# AN ANALYSIS OF IMPACTS ON MODEL PLANING BOATS

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## ABSTRACT

This study aims to analyze the impacts encountered in boats in a towing tank. It was carried out on a planing boat model at Ata Nutku Model Experiment Laboratory in Istanbul Technical University. Through the developing technology more powerful engines and lighter composite structures led the boat speeds increased. Increase in speed will also increase the pressure, hydrodynamic loads, trim and dead rise angle of the boat. Additionally, apparent waves make the acceleration and shock problem on boats become superficial. These effects make the hydrodynamic acceleration problem very complicated. Also the boat which is operating at high speed over rough sea is exposed to severe repeated shocks. The first part of this study consists of the standards and methods for impact problem. The second part covers an experimental case, the results and includes comparison of the results.

**Key Words:** Model experiments; Impacts; Vibration Dose Value; IMU Device; Hydrodynamic Accelerations.

## 1. Introduction

With increased boat speeds, the acceleration and shocks that are affecting both the passenger, crew and boat become more apparent. The impacts (accelerations, shock and vibrations) on the boat must be minimized to provide a more comfortable and healthy conditions for work and travel. This study aims to analyze the acceleration and shocks encountered in boats with the help of inertial measurement unit, or IMU was carried out a planing hull model was carried out at Ata Nutku Model Basin at Istanbul Technical University to investigate the impact on the boat. Although this study is done in laboratory with a model, it can be done at the open sea by repeating the steps that are described in the study.

A boat that normally used in the open sea is fast and it experiences six degrees of freedom (heave, surge, sway, yaw, roll, and pitch) in rough water. With the developing technology more powerful engines and lighter composite structures were produced, these developments have also led to an increase in boat speeds. Increased speed rises the pressure on boat, weight of the boat, loads on boat, trim, dead rise angle of the boat. Beaufort scale of sea has made the acceleration and shock problem on boat become apparent. These effects make the hydrodynamic acceleration problem very complicated. Also the boat which is operating at high speed over rough sea is exposed to severe repeated impacts. Accelerations on a high speed boat can be subdivided as longitudinal, transverse and vertical accelerations.

- Longitudinal accelerations: These accelerations caused by horizontal increases or reductions in speed, collisions and crash stops.

- Transverse accelerations: This one is mainly about high speed turns. During the high speed turns the centrifugal force causes transverse accelerations.
- Vertical accelerations: Vertical accelerations caused by waves (Nazarov,2012).

There are several work in the literature investigating the accelerations on land vehicles. Nowadays, the dynamic accelerations of water crafts can also be investigated by numerous researchers. Nazarov (2012) published a paper about acceleration problem about high speed crafts (HSC). Allen et al. (2008) studied shock impacts and vibration dose values onboard HSC. Kearns (1994) analyzed mitigation of mechanical shock effects on high speed planing boats. Bass et al. (2004) investigated shock mitigation for the human on HSC. They evaluated an impact injury design rule. Nazarov et al. (2015) tested impact loads on catamaran structure. A catamaran wind farm support vessel has been investigated for assessment of structural loads. Blount et al. (2011) investigated the effects of small craft high speed transits on personnel involved in transits on small HSC. The study includes the measurement of acceleration on the craft. Bowles et al. (2006) done an experimental study of accelerations and motions of a high-speed, double chine craft. They used a rough water model test program for observing the vertical accelerations and motions in relationship to mean running trim angles. Hudson et al. (2010) investigated performance analysis of hard chine planing hulls in waves. They observed rigid body motions and accelerations at three different speeds. Liam (2011) conducted a study about shock mitigating seat design for high speed craft. Shock mitigation in a high speed craft is important for improving operational comfort and health care of crew and passengers. Ullman (2014) investigated slamming standards for high speed boats. The author examined the standards about acceleration, vibration and shock exposure for crew and passengers and suggested some ideas about mitigation of those problems. Dobbins et al. (2008) evaluated HSC motion analysis with the help of Impact Count Index (ICI) method. To achieve this, the authors have used the technique of analyzing impact magnitude and frequency and displaying the results in the form of an Impact Count (IC) histogram. Then they used IC histogram to derive an Impact Count Index (ICI). Olausson (2012) conducted a research about vibration and shock mitigation for high speed craft. The crew of small HSC is exposed to high levels of vibrations and shocks that can imply risks for adverse health effects. There are some studies to standardize the problems of acceleration, shock and vibration which are encountered in the boats as well as the studies and experiments. ISO 2631-1, BS 6841, ISO 2631-5, IMO HSC 2000 Code, European Union Directive 2002/44/EC are some of the typical examples of standardization process. Used standards for measurement and evaluation of human exposure to whole-body vibration are ISO 2631-1, BS 6841, and ISO 2631-5. In addition to these standards, there are European Union Directive 2002/44/EC which is related to level of human exposure to vibration, IMO 2000 HSC Code which is about allowable maximum accelerations on the boat. In addition to those standards, there are other statistical methods for evaluation of human exposure to vibration and shock such as statistical analysis of acceleration data such as Dynamic Response Index (DRI), and Impact Count Index (ICI). Most of these standards and methods are currently being used for assessment of vibration environments on HSC. Some methods provide good concepts for evaluating human exposure to shock, acceleration and vibration.

This study aims to analyze the acceleration and shocks encountered in a boat model with the help of inertial measurement unit, or IMU. In further work, a similar study can be done at open sea with no significant wave for comparing the results of the VDV value, RMS value and IC value with the model results.

## 2. Materials and Methods

In high-speed boat motion, not only accelerations are effective but also temporary vibrations caused by wave impacts and repetitive shocks (Liam C, 2011). About the acceleration and the shock problem Nazarov states that: “A boat’s accelerations may cause seasickness, also known as ‘motion sickness’; giddiness, vomiting, reduced ability to work, fatigue.” (Nazarov,2012). There is no doubt that being exposed to vibration is unhealthy. Vibration can cause various health problems including accelerated aging of spinal disks and cartilage. Those problems contribute to cumulative injuries that can weaken structures and increase the risk of acute injury. However acute injury is most commonly triggered by impacts (Merdivenci et al., 2014).

### 2.1 Impact Studies

To measure the dynamics of a moving craft, it is the best option the measurement device at a position where we expect the smallest transients accelerations. This is typically close to the centre of gravity (CG) of the craft since any rotations around the centre of gravity into centripetal accelerations at any point of rotation, which is usually close to the CG. There are some existing standards that might help boat designers and builders determine limits for “how much” and “what kind of exposure” is safe or dangerous. Some of the existing standards were given in Avcı et al. (2016). In this study, Root Mean Square (RMS) value, Vibration Dose Value(VDV) and Impact Count Index(ICI) is calculated. Vibration Dose Values (VDV) were determined for each axis the VDV was calculated by

$$VDV = \left(\int_0^T a^4(t)dt\right)^{1/4} \tag{1}$$

where *T* is the duration of the exposure and *a* is the frequency weighted acceleration.

The unit of measure of VDV is $ms^{-1.75}$. The weightings used were Wd for the X and Y axes, and *W*b for the Z axis. The combined VDV in all axes was determined by

$$VDV_{xyz} = (VDV_x^4 + VDV_y^4 + VDV_z^4)^{1/4} \tag{2}$$

and the total VDV of entire trials by,

$$VDV_{TOTAL} = (\textstyle\sum_{i=1}^{2} VDV_i^4)^{1/4} \tag{3}$$

where $VDV_i$ are the combined axis VDVs of all trials as given by Eq. (2).

### 2.2 Measuring The Impacts On Planing Boat Model

Inertial Measurement Unit (IMU) is an electronic device that measures a body’s velocity, orientation, and gravitational forces, using a combination of accelerometers and gyroscopes. It works by detecting the current rate of acceleration using one or more accelerometers, and detects changes in rotational attributes like pitch, roll and yaw using one or more gyroscopes. General view of the IMU device XSens Mti-200 used during the experiments is shown in Figure 1. All the experiment steps have been discussed below. For data acquisition an IMU sensor which is XSens Mti-200 and a laptop were used in the experiment. Before the beginning of the experiment, the model which is chosen for the experiment, is placed to the towing car. The attached device which is Xsens-Mti-200, was placed in a position near the centre of gravity of the model. Because, to measure the dynamics of a moving craft, it is the best option the measurement device at a position where we expect the least (smallest) transients accelerations. This is typically close to the centre of gravity (CG) of the craft since any rotations around the centre of gravity into centripetal accelerations at any point of rotation, which is usually close to the CG. In the experiment Xsens Mti-200 was located close to centre of gravity. After the connections were made between the laptop and Xsens Mti-200, about 20 minutes were waited for the waving of the pool to stop. The experiments are made at steady calm water conditions. In calm water state, the accelerations are directly based on the changes in velocity, especially during planing regimes. The experiment was started and records were made for five different speed values which are 2.52 m/s, 3.04 m/s, 3.67 m/s, 3.90 m/s and 4.35 m/s.


**Figure 1:** XSens Mti-200 IMU device

## 3. Results

In this study, experiments and measurements were made in the Ata Nutku Ship Model Testing Laboratory in order to examine the acceleration and the shocks on the boat. The model (See Figure 2) which is selected for the experiment was derived from a high speed planing hull developed for rough water. Main dimensions of the model are given in Table 1 and the model which is used in the experiment also showed in Figure 2. The experiments were conducted in Ata Nutku Ship Model Testing Laboratory at ITU which is 160 m long, 6 m wide, 3.4 m deep towing pool.

**Figure 2:** Planing boat model.

**Table 1**: The main dimensions of the planing boat model.

| Parameter | Abr. | (m) |
|---|---|---|
| Length over all | $L_{OA}$ (m) | 2.429 |
| Waterline Length | $L_{WL}$ (m) | 2.304 |
| Breadth | B (m) | 0.7 |
| Draught (midship) | T (m) | 0.19 |
| Block Coefficient | $C_B$ | 0.438 |
| Displacement | Δ (tonnes) | 0.134 |
| Service Speed | $V_S$ (m/s) | 4.49 |

The main objective of our experiment was to analyze the accelerations and shocks on the model. The experiment (Figure 3) is done at five different speeds which are 2.52 m/s, 3.04 m/s, 3.67 m/s, 3.90 m/s and 4.35 m/s. Five seconds of recordings were taken for each speed value. The axes of the accelerometer were aligned such that the Z axis measured vertical acceleration or heave, the Y axis measured transverse or lateral acceleration and the X axis fore-aft accelerations. The X, Y and Z axes (Figure 3) of the rate gyros were aligned to measure roll, pitch and yaw, respectively.

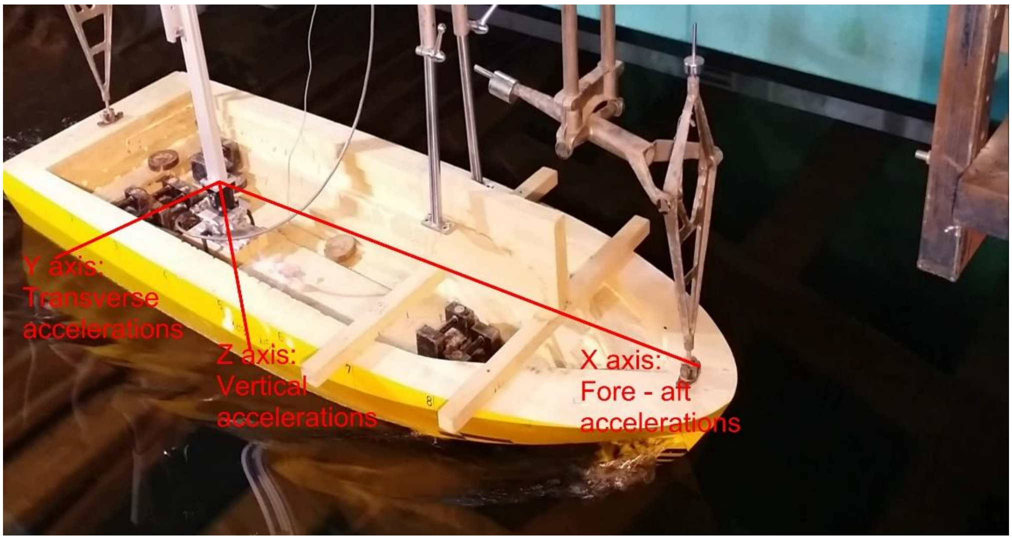


**Figure 3:** X, Y, and Z axes of the IMU sensor

The total VDV of 23.384 $ms^{-1.75}$ at z direction far exceeded the action limit of 15 $ms^{-1.75}$ recommended in BS and the maximum daily dose of 21 $ms^{-1.75}$ permitted by the European Directive. The real time accelerations of the experiment are given in Figures 5 – 8.

**Figure 4**: A photograph during the experiment.

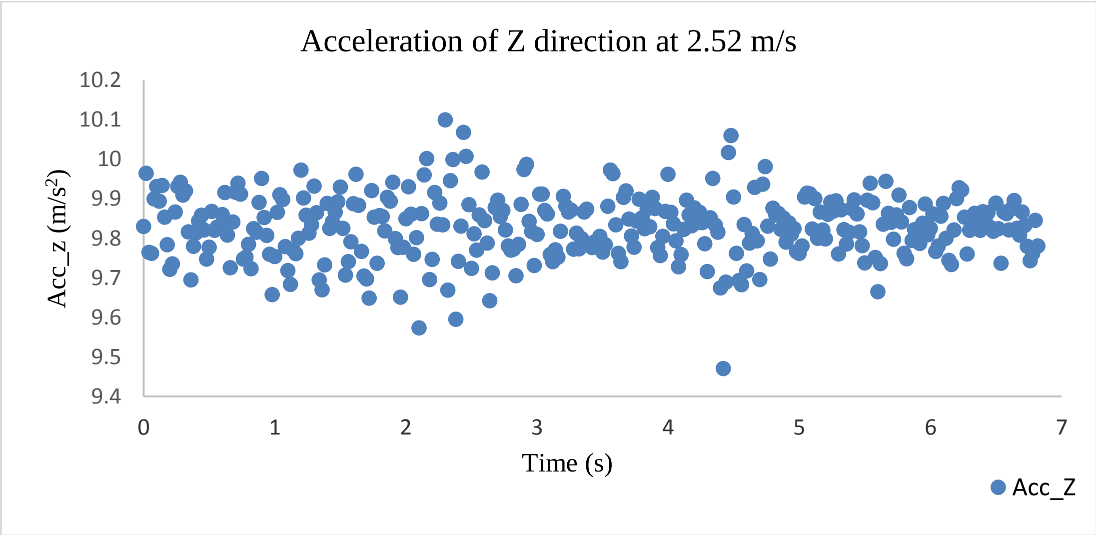


**Figure 5**: The plot of the vertical accelerations at 2.52 m/s.

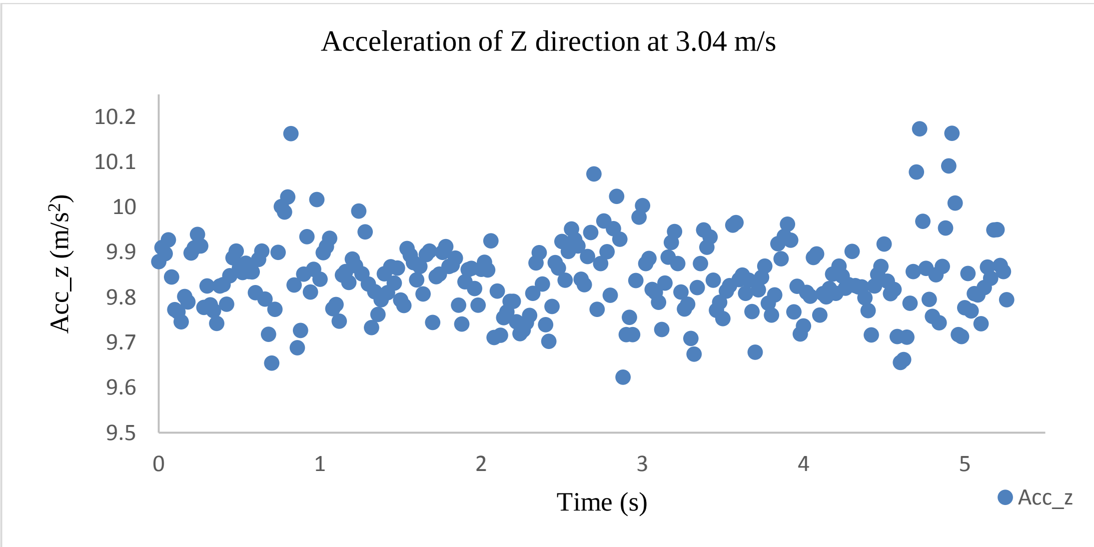


**Figure 6**: The plot of the vertical accelerations at 3.04 m/s.

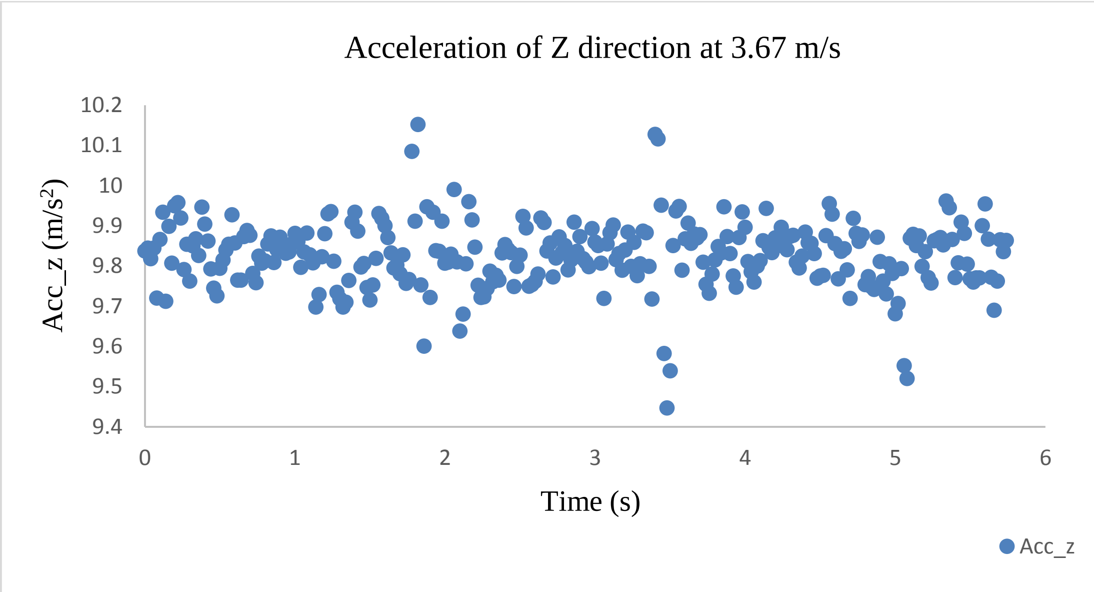


**Figure 7**: The plot of the vertical accelerations at 3.67 m/s.

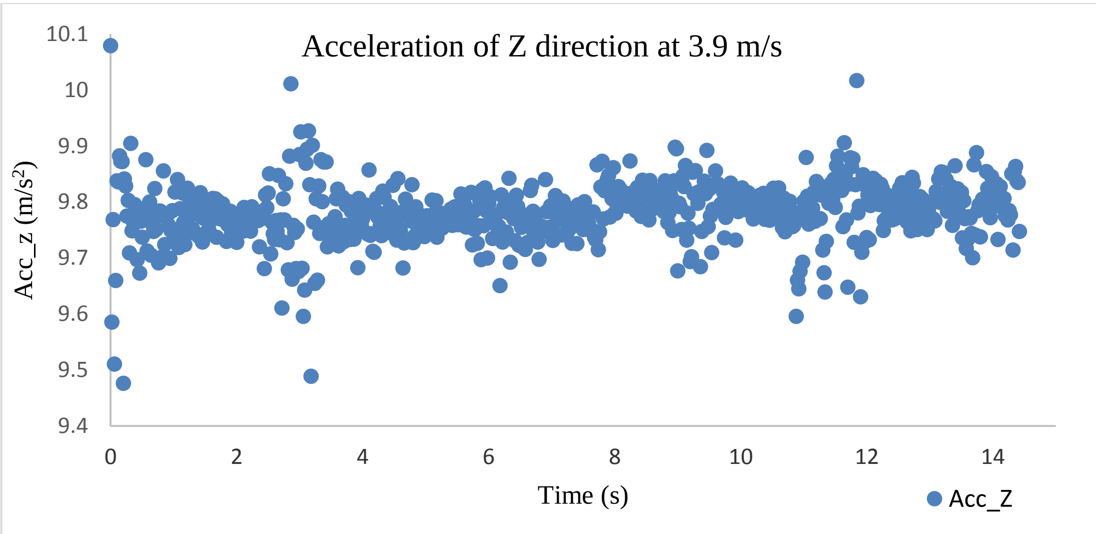


**Figure 8**: The plot of the vertical accelerations at 3.90 m/s.

The VDV values calculated for each speed value. Calculated VDV values are given in Table 2.

**Table 2**: Calculated VDV Values.

| Speeds (m/s) | VDV ($ms^{-1.75}$) |
|---|---|
| 2.52 | 15.886 |
| 3.04 | 14.907 |
| 3.67 | 15.214 |
| 3.90 | 19.060 |
| Total VDV | 23.384 |

Also the Impact Count for the experiment is calculated. The impacts measured on boat are shown for each speed value at Figures 9 – 12.

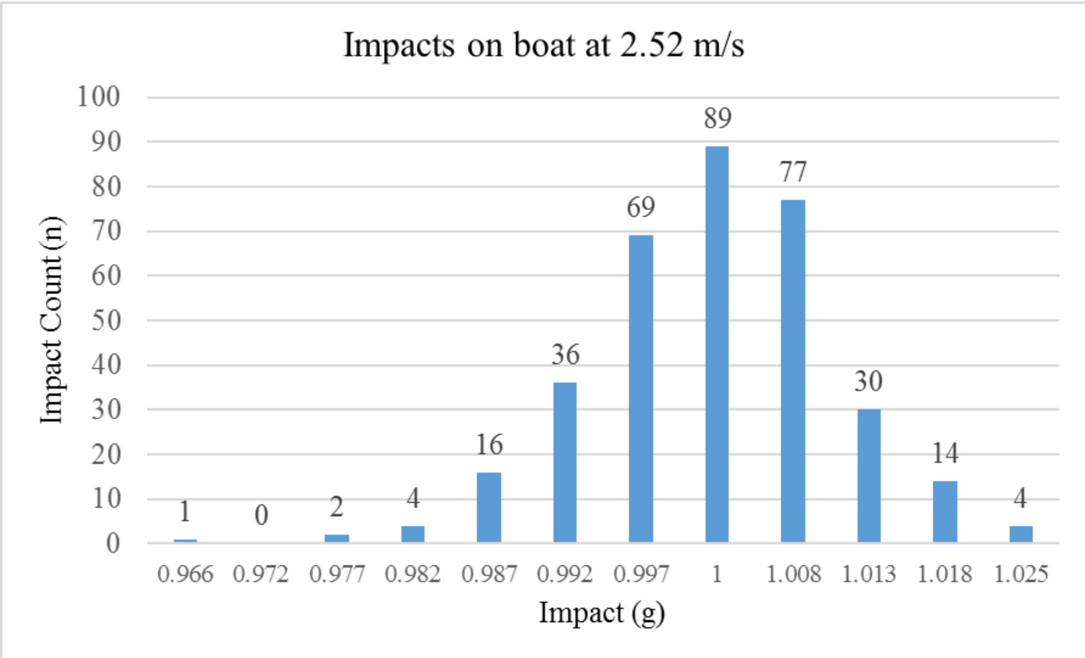


**Figure 9:** Impacts on the model at 2.52 m/s.

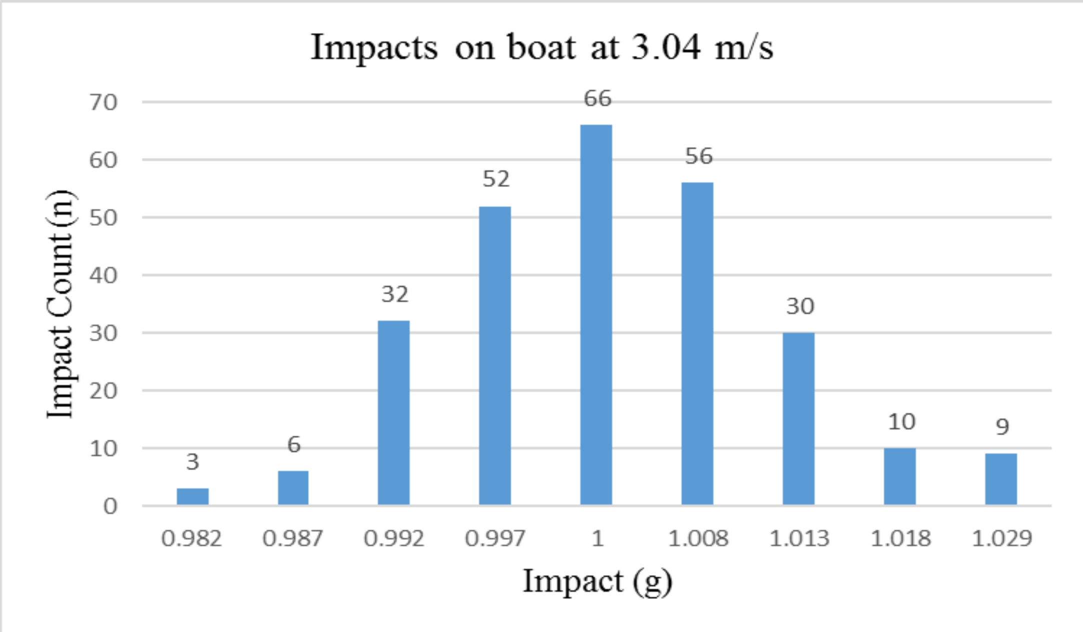


**Figure 10:** Impacts on the model at 3.04 m/s.

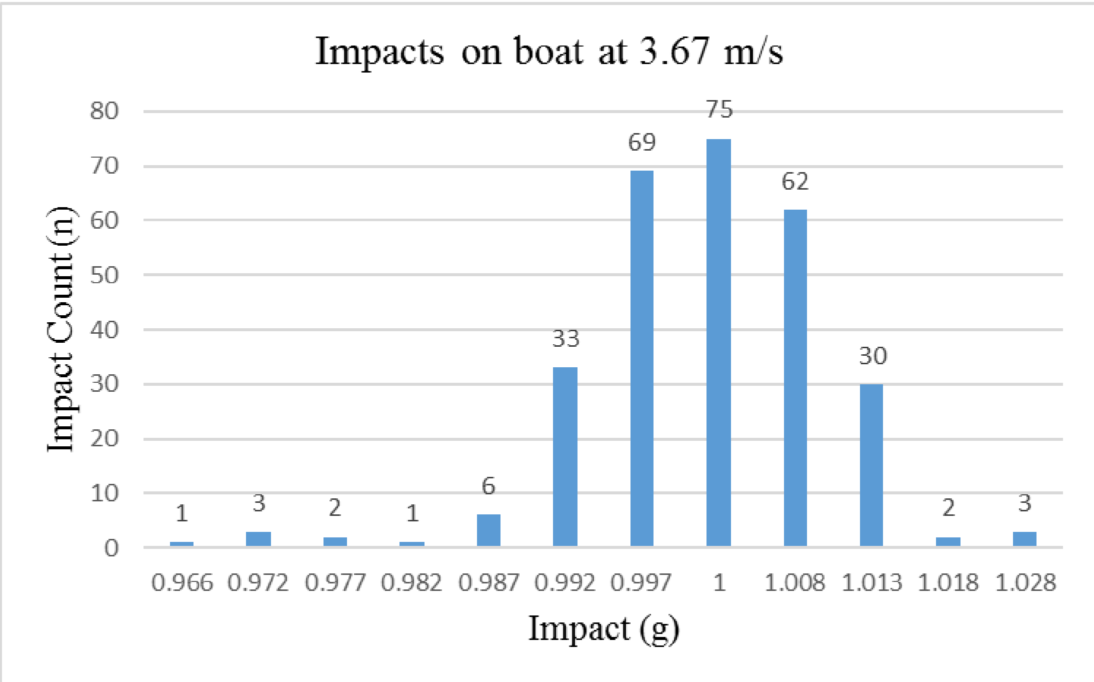


**Figure 11:** Impacts on the model at 3.67 m/s.

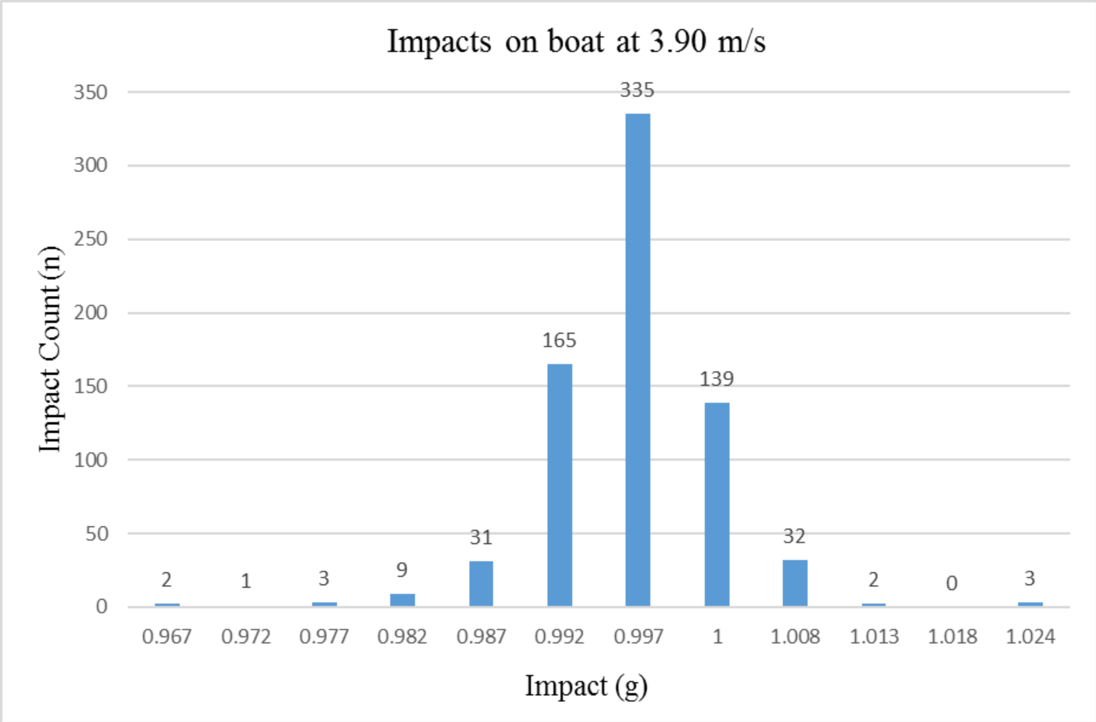


**Figure 12:** Impacts on the model at 3.90 m/s.

## 4. Conclusions

In this paper, the accelerations and shocks on the boat model are examined. For this purpose, experiments were carried out with the help of IMU sensor in a planing boat model with a length of 2.429 m at Ata Nutku Model Experiment Laboratory in ITU. The VDV values are compared with the standards. Although this study was done on the model scale, it can be repeated on the boat in the open sea by using the methods which are described in the paper. Since the study is done with a single boat model, it is not right to generalize about the acceleration and shock problems for all the boat models. In order to have such an idea, serial experiments can be made for different boat models in future works. Also, because of time constraints, the uncertinity analyses could not be performed. It is recommended to accomplish an uncertinity analyses in the future work.

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