5 m in height. It has a servo-hydraulic system with a ram actuator supplied by pressure from two pre-charged accumulators. The velocity of the ram is controlled by a computer feedback system and servo-valve, enabling constant or variable-velocity impacts to be achieved up to velocities of 10 m/s. Attached to the end of the ram is a test fixture, which slides vertically on linear bearings. The motions of the fixture are therefore restricted in all degrees of freedom except for vertical motion. More details of the SSTS can be found in Battley and Allen (2012) and Stenius et al. (2013).

Fig. 1 illustrates the main components of the SSTS. The tank was filled to a depth of 1.15 m with fresh water at a temperature of approximately 11 °C. The water depth was considered sufficient as it was comparable with water depths used in previous constant velocity drop-test experiments of similar or larger test specimens, such as those recently presented by Alaoui et al. (2015) and Tveitnes et al. (2008).

A sight window measuring 0.1 m width × 0.4 m height was cut into the side of the tank covered by 3 mm clear perspex in order to allow the high-speed camera's lens to face the model.

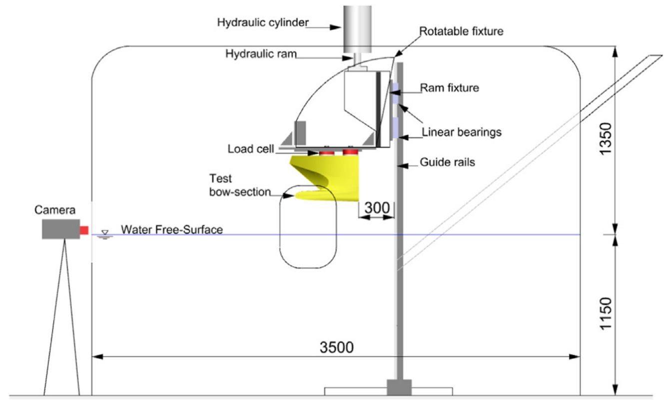

Fig. 1. Profile view of hydraulic test installation (dimensions in mm).

Although the test fixture can be used to set up different angles of trim for the model, from 0° up to 40° in 10° increments, based on results from previous full-scale trials and seakeeping tests for this particular type of vessel (for example those conducted by Jacobi et al. (2012) which showed slamming occurring at small pitch angles, all tests were conducted at zero trim angle.

2.2. The test model

A generic wave-piercer catamaran model was constructed at the Australian Maritime College (AMC), with the lines plan as shown in Fig. 2. The hull form is for a wave-piercer catamaran with a centrebow similar in style to those designed by Revolution Design Pty Ltd and manufactured by Incat Tasmania. The body lines of the generic wave-piercer catamaran hull form are presented (on the right hand side) with a 25 mm longitudinal spacing. On the left hand side of this diagram the transverse sections on which the pressure transducers were mounted are presented. This is to clarify the geometrical variations in the sections where the transducers were located.

The test model has a length (L) of 500 mm, beam (B) of 638 mm, height (H) of 327.6 mm and total mass of 14.8 kg. It was sized to ensure that there would be a gap between the model and the tank wall of double the model's overall beam. This was to minimise boundary condition effects and the possibility of wave reflections.

A three-dimensional Computer Numerically Controlled (CNC) router was used to cut the model out of 15 layers of glass reinforced plastic giving a total shell thickness of 10 mm with minimal surface roughness. This construction technique ensured high accuracy in positioning the pressure transducer locations (±0.1 mm). In addition the model was internally stiffened by a grid of 12 mm thick plywood in both the longitudinal and transverse directions with a maximum spacing of 150 × 100 mm (see

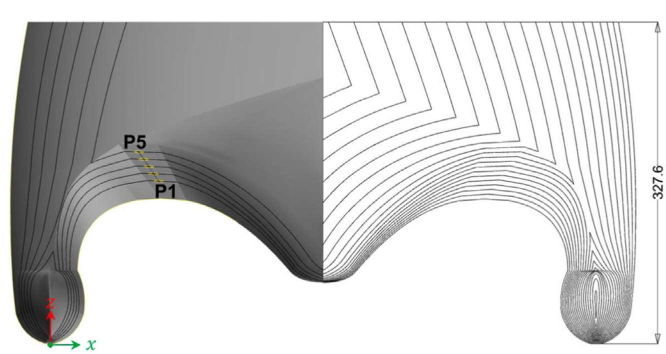

Fig. 2. Body lines of generic catamaran hull form, also showing the locations of the five pressure transducers.