Measurement of bottom pressures on planing craft

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Abstract

The knowledge of the pressures on the bottom of vessels sailing at high speeds is essential for the design bottom plate and its scantlings. However, only a few semi-empirical methods based on scarce full or model scale experimental results can be found in the open literature. The shortage of measured data is partly due to the complexity of the measurements. This kind of data is valuable for validating the proposed analytical methods and for providing background to the rules issued by the classification societies. Two methods are reviewed in this paper to measure the pressure distribution on the bottom of fast ships. In the former, membrane-type pressure sensors are fitted on a grid of points on the bottom of the vessel, while in the latter Pitot-tubes are connected to digital pressure transducer through a 48-channel fluid switch wafer. The pros and cons of both methods, which were tested in the Towing Tank of the Laboratory for Ship and Marine Hydrodynamics of the National Technical University of Athens, are presented and discussed.

1 Introduction

The hydrodynamic pressures applied on the bottom of a small craft at planing speeds can locally obtain values in excess of 5 bar even in calm water. Although, the knowledge of these pressures is essential for the design of the bottom structure of high-speed craft, both their prediction by the currently available numerical methods and their measurement by experimental techniques are quite complicated. This is supported by the fact that only a few attempts have been made in the past to estimate or to record them.

However, since the designers of planing craft have to use some formulae to determine the design loads on their bottom, they resort to some analytical or semi-empirical methods based on a few experimental results of full or model scale tests that can be found in the open literature. Thus, experimental data are valuable for validating the analytical methods and for providing background to the rules issued by the classification societies.

As it is well known from the hydrodynamic theory, the maximum pressure on a planing surface (i.e. a surface sliding at an angle of attack on the intersection between water and air) occurs along a line where the flow velocity diminishes. This line, which is called stagnation line, depends mainly on the sailing speed and the geometry of the hull bottom, which is usually characterised by the deadrise angle. Furthermore, the dynamic trim and the displacement of the boat affect the longitudinal location of the stagnation line. A typical stagnation line of a high-speed vessel is depicted in Figure 1.

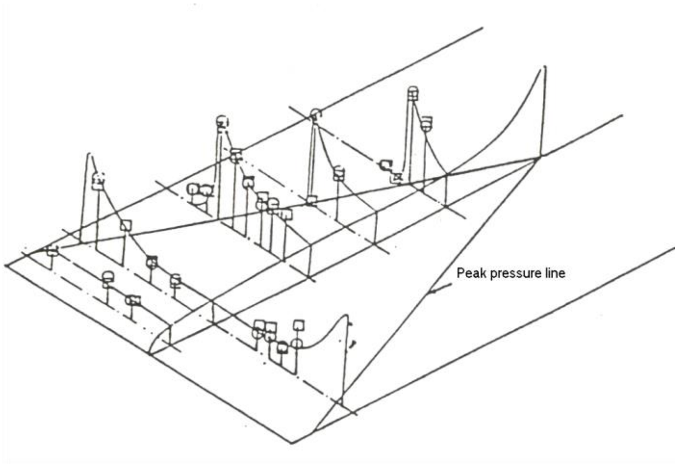

Figure 1: Typical stagnation line of a high-speed craft

Unfortunately, the stagnation (peak pressure) line on a planing hull, where the pressures are significantly higher than those at points ahead or astern of this line, cannot be pre-determined accurately. This shortcoming necessitates the fitting of a dense grid of sensors in order to detect the maximum wave loads acting on the bottom structure. Furthermore, especially in full-scale trials, the measuring range of the sensors to designate the pressure extremes should be broader than that of the sensors fixed on the rest of the bottom surface.

In this paper, following a state-of-the-art review, two experimental techniques for bottom pressure measurements both in model and full scale, are presented. In these techniques, which make use of currently available signal conditioning data acquisition systems, Pitot-tubes and membrane-type pressure sensors are fitted on a grid of points on the bottom of the model or the vessel. The Pitot-tubes are used also for recording the flow field around conventional ships or their models [1]. The pros and cons of the two methods are discussed on the basis of experimental results using a model of a planing hull.

2 State-of-the-art-review

In 1955, Kapryan and Boyld [2] surveyed the pressure distribution on five similar prismatic surfaces, with deadrise angles of 0º, 20º and 40º, with and without horizontal chine flare, for a grid of carrying weights and planing trims. They used a bank of mercury manometers connected to 100 orifices on each model and recorded photographically their indication. Their experimental results were in adequate agreement with the theoretical predictions of that time for the simple forms they tested.

In 1960, Heller and Jasper [3] tested a torpedo boat hull at high speeds in rough weather. Following the analysis of experimental results, they fine-tuned their analytical method to derive a semi-empirical equation for the estimation of the maximum pressure along the ship's length to be incorporated in the design procedure of this kind of vessels. The method is based on the experimental evaluation of the vertical accelerations onboard. Silvia et al. [4] proposed a variant of Heller and Jasper method based on Spaulding's approach [5]. The latter applied a transverse distribution factor to the plating and the longitudinal stiffeners and a longitudinal factor to the transverse ones.

Spencer [6] calculated the maximum impact pressures for a series of deep-Vee, planing crew boats. He used Savitsky's method [7] to estimate the running trim, Fridsma's [8] experimental data to predict the impact accelerations, and the equation proposed by Heller and Jasper [3] to derive the pressures. By applying regression analysis on 112 hull forms with a constant deadrise angle of the order of 16º, they concluded to a simple expression for the estimation of the maximum bottom pressures.

Allen and Jones [9] carried out full-scale measurements on two planing hulls and one small surface effect ship (SES) using strain and pressure gauges on their bottoms. Afterwards, they combined the experimental results with some theoretical background to compose a simplified method, which predicts the structural design-limit impact pressures for a number of high-performance marine vehicles. The authors provided a numerical example of implementation of their method.

Codega and Lewis [10] conducted full-scale measurements on a high-speed surf rescue boat (SRB) of the US Coast Guard, both in calm water and in waves. By using a set of 13 pressure transducers they recorded the pressure values at a grid of points on the bottom of the boat and the derived approximately the peak pressure lines at each speed.

Classifications societies make use of semi-empirical methods to predict the maximum impact pressure on the bottom of advanced marine vehicles. The majority of their rules are based on the approach of Heller and Jasper [3] using some slightly modified variants of that method. To be more specific, they correlate the maximum bottom pressure to the impact vertical accelerations on the center of gravity of the vessel, which can ether be measured or estimated using i.e. the equations of Savitsky and Brown [11]. In addition, they propose a “pressure reduction factor” to correlate the average pressure on a typical design area to that on the actual panel area. A comparative presentation of the respective rules can be found in Koelbel [12].

3 Description of experimental procedures

In this section the two procedures used in the tests are thoroughly described. These methods require a very scrupulous calibration procedure to be performed both at the beginning and at the end of the measurements.

3.1 Pitot-tubes

The use of Pitot-tubes to measure surface pressure constitutes a quite common practice. The tubes have to be fitted perfectly perpendicularly to the punctured bottom surface of the hull, so that the recorded pressure is equal to the pressure at their open end point. Flexible PVC clear tubes of 1mm inner diameter are used to transfer the pressure from the hull surface to the transducer. The extremely low diameter of the tubing system was important for the measurements in order to minimize the sensitive area on which pressure is recorded. In our tests the tubes were connected to a digital differential pressure transducer with a measuring rate of 1 psi, through a 48-channel fluid switch wafer. The analog output signal of the transducer was amplified via a signal conditioner and it was converted to a digital format using an A/D converter board operating at a sampling rate of 25 Hz.

The accuracy of the aforementioned recording technique depends on the proper transaction of the vaporization of each tube and the calibration with respect to the atmospheric pressure, carried out via a water column.

3.2 Membrane-type pressure sensors

The membrane type pressure sensor used in our tests consists of a 6-mm disk with a strain gauge fixed on its backside. The disk axis has to be vertical to the external surface of the hull in order to measure the pressure load on each point. The strain gauge is integrated with a signal conditioner circuitry and an amplification unit.

This kind of sensors is more appropriate for recording the relatively higher pressures apparent in the vicinity of the stagnation line. However, the area of their disk is too large for measuring peak pressures at small models where the high-pressure area consists of two narrow strips. Thus, their indications correspond to the average pressure on the sensitive disk membrane.

3.3 Experimental set up

As a first attempt to experimentally validate the above techniques a wooden model of a double chine wide transom planing craft, was tested in the Towing Tank of the Laboratory for Ship and marine Hydrodynamics (LSMH). Six membrane-type strain gauge pressure sensors and three Pitot-tubes were fitted on the model, as is depicted in Figure 2. The model was towed at speeds up to 5 m/sec, corresponding to Froude numbers up to 1.0, in calm water and in regular waves.

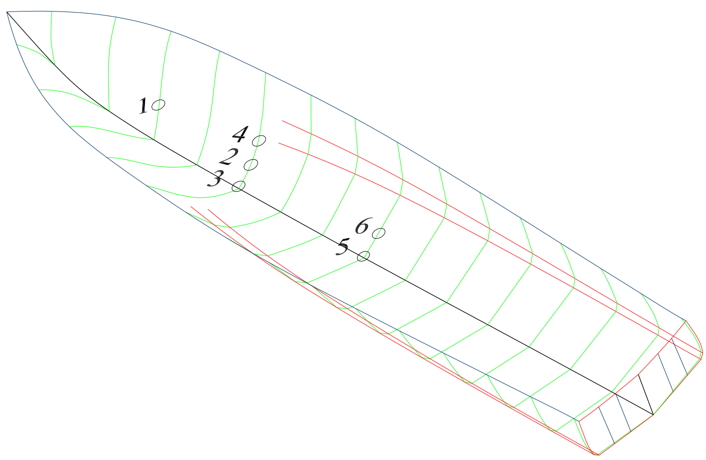

Figure 2: The positions of membrane type sensors

As it is evident in the above figure, three longitudinal positions forward of the vessel transom, at distances 50%, 65% and 80% of the model waterline length were selected. In an attempt to record the maximum wave loads, two, three and one point were used at the aforementioned locations respectively. Points no. 6, 2 and 1 are at an offset of B/4 to the port of centreline, where B is the maximum breadth of the model. Point 4 is on the lower chine of the model. The Pitot-tubes no. 1 and 2 were fixed at the respective starboard points to the equi-numbered membrane type sensors. Pitot tube no. 3 was fitted just in front of membrane sensor no. 3.

4 Experimental results

In Figures 3 and 4 the time records of the membrane-type sensors and the Pitot-tubes, in calm water and at the highest towing speed (5 m/sec) are plotted. The respective average values are given in Table 1. Even at that speed, which corresponds to a quite high speed at full scale (i.e. about 50 knots for a 55-metre ship), the measured pressures are of small magnitude. This is attributed to the fact that the speed of the model, as scaled by Froude's similitude law, has a quite low value. In general, Pitot-tubes give more stable indications than the membrane type sensors.

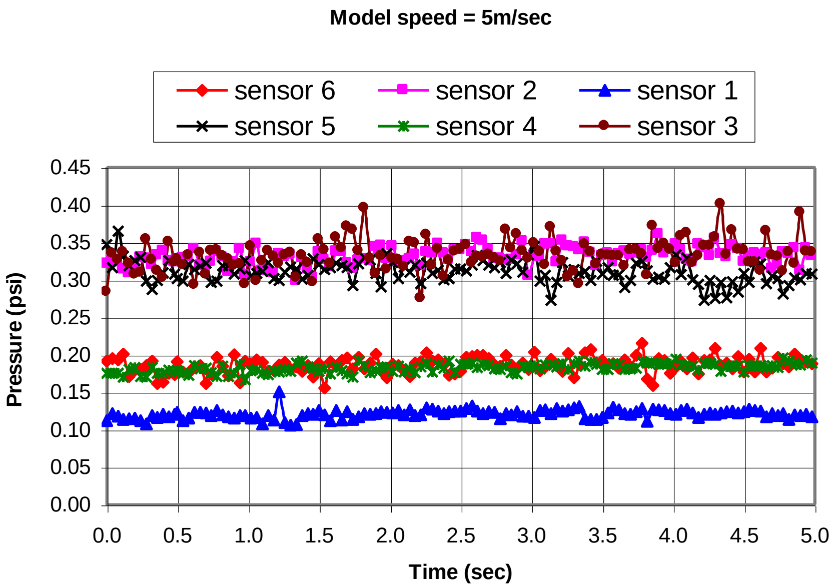

Figure 3: Time records of the pressures on the membrane type sensors.

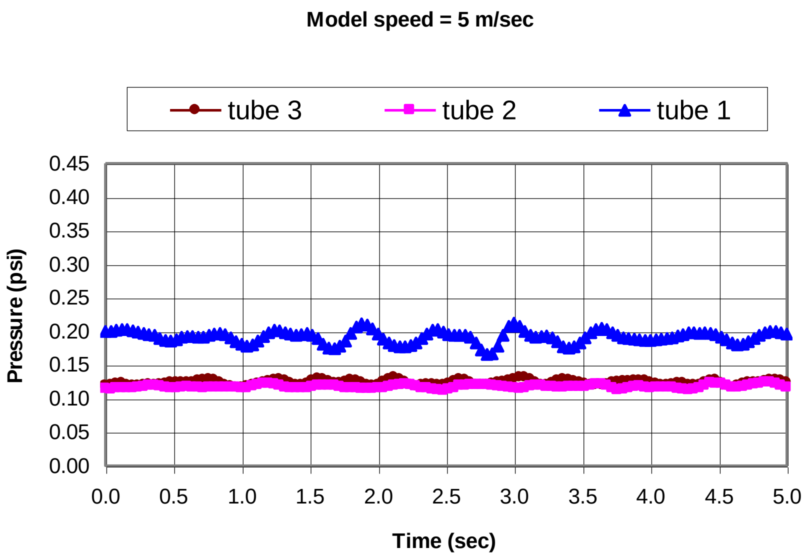

Figure 4: Time records of the pressures on Pitot-tubes

On the other hand, the membrane-type sensors at points 2 and 3 deviate considerably from the respective Pitot-tubes, while the indications of the two procedures points no. 1 are more consistent. Since these measurements have been carried out repeatedly, with satisfactory repeatability, the only explanation to the above discrepancies can be attributed to the significantly larger sensitive area of the membrane disk, which seems to be quite spacious compared to the inhomogeneous flow field. Especially, the membrane type sensors are too large to measure at points along the keel line.

Table 1. Average pressure values (psi) in calm water for the towing speed 5/sec

Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6	Tube 1	Tube 2	Tube 3
0.120	0.308	0.330	0.181	0.328	0.185	0.192	0.117	0.123

In order to demonstrate the applicability of the technique using the membrane-type sensors, time histories in sine waves have been recorded. Pitot-tubes could not be used in this case, because the bottom of the model emerges periodically and air bubbles enter the tubing system. In Figure 5 the experimental results for a wave period of 0.60 Hz are depicted. In order to distinguish the slamming impact pressures, the sampling rate was double to that in the calm water case, Impact pressures of the order of 0.50 psi were recorded in this case.

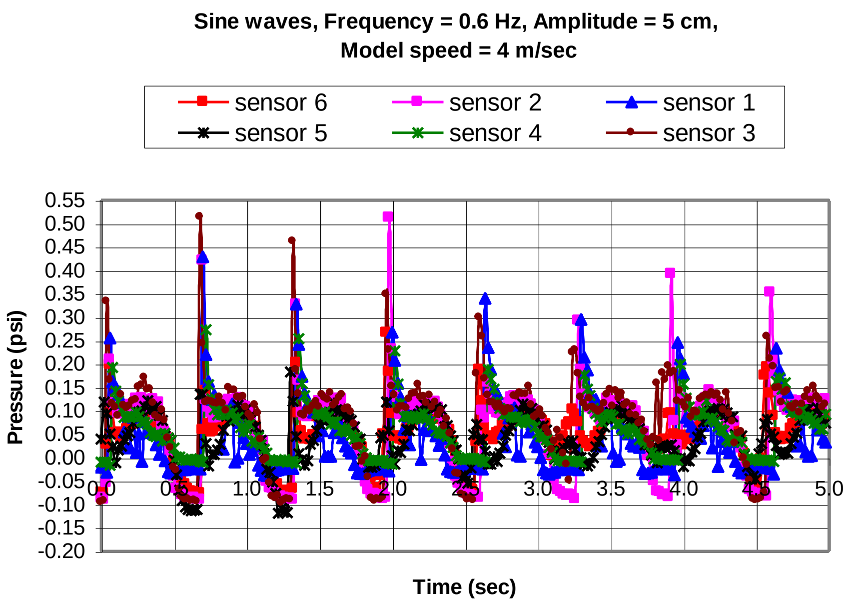

Figure 5: Pressure records for the model towed in sine waves.

5 Discussion and conclusions

On the way to the preparation of full–scale measurements on board of fast inflatable vessels in calm water and in waves, a series of tests have been carried out with a model of double-chine planing craft. Having in mind that the instantaneous pressure loads at a quite extensive grid of points has to be recorded, the idea to use a combination of Pitot-tubes and membrane type sensors was implemented.

Since the former possess a wider measuring range they would be used in the vicinity of stagnation line. The latter would be used in the rest of the measuring positions, because they necessitate the drilling of significantly smaller orifices (about 2 mm compared to 8 mm for the membrane type sensors). Furthermore, a great number of Pitot-tubes (up to 48) can be controlled via a single fluid switch wafer. This instrument permits the sequential reading of successive Pitot-tubes driving their pressures to a single digital pressure transducer connected to it. However, they are not operable at positions where air inflow is suspected.

On the other hand, membrane-type pressure sensors are more robust and amenable to high pressure-load fluctuations. They are easily calibrated but their use for a thorough pressure field investigation on a vessel results in a destructive survey. Finally, these sensors are quite expensive to be used massively.

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