Remedial Solutions to Control Excessive Propeller Induced Hull Vibrations on a Landing Craft

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Synopsis

Although landing craft are not sophisticated vessels, their functional/operational requirements often result in a hull shape which may encounter unusual hydrodynamic phenomena, requiring remedial attention. One such instance is discussed in this paper, which presents hull form solutions adopted to address excessive vibration experienced on-board an enhanced landing craft operating in the Arabian Gulf region. Through Computational Fluid Dynamics (CFD) simulations, the sources of excessive vibration experienced by this vessel were identified. The sources included the current bow design, which promoted aeration; an extensive flat bottom, which channelled the air to a shallow buttock-flow stern region; angled pram type stern fitted with blunt-ended appendages generated a non-uniform flow that was too severe for the existing propeller-hull clearances. The combination of these unfavourable flow conditions with the cavitating propellers resulted in undesirable Propeller-Hull Vortex Cavitation (PHVC) which manifested itself with excessive aft end vibrations and noise.

To remedy the situation and to control the excessive vibrations, further CFD simulations guided the necessary hull form modifications. The identified countermeasures included anti-Propeller Hull Vortex (PHV) plates and streamlining of stern appendages. Subsequent sea trials showed horizontal vibration levels were reduced by 85%, which significantly improved the conditions on-board.

This paper presents a technical summary of the above countermeasures, their implementations on the vessel, which included full-scale trials to measure the speed-power performance, hull vibrations and cavitation observations using a borescope system, and discussions of the results of these countermeasures. The paper concludes with an outline proposal for further design study, which could reduce on-board vibrations even further as well as providing other operational benefits regarding propulsive efficiency and manoeuvrability using the recently developed “Gate Rudder System ®” as a novel Energy Saving Device (ESD).

Keywords: Propulsion; Propeller Hull Vortex; Cavitation induced hull vibration; CFD; Borescope; Gate Rudder

1. Introduction

The United Arab Emirates’ (UAE) man-made islands are famous around the world and are an example of the time and effort that has been put into its growth. Several island projects are currently underway particularly in Abu Dhabi, the second most populated city of UAE. Such artificial islands require logistic support, heavy construction equipment, vehicles and materials for the development of the infrastructure on such newly reclaimed land. To provide such support landing craft, which are classically used for a military role, are vital to the building phases of these islands and are thus one of the major ship types built in the area.

Generally, landing craft are small to medium size seagoing vessels, having a flat-bottom, an integrated ramp door, rather than a normal bow. Such design features can adversely affect the underwater hull flow (flow separation and air entrapment) leading to masking speed log sensors and causing undesirable flow into the propeller. Furthermore, the often simple buttock-flow (i.e. pram) stern-forms, have a high stern rise to provide adequate propeller-hull clearances. Twin propeller shaft configurations can incorporate A-brackets, shaft fairings, rope guards, grounding protection and rudder supporting structures.

All of these aspects can impose highly non-uniform propeller inflow conditions which may challenge the propeller designer to avoid highly dynamic and unstable cavitation phenomenon. Cavitation may lead to hull vibration due to propeller induced pressure pulses, onboard and underwater radiated noise, blade and rudder erosion and loss of thrust (Kuiper, 2001). The onboard noise and vibration can be uncomfortable for crew and passengers and can compromise structural integrity of the vessel (IMO, 2012; Plunt, 1980). The dominant source of excessive onboard noise and vibration is mainly due to highly dynamic cavitation volumes (blade sheet and tip vortex) emanating from the propeller in the proximity of the hull (Plunt, 1980; Pylkkanen, 2002)

In addition to sheet and tip vortex cavitation, which are being the most common sources of propeller-excited vibration, the literature cites the Propeller Hull Vortex Cavitation (PHVC) as a notorious phenomenon in cases of excessive hull vibration (Nishimaya, 1986; Sato, 1986). PHVC is characterised by strong intermittent vibration and is known to create high vibrations at Blade Passage Frequencies (BPF) with low order multiples. PHVC generally occurs when a propeller operates under a highly loaded condition and reveals itself as an unsteady ″standing″ line vortex between the propeller and nearby hull surface (Huse, 1972, 1971). This ″standing″ vortex can inflate normal sheet cavitation as each blade passes through near the 12 o′clock position. To a certain extent, the vibration can also be sensitive to small helm angles, which can be a characteristic to be associated with PHVC, but not exclusively so. Typical design features that can lead to PHVC may include: unfavourable after body form with poorly designed appendages; small propeller tip and hull clearances; inclined buttock flow; and cavitating propellers in highly loaded condition.

Another hydrodynamic phenomenon known to give rise to excessive onboard vibration is propeller ventilation. Such air suction into the propeller generally occurs when the propeller tips are in proximity to the water surface. However, there are also cases where air suction may occur. For example, vessels using an air lubrication system for frictional drag reduction purposes as well as a vessel with a shallow draft, flat bottom and buttock flow type fore and aft ends. For a typical landing craft, of course, the latter design features are the likely scenarios that may further contribute to the vibration problems (Takekuma, 1980).

Based on the extensive full-scale knowledge of the authors, the above mentioned two phenomena were experienced on a class of landing craft recently built and suspected to be the most probable sources of the excessive vibration experienced by these vessels. To control the excessive vibrations, and hence address the associated problems, established remedial solutions were devised for implementation in a short period before the delivery of the vessels. This paper presents the details of these measures applied on these vessels which involved the use of CFD analysis and full-scale observations of the propeller inflow and cavitation by using borescope technique. Apart from the design and full-scale applications of these remedial solutions, the paper also proposes an improved new aft end design for such craft including a novel combination of the propeller-rudder arrangement for further performance improvement.

2. Landing Craft

The test vessel is a generic landing craft of a type, commonly utilised throughout the Gulf Cooperation Council (GCC) region. A combination of size and top speed meant that the test vessel was required to operate in challenging flow conditions for its simple hull form. Figure 1 shows a Computational Fluid Dynamics (CFD) simulation of the surface wave patterns of the test vessel.

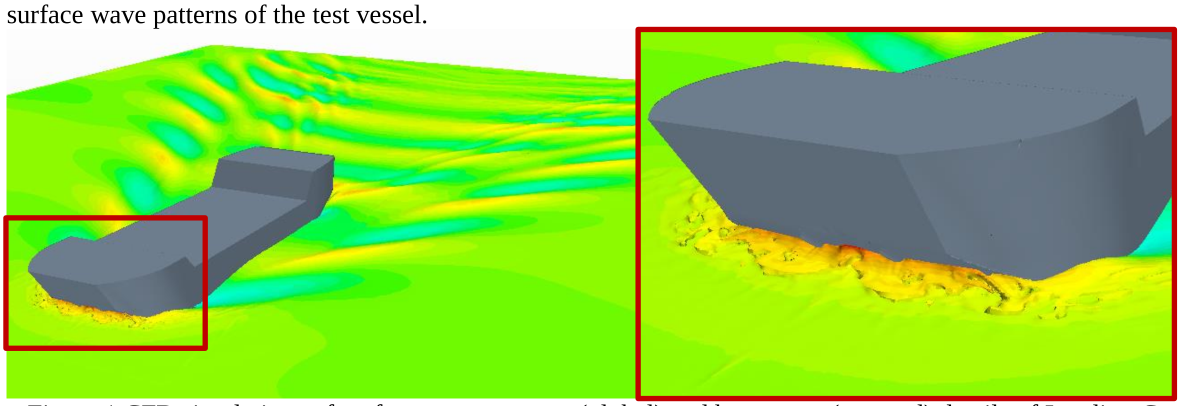

Figure 1 CFD simulations of surface wave patterns (global) and bow wave (zoomed) details of Landing Craft

Figure 2 shows a model of the stern region. Several appendages, such as A-brackets, rope guards and stern tube housing, are shown with blunt endings which promote vortex shedding and may cause unsteady cavitation phenomenon at the propeller. The lower horizontal bar was also used as a sole-piece to support the rudder as well as to guard the propellers during beaching or grounding. While these appendages are designed based on the principle of easy to manufacture and hence low cost, in some cases, they can compromise the hydrodynamic performance of these craft requiring remedial solutions as experienced in this study.

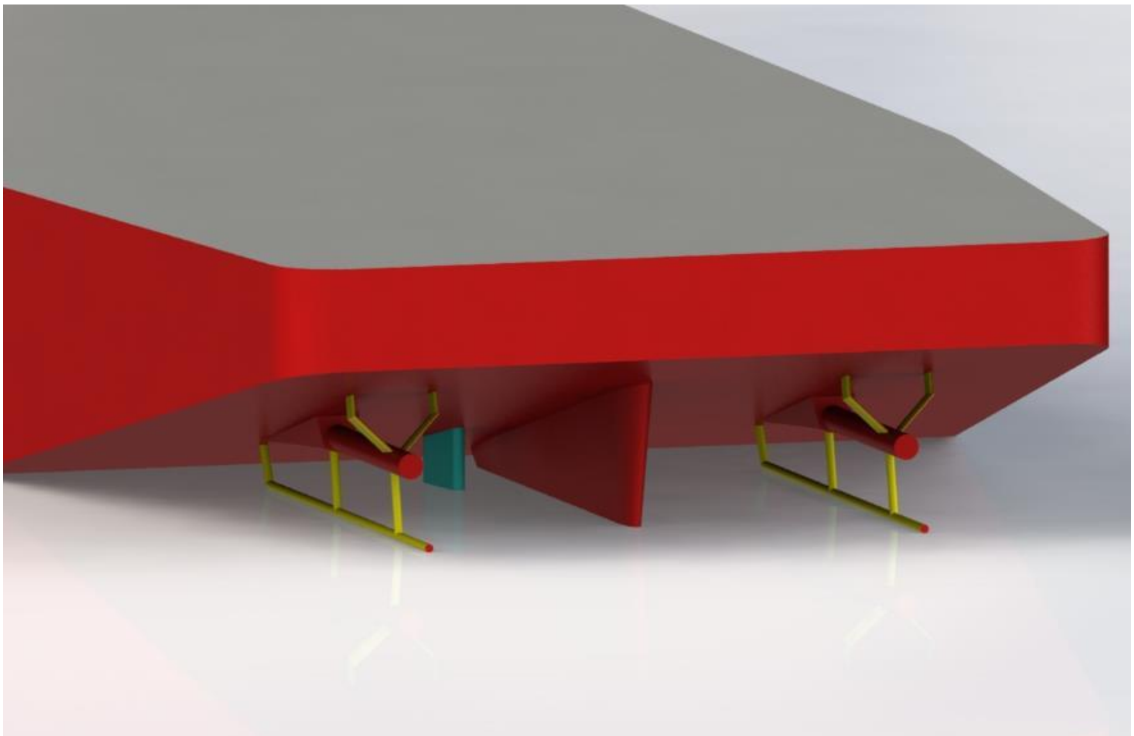

Figure 2: Stern part of the landing craft

3. Remedial Solutions

Noise and vibration measurements during preliminary full-scale trials of the test vessel indicated values both more than the threshold in ABS Guidelines for Crew Habitability on Ships (ABS, 2016) and where structural damage could occur. As the hull form could not be altered at this stage, suitable retrofit countermeasures were investigated in an attempt to reduce vibration levels to within those of the classification guidelines. In addition to beneficial hydrodynamic properties, a key criterion for the retrofit measures was to avoid disturbance to the shaft line by minimising welding; hence in-situ composite construction was maximised.

Because of these limitations, some immediate countermeasures were adopted. The proposed remedial solutions were designed and fitted including:

- Anti-PHV plates
- Shaft fairings
- A-Bracket fairings
- Rope guard fairings
- Anode re-locations

Figures 3 and 4 show these solutions, modelled using Computer Aided Design (CAD) software and communicated to the ADSB for implementation while the vessel was in dry-dock. Anti-PHV plates were introduced as proposed by (Kooij & Berg, 1974) and presented by e.g. (Carlton, 2012). The stern tube fairing was modified to incorporate a flow-kindly fairing providing a smoother transition in contrast to the original bluff edges. The trailing edges of the A-brackets were also found to be disruptive to the flow and were updated with extensions where they are attached to the hull. Similarly, the anodes on the A-brackets were removed to locations on the hull where they could not disturb the flow into the propeller. The cylindrical shaping of the rope guards was considered conducive to Karman type vortex shedding. Hence fairing extensions were added in their slipstream to mitigate vortex production as much as possible.

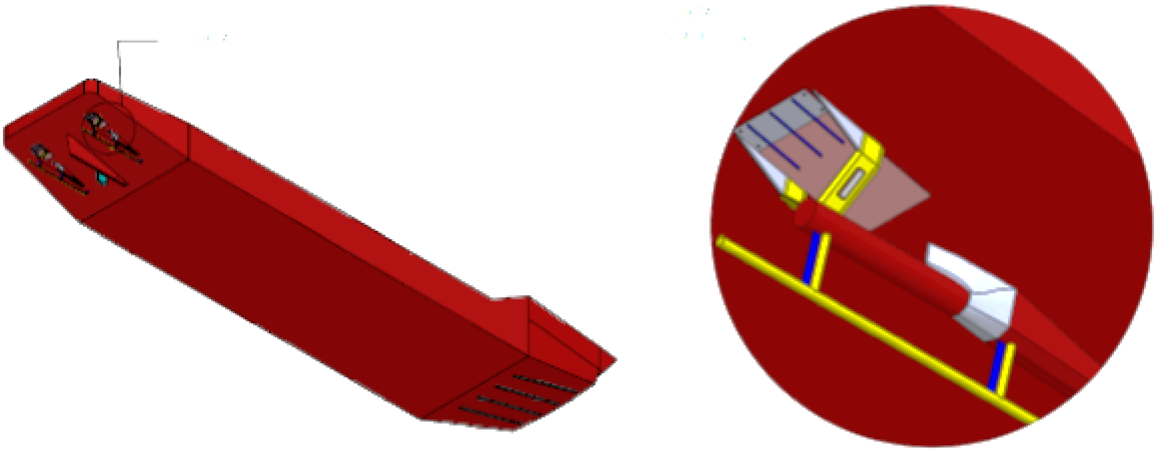

Figure 3: Global and zoomed in view of the proposed retrofitting to improve the flow to the propeller

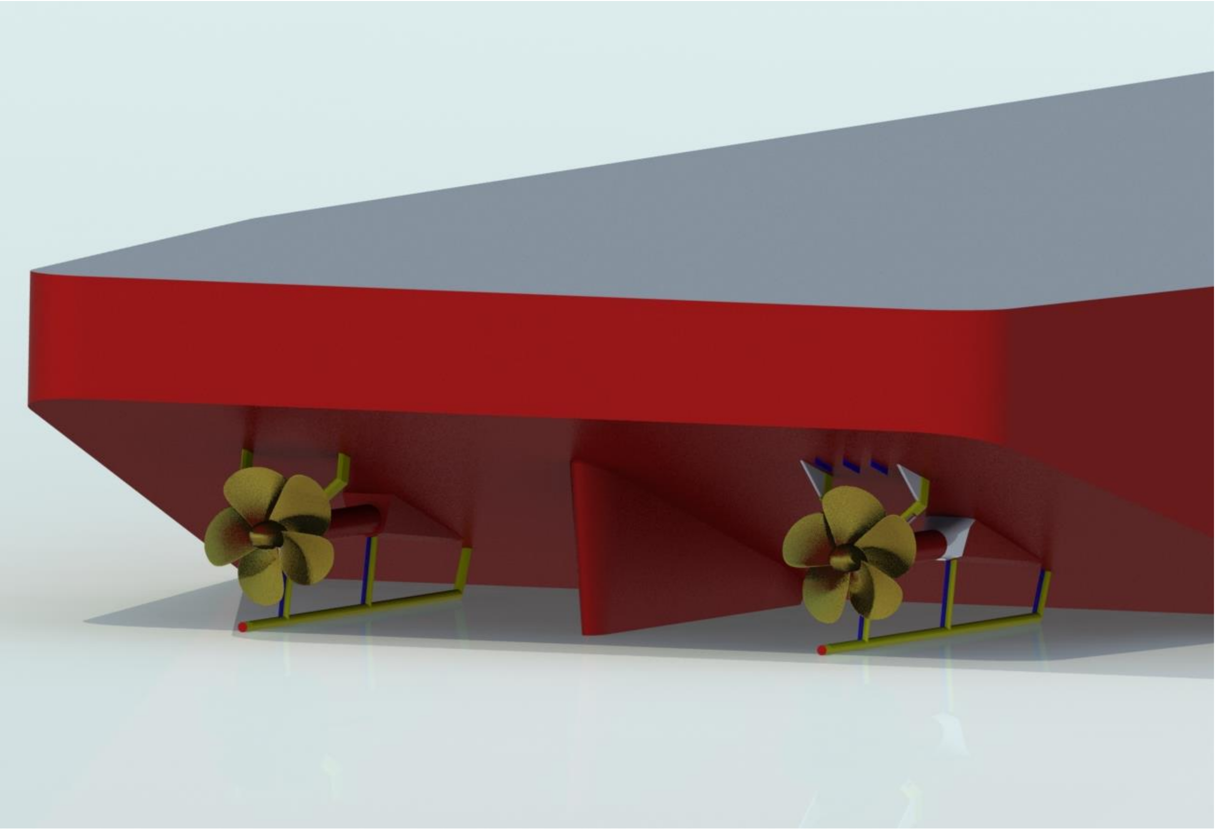

Figure 4: Before (port side) and after (starboard side) the remedial solutions for the excessive vibration

These remedial solutions were installed successfully by ADSB during the dry-dock period. Figure 5 shows the modifications as implemented on the vessel.

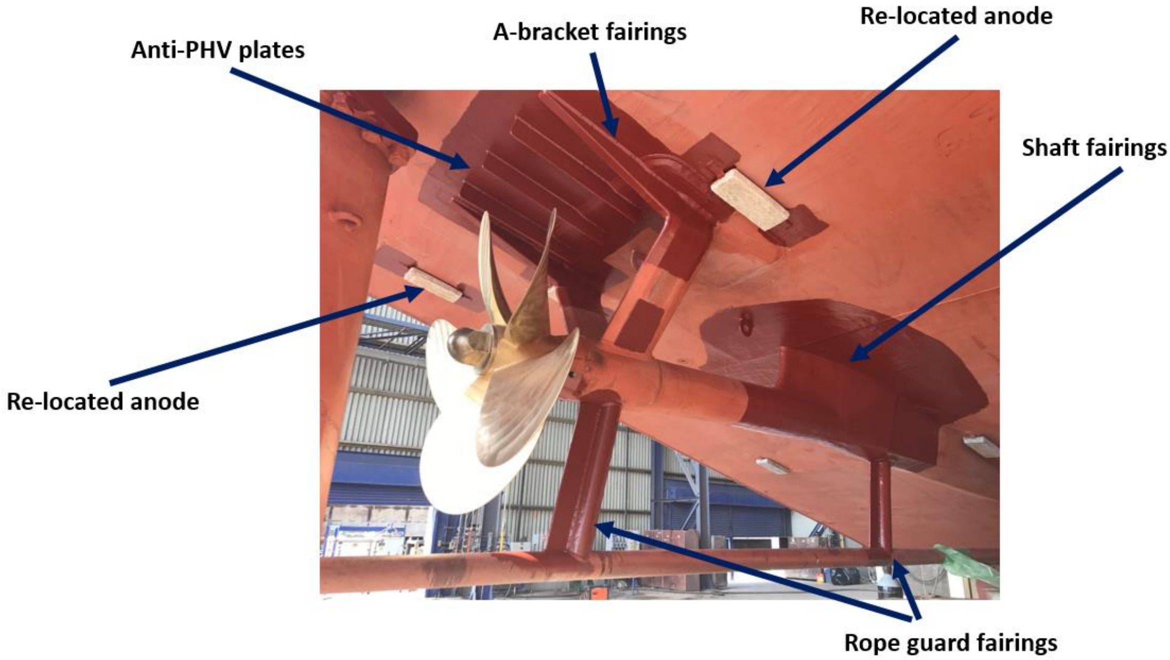

Figure 5: Remedial solutions as implemented on the landing craft in dry-dock

4. Full-scale Trials

The first full-scale trial was conducted before the implementation of the modifications. For this trial, a thorough vibration assessment was carried out, and it became apparent that measurements in some locations exceeded the levels recommended by ABS, (2016). A second trial was conducted after the remedial solutions were applied to the test vessel. For the second trial in addition to the vibration assessment, cavitation observations were also recorded using a borescope technique developed by Fitzsimmons and Boorsma, (2007). Both of the trials were conducted following the International Organization for Standardization guidelines (ISO, 2016).

4.1. Vibration & acceleration measurements

The vibration and acceleration measurements collected during the two sea trials enabled comparison of the levels before and after applying the remedial measures. While measurements were carried out throughout the ship, the most indicative ones regarding the modifications are chosen to be the ones that are in close proximity to both starboard and port propellers.

Figure 6 shows the acceleration measurements conducted before the implementation of the modifications. Accelerations were measured for all three components, axial, vertical and horizontal with horizontal being the dominant component inherently because of the location of the measurement and physical impacts of the cavitation phenomenon. These measurements are presented for the 100% Maximum Continuous Rating (MCR) condition.

The measurements for this trial were conducted at 1610 Engine Revolutions Per Minute (RPM) with a reduction gear ratio of 1:3.519. The x-axis of the measurements are presented in Cycles Per Minute (CPM). Therefore, the 1st Blade Passage Frequency (BPF) is seen at 2287.6 CPM, 2nd BPF at 4575.2 CPM and 3rd BPF at 6862.75 CPM. Maximum acceleration levels were observed for the horizontal component at the 1st BPF in steering gear flat for both port and starboard propellers; these were 38.08 mm/s Root Mean Square (RMS) and 50.73 mm/s RMS respectively. The overall acceleration levels for the port propeller were measured as 49.8 mm/s RMS and 68.86mm/s for the starboard propeller.

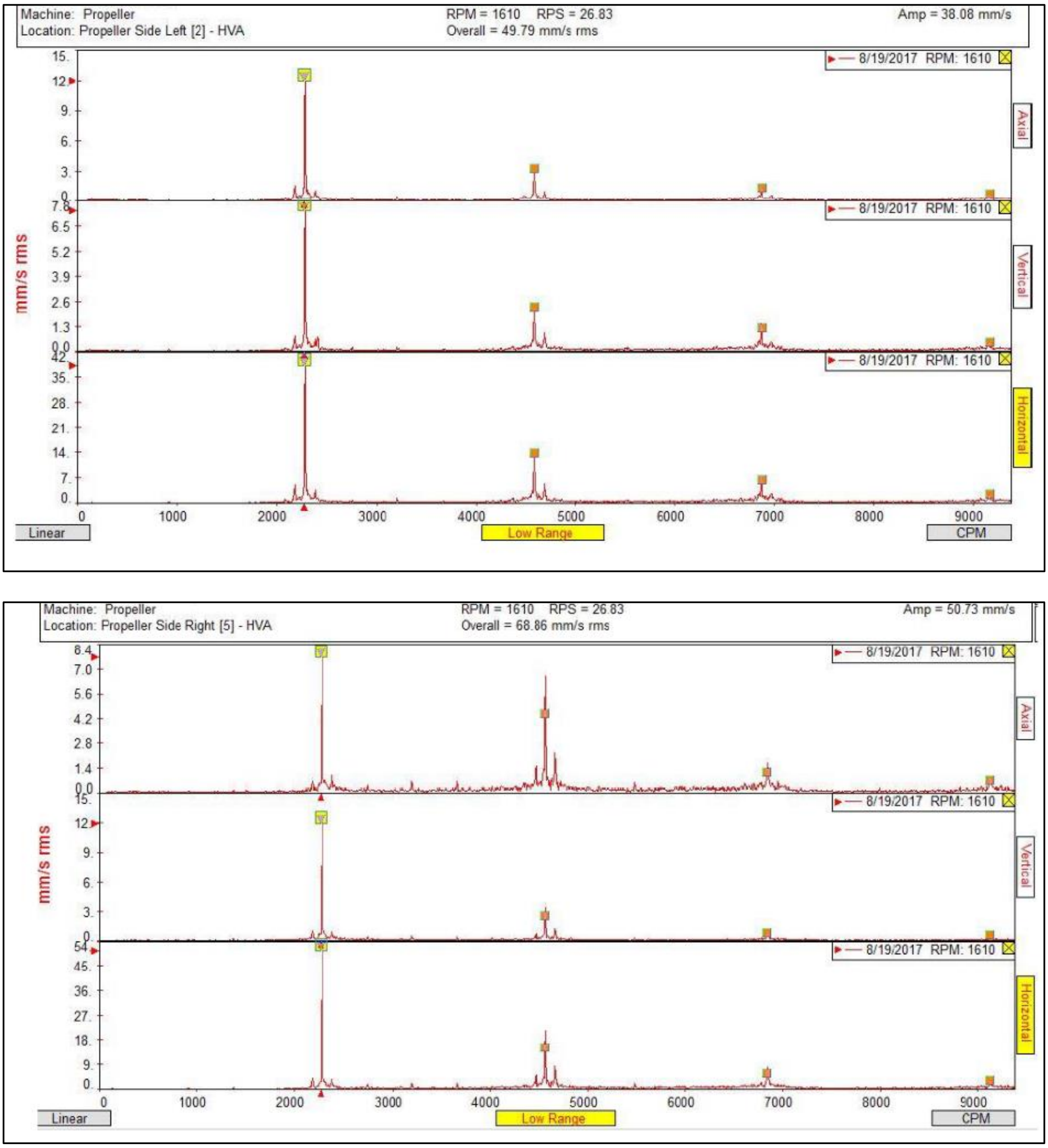

Figure 6: The Propeller Test Point before the modifications

During the second trial, with the remedial measures applied, the vessel achieved a slightly higher 100% MCR rating at 1630 Engine RPM. Due to this slight increase in the RPM, 1st BPF moved to 2316 CPM, 2nd BPF to 4632 CPM and 3rd BPF to 6948 CPM. Besides the slight increase in the maximum RPM that engines achieved, the vibration levels were significantly reduced, particularly at the 1st BPF. Maximum acceleration levels were measured from the horizontal component for both port and starboard propeller at the 1st BPF as 7.129 mm/s RMS and 6.71 mm/s RMS respectively. The overall acceleration level for the port propeller was measured as 21.7 mm/s RMS and 32.35 mm/s for the starboard propeller.

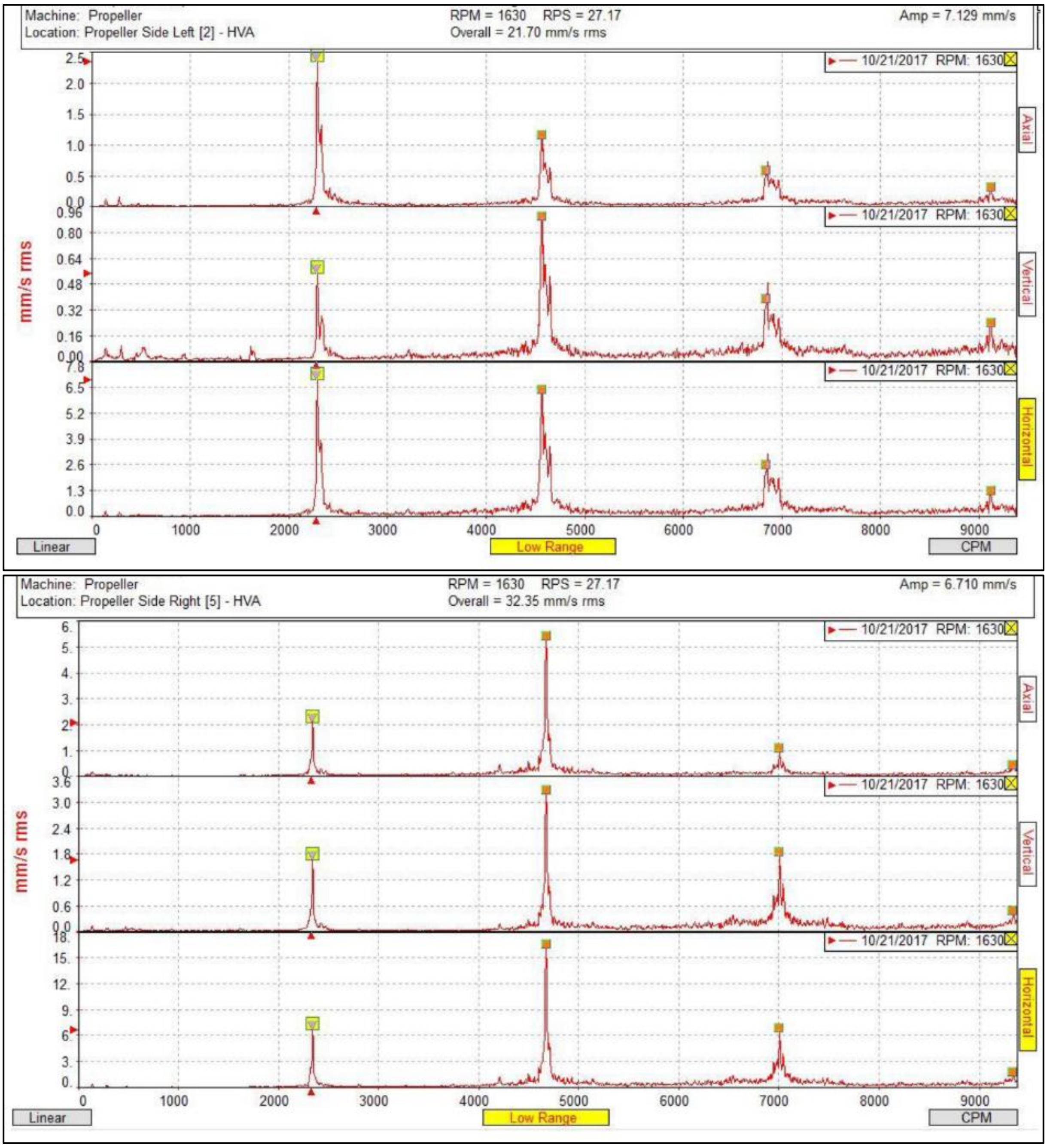

Figure 7: The Propeller Test Point after the modifications

Comparison of the vibration levels presented in Figure 6 and 7, respectively, before and after the remedial solutions applied, indicate that the measured vibration levels were reduced significantly both in terms of the overall levels and horizontal levels (the dominant component). The overall levels reduced by approximately 55%, while the maximum horizontal levels at the 1st BPF reduced by approximately 80%.

4.2. Borescope observations

In order to confirm the influence of the remedial measures on propeller cavitation, observations were also conducted during the second sea trials. Borescope observations of the propeller were made using the system (Figure 8) developed by Lloyd′s Register, Fitzsimmons & Boorsma (2007), with the borescope fitting initially put into place alongside, in an emptied ballast tank.

Figure 8: Borescope equipment

Figure 9 shows preliminary views at low shutter speed through the borescope before trials in the dry-dock and at berth on the trial day. The visibility in water deteriorates due to water quality and a reduction in the ambient light.

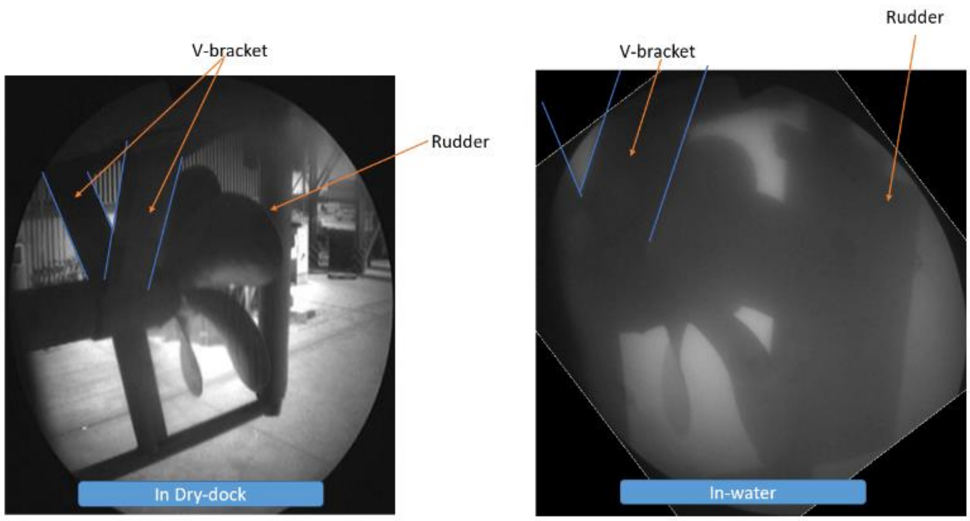

Figure 9 Propeller views with borescope in Dry-dock and in-water

Figure 10 was grabbed from the image sequence recorded during one of the trial runs at 1200 engine RPM condition. The image shows some tip vortex cavitation in the 12 oʹclock region of the propeller plane. Such cavitation is commonly observed under high, steady, loading conditions. The absence of the PHVC was encouraging. A PHVC was only observed during rapid acceleration of the vessel, as shown in Figure 11. This was not a concern as such observations are very common during the acceleration of the vessel when the propeller has a very high loading, while the inflow velocities from the hull are very low.

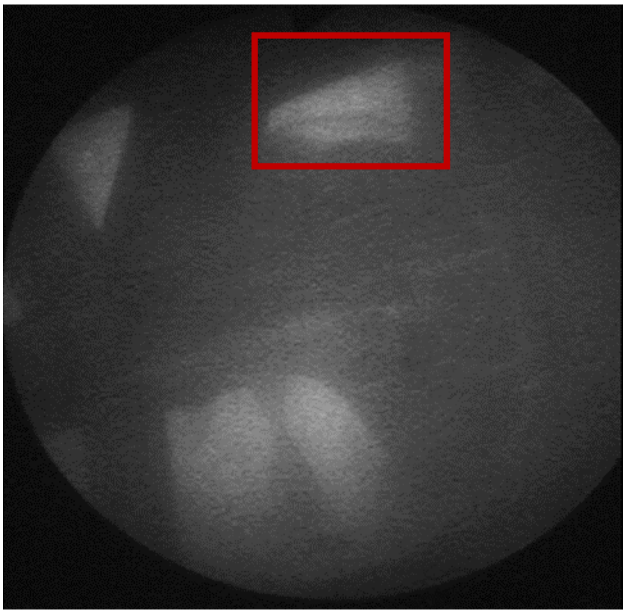

Figure 10 Propeller Cavitation observations with borescope technique

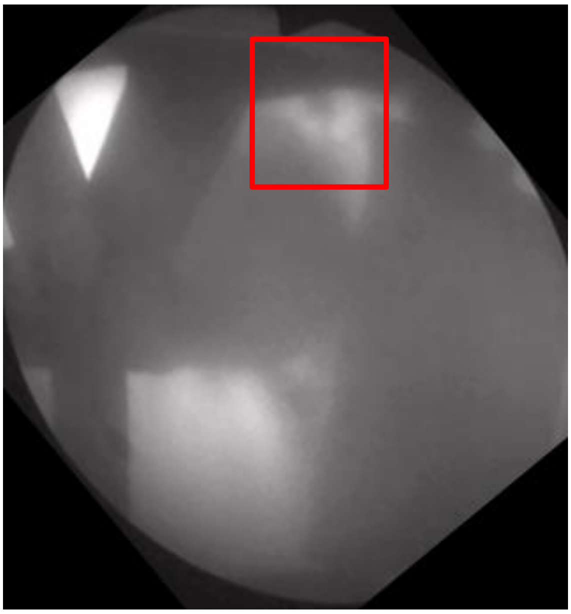

Figure 11: PHVC observed during acceleration

5. Further Studies in a Re-design of the Target Landing Craft

The remedial modifications, Section 4, focused mainly on the aft end details which could be implemented quickly. However, the present excessive vibration was also due retarded hull-flow feeding into the propellers together with a mixture of air sucked in at the bow region. The latter flow has been cited in the literature for vessels with shallow draft and flat buttocks.

Based on these experiences and detailed flow analysis of the test vessel using CFD, the authors propose more effective hull form re-design of such a craft involving key modifications to the bow/fore body as well as the stern/after body sections and appendage as shown in Figure . The enhancements were intended to be kept to a minimum due to the long-term familiarity and experience of the builders with the construction of this vessel type.

The redesigned features in Figure 13 were introduced in order to prevent the risk of PHV development, air ingestion by the propeller and to improve the aft end hull flow in general for a favourable inflow to the propellers. The afterbody of the vessel incorporates a tunnel stern to encourage strong longitudinal propeller-hull interaction. The current appendages, i.e. stern tube fairings, V-brackets, and integrated twin-skeg application with streamlined sole-piece can be introduced. The re-designed hull could also replace the current rudder arrangement with a true spade/suspended rudder without any sole-piece support.

To complement the above enhancements, the forebody section of the vessel also needs to be re-designed with a more scalloped/spoon shape bow with mild dihedral angles as opposed to flat buttock lines and blunt frontal area at the water line. This new design feature will reduce the wave breaking and mitigate the slamming phenomena as well as reducing the risk of air ingestion. The proposed modifications naturally will have an impact on the ramp level and its structure as well as the level of the main deck at the bow, but these can be compromised with the overall performance benefits to be gained from the design upgrade.

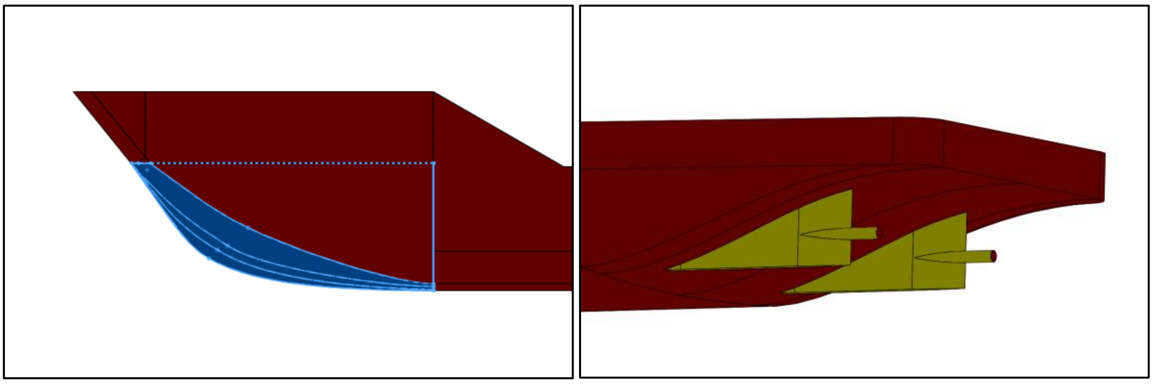

Figure 13: New Hull Re-design features proposed for the forebody (left) and afterbody (right) of landing craft

On a final note, the authors believe that both the re-designed hullform and the current design can also greatly benefit from the application of the very recently introduced novel propeller-rudder arrangement system, “Gate Rudder ®”, Figure 14, which has been under development in Strathclyde University, e.g. Sasaki et al. (2016). The Gate Rudder system, can improve the fuel consumption by up to 15%, provides superior manoeuvrability, less vibration and noise as well as reduced hull wash. It comprises two independently controlled rudder blades of asymmetric profiles adjacent to the propeller, providing the vessel with additional thrust due to the duct effect and without the drag of a conventional rudder. Independent control of the rudder blades provides the vessel with superior manoeuvrability, especially for the harbour manoeuvring. Such advantages have been demonstrated on the world’s first Gate Rudder application on a 110m container vessel which entered into service at the beginning of 2018, as shown in Figure 14, Sasaki et al. (2018).

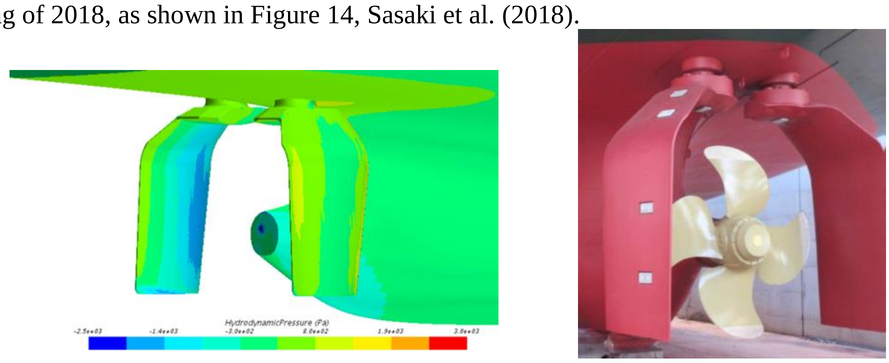

Figure 14: Gate Rudder Application to the stern (CFD and full scale image) of a 110m Container ship

The preliminary feasibility analyses have indicated that the application of the above-described design features can provide this landing craft with much-improved propeller excited vibration characteristics as well as about 15% propulsive efficiency improvement. If the proposed design enhancements are combined with the Gate Rudder system, the vessel will get superior manoeuvrability characteristics, especially in slow speed, while the propulsive efficiency gain can be easily doubled (about 30%) in addition to the benefits of further reductions in aft end vibration, noise and hull wash.

6. Concluding remarks

This study documented and verified a range of remedial solutions which have successfully been applied to a landing craft to address excessive propeller-excited vibration problems on-board. Landing craft employs relatively unsophisticated hull forms due to the "work-horse" nature of their mission requirements. When the operation profiles of such vessels require them to operate at higher speeds and powers, the propeller starts to work under higher loading conditions which can result in a cavitation phenomenon called Propeller-Hull Vortex Cavitation (PHVC) being experienced. Furthermore, the bow region of such vessels incorporates a front-loading ramp for which its supporting structures can produce air ingestion from breaking waves and slamming motions. The Computational Fluid Dynamics |(CFD) studies conducted have conclusively shown that such entrained air travels along the substantially flat of the bottom of the hull and can be sucked into the propeller. These two hydrodynamic phenomena give rise to high levels of acceleration and vibration levels such as experienced onboard the present test vessel. Within the framework of providing a range of solutions to control the above highlighted problems of the subject craft, this study indicated that:

- To reduce the excessive vibration onboard, local modifications were derived from the experience and studies available in the open literature and applied to the subject vessel. The proposed modifications included: Shaft fairings; Anti-PHV plates; A-Bracket fairings; Rope guard fairings; Anode re-locations. Sea trials were conducted before and after the successful implementation of the proposed remedial solutions on the test vessel. For both trials, vibration and acceleration assessments for onboard habitability requirements were carried out. Verification of cavitation improvements was observed and recorded using a borescope technique for the trials after the modifications. The acceleration measurements showed improvements of up to 55% in the overall levels and approximately 80% reduction in the dominant amplitude at blade passing frequency. The cavitation observations have shown no trace of PHVC during steady running.

- To offer a more design oriented solution to the vibration problems, a concept re-design of the target landing craft is proposed to enhance the hydrodynamic performance of the landing craft based on understandings gained using CFD methods while resolving the vibration problems experienced by the target vessel, The enhancements incorporated in the concept design consist of bow form/fore body re-design to reduce breaking bow waves. These aim to improve resistance, slamming and air ingestion as well as providing adequate buoyancy and strength. Re-design of the afterbody and appendages (including rudder) aim to improve the wake inflow to the propellers as well as to reduce the hull resistance.

- Finally, to offer a further optimised design oriented solution, a novel ESD and propeller/rudder arrangemen, as such the recently introduced, Gate Rudder ® system, which is being further developed at Strathclyde University, is proposed. The benefit of applying such device on the subject vessel can be as high as 30 % more fuel efficiency compared to the current vessel′s conventional propulsion arrangement beside the expected superior manoeuvrability and comfort on board.

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