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Hydrodynamic Interactions during Launch and Recovery of a Small Boat from a Ship in a Seaway

ABSTRACT

Wave-induced vessel motions often determine whether launch and recovery operations can proceed safely. For launch and recovery of a small craft from a larger ship, wave-induced motions of the larger ship will influence dynamic loads on the crane. The motions of the small craft will be a major determinant of the safety of onboard personnel. This paper examines wave-induced motions during launch and recovery, including the effect of hydrodynamic interactions between the two vessels. The presence of a larger ship is shown to have a major influence on motions of the small craft. Sample polar plots demonstrate the variation of relevant motion parameters with speed and heading, and can be used as the basis for operational guidance.

INTRODUCTION

Launch and recovery of small boats from ships is a vital part of naval ship operations. Interest in launch recovery among navies is currently very high for a variety of reasons. Interdiction operations have become increasingly important in recent years, and require safe launch and recovery of small boats and personnel. Autonomous systems requiring launch and recovery continue to become more widely used for a variety of naval missions. Furthermore, greater concern for health and safety of naval personnel has brought attention to launch and recovery, which can present increasing risk to crew as sea state increases.

Simulation is being increasingly used to support naval operations involving dynamics of multiple bodies. McTaggart and Langlois [1] simulated replenishment at sea between a supply ship and a frigate. Their simulation modelled the seaway, motions of both ships, and the replenishment gear used to transfer a payload between the ships. McTaggart, Roy, Steinke, Nicoll, and Perrault [2] simulated launch and recovery of a small boat from a naval frigate. Their simulation modelled the seaway, motions of the frigate and small boat, and the crane used to launch and recover the small boat. Irani, Kehoe, Spencer, Watt, Gillis, Carretero and Dubay [3] simulated a small unmanned underwater vehicle (UUV) docking with a submarine.

Hydrodynamic interactions can significantly influence bodies that are within proximity of each other. Several authors have examined hydrodynamic interactions during replenishment at sea, including McTaggart, Cumming, Hsiung, and Li [4] and Andrewartha, Thomas, Turner, and Lin [5]. The present paper examines hydrodynamic interactions that can occur during launch and recovery of a small boat from a frigate.

THEORY FOR MOTIONS OF A SINGLE VESSEL IN WAVES

Prediction of motions for a single vessel in waves is most commonly done using the assumption of potential flow, which can give generally accurate results with moderate computing requirements. The present method is based on the work of Papanikolaou and Schellin [6], which computes motions in the frequency domain using a panel method and free surface Green function for zero forward speed. The vessel is assumed to travel with quasi-static forward speed and heading. This approach gives generally good results when the Froude number $Fr = U/(g\ L_{pp})$ is less than 0.4, where U is ship forward speed, g is gravitational acceleration, and L_{pp} is ship length between perpendiculars. For sway, roll, and yaw motions, lift and viscous forces can be significant and are modelled using coefficient-based approaches, as described by Schmite [7].

The motions of a body with no moving appendages can be evaluated in the time domain as follows:

$$([M]+[A])\ \{\ddot{\eta}(t)\}\ +\ [B]\,\{\dot{\eta}(t)\}\ +\ [C]\,\{\eta(t)\} = \left\{F^I(t)\ +\ F^D(t)\right\} \quad (1)$$

where $[M]$ is the ship mass matrix, $[A]$ is the added mass matrix, $\{\ddot{\eta}(t)\}$ is the acceleration vector, $[B]$ is the damping matrix, $\{\dot{\eta}(t)\}$ is the velocity vector, $[C]$ is the stiffness matrix, $\{\eta(t)\}$ is the motion displacement vector, $\left\{F^I(t)\right\}$ is the incident wave force vector, and $\left\{F^D(t)\right\}$ is the wave diffraction force vector. The acceleration, velocity, and displacement vectors each have six terms, representing surge, sway, heave, roll, pitch, and yaw motions. The displacements $\eta(t)$ in the time domain can be expressed in terms of frequency domain values as follows:

$$\eta(t) \ = \ \text{Real}\left(\widetilde{\eta}\ e^{i\,\omega_e\,t}\right) \quad (2)$$

where $\widetilde{\eta}$ is complex motion amplitude in the frequency domain and ω_e is wave encounter frequency. The equation of motions in the frequency domain can thus be written as:

$$\left(-\omega_e^2\,([M]+[A])\ +\ i\omega_e[B]\ +[C]\right)\ \{\widetilde{\eta}\} = \left\{\widetilde{F}^I\ +\ \widetilde{F}^D\right\} \quad (3)$$

Note that the wave excitation forces $\left\{\widetilde{F}^I\ +\ \widetilde{F}^D\right\}$ in the frequency domain are complex quantities, containing phase information.

A real ship will include appendages that will introduce additional degrees of freedom to Equations (1) and (3). These degrees of freedom can include rudder rotations, stabilizer fin rotations, azimuthing propeller rotations, and fluid motions within stabilizer tanks. Lloyd [8] describes incorporation of appendages into ship equations of motion.

THEORY FOR MOTIONS OF TWO VESSELS IN WAVES

The approach used for computing the motions of a vessel in waves has been extended to consider the presence of both vessels. Van Oortmerssen [9] was among the first to compute interaction effects between two bodies using a panel method. Subsequent related work has been performed by others, including Li, McTaggart, and Hsiung [10]. When solving the radiation problem for two bodies, it is necessary to consider flow arising from motion of each body while the other body is present and stationary. The positions of the ships relative to each other are assumed to be quasi-steady. Solution of the wave diffraction problem considers both bodies as stationary, similar to the wave diffraction problem for a single body. For the case of

neither vessel having moving appendages, the equations of motion in the frequency domain for two ships A and B are written as:

$$\left(-\omega_e^2\left(\left[\begin{array}{c|c} M^A & 0 \\ \hline 0 & M^B \end{array}\right] + \left[\begin{array}{c|c} A^{AA} & A^{AB} \\ \hline A^{BA} & A^{BB} \end{array}\right]\right) + i\omega_e \left[\begin{array}{c|c} B^{AA} & B^{AB} \\ \hline B^{BA} & B^{BB} \end{array}\right] + \left[\begin{array}{c|c} C^A & 0 \\ \hline 0 & C^B \end{array}\right]\right) \left\{\begin{array}{c} \widetilde{\eta}^A \\ \hline \widetilde{\eta}^B \end{array}\right\} = \left\{\begin{array}{c} \widetilde{F}^{IA} + \widetilde{F}^{DA} \\ \hline \widetilde{F}^{IB} + \widetilde{F}^{DB} \end{array}\right\} \quad (4)$$

where superscripts A and B refer to the two individual ships. Note that the added mass and damping terms for the the pair of ships include cross-ship terms because motions of one ship will induce radiation forces on the other ship. Degrees of freedom for appendages such as rudders, stabilizer fins, azimuthing propellers, and U-tube tanks can be added to the above equation in a manner similar to the single ship case of Equation (3).

NUMERICAL IMPLEMENTATION

The ShipMo3D ship motion suite [11] has been extended to model seakeeping in waves for a pair of vessels. ShipMo3D is written mostly in C# [12], with some portions of the code written in C++ [13] to give faster performance for numerical computations. ShipMo3D uses the Math.NET numerical library [14], which provides efficient performance for tasks such as solving systems of linear equations.

To eliminate the occurrence of irregular frequencies with erratic results for predicted hydrodynamic forces [15], panelled lids have been implemented at the waterplane of each ship, with a specified boundary condition of zero vertical velocity. This approach has been implemented for both single ship and dual ship cases, and has been shown to be very successful for eliminating irregular frequencies.

Computational requirements for ship interaction cases are typically much greater than single ship cases when solving for radiation and diffraction forces. While a single ship case normally assumes lateral symmetry when solving radiation and diffraction forces, this symmetry is typically lost when considering a pair of ships. Consequently, the number of unknowns to be solved increases by a factor of approximately 4, and the number of influence terms for solving flow parameters increases by a factor of approximately 16. In consideration of these large computational requirements, care has been given to using memory efficiently, including minimizing the number of times that large arrays are initialized in memory.

The ShipMo3D application RadDifPair computes a radiation and diffraction force database, which is intended to cover all combinations of encounter frequency, ship speed, relative sea direction, and wave frequency that a pair of ships might encounter. Typical values for a pair of ships with lengths between 100 and 200 m are:

1. encounter frequencies $\omega_e = 0.05, 0.10, 0.15, \ldots, 5.0$ rad/s (100 values),
2. ship speeds $U = 0, 2, 4, \ldots, 30$ knots, (16 values),
3. relative sea directions $\beta_s = 0, 15, 30, \ldots, 360$ degrees, (37 values),
4. incident wave frequencies $\omega_I = 0.10, 0.15, 0.20, \ldots, 2.0$ rad/s.

Computation of added mass, damping, and diffraction force terms for the above conditions

typically requires 24 hours and 6 GB of memory on a desktop workstation with 8 dual-core processors.

VERIFICATION AND VALIDATION

Numerical verification tests were conducted to ensure that the ship interaction software was performing as expected. Motion predictions were conducted for two ships far away from each other, with predicted motions showing no significant influence from interaction effects. Motion predictions were also conducted for a pair of identical ships in close proximity and aligned longitudinally. The surge, heave, and pitch motions were identical for the two ships. The sway, roll, and yaw motions were identical in magnitude but opposite in phase between the two ships.

Validation of motion predictions was conducted using the experiments of McTaggart, Cumming, Hsiung, and Li [4]. During the experiments, the ship models were constrained in surge, sway, and yaw. These constraints were included in the numerical simulations by applying high external stiffness to the ship models. The numerical predictions very good agreement with experiments.

The ShipMo3D ship motion software has been validated for a variety of vessels; however, it hasn't yet been validated for a RHIB.

EXAMPLE MOTIONS OF A SMALL BOAT NEAR A FRIGATE

Motion computations have been performed for a rigid-hull inflatable boat (RHIB) operating in close proximity to a naval frigate, as would occur during launch and recovery. The RHIB is based on a Zodiac H935, with properties given in Table 1 when loaded with 12 personnel. Figure 1 shows the hull surface model for the RHIB, which formed the basis for panelling the hull for radiation and diffraction computations. Figure 2 shows the RHIB model for motion simulation, including the wet panelled hull in yellow, the dry panelled hull in green, and azimuthing propellers from outboard engines in blue.

The generic frigate is a nominal ship that has never been built, and has properties given in Table 2. Figure 3 shows the hull surface model for the generic frigate, which formed the basis for panelling the hull for radiation and diffraction computations. Figure 4 shows the generic frigate model for motion simulation, including the wet panelled hull in yellow, the dry panelled hull in green, the propellers in blue, and the bilge keels, skegs, propeller shaft brackets, and rudder in red.

Single vessel motion computations were performed for the RHIB and generic frigate. Ship interaction computations were performed for the RHIB along the starboard side of the frigate, with a 1.5 m gap between the 2 vessels. All computations were performed for the upper limit of Sea State 3, with a significant wave height H_s of 1.25 m and a peak wave period T_p of 7.5 s. This sea state is considered representative of the upper limit at which launch and recovery operations might be safely performed. Ship speeds of 0 to 12 knots were evaluated, encompassing speeds that would be realistically used for launch and recovery operations. For a ship speed of 12 knots, the associated forward speed Froude number for the RHIB is 0.65, which likely is sufficiently high to introduce challenges for the numerical predictions.

Among the various vessel motion parameters that will influence launch and recovery, the fol-

Length	9.35 m
Beam	3.00 m
Displacement	7242 kg
Number of outboard engines	2
Number of personnel onboard	12
Natural roll period	2.4 s

Table 1: Properties of Rigid-Hull Inflatable Boat

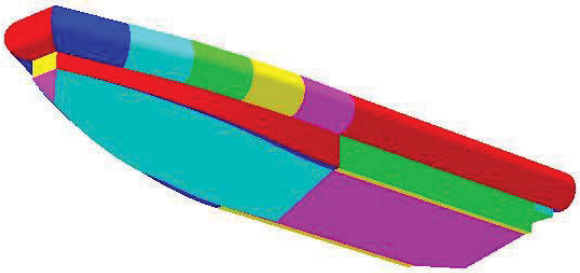

Figure 1: Model of Hull Surfaces for Rigid-Hull Inflatable Boat

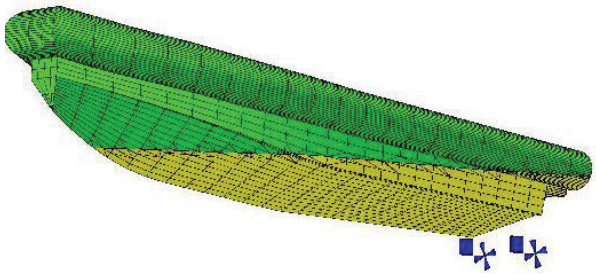

Figure 2: Ship Motion Model for Rigid-Hull Inflatable Boat

Length between perp.	120 m
Beam	14.1 m
Displacement	3713 tonnes
Number of rudders	1
Number of propellers	2
Natural roll period	8.9 s

Table 2: Properties of Generic Frigate

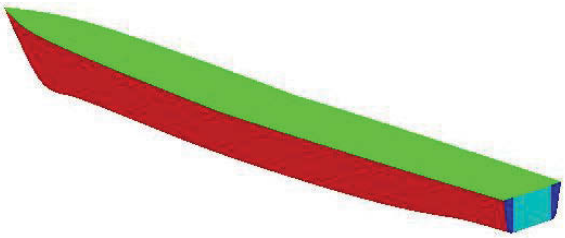

Figure 3: Model of Hull Surfaces for Generic Frigate

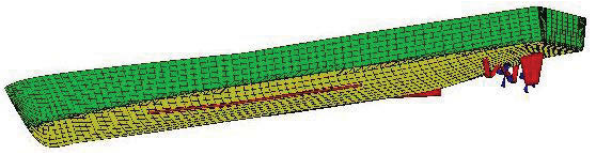

Figure 4: Ship Motion Model for Generic Frigate

lowing are likely among the most important:

- vertical acceleration of generic frigate crane tip,
- relative vertical velocity between generic frigate crane tip and ocean surface,
- vertical acceleration of RHIB,
- relative vertical velocity between generic frigate crane tip and RHIB attachment point,
- relative lateral velocity between generic frigate crane tip and RHIB attachment point,
- relative vertical displacement between generic frigate crane tip and RHIB attachment point,
- relative lateral displacement between generic frigate crane tip and RHIB attachment point.

Vertical acceleration of the crane tip will influence loading on the crane, particularly when the RHIB is emerged from the water and the crane is supporting its full weight. The relative vertical velocity between the crane tip and the ocean surface will provide a good indictor of relative motion between the crane tip and RHIB because the small RHIB will tend to follow the ocean surface. Vertical acceleration of the RHIB will place demands on the RHIB crew, including coupling and decoupling between the crane hook and RHIB attachment point. Relative vertical velocity, relative lateral velocity, and relative vertical displacement will contribute to the general complexity of the operation. Relative lateral displacement could cause collisions between the RHIB and generic frigate.

Figures 5 to 10 show polar plots of some responses influencing launch and recovery. For each plot, speed is given on the radial axis and relative sea direction is given on the angular axis. The color scale for each plot is based on the range of numerically predicted values rather than on any operational limits that might exist. For the current configuration with the crane on the starboard side of the ship, a typical launch and recovery scenario would have the ship and RHIB travelling at 10 knots with the nominal sea direction coming from the port bow quarter.

Figure 5 gives vertical acceleration at the crane tip on the frigate. The crane is located amidships on the frigate; thus, vertical accelerations are greater in the vicinity of beam seas, which will include roll and associated vertical motions on the crane. Figure 6 shows the vertical velocity of the crane tip relative to the ocean surface. Note that wave radiation and diffraction have need been included when evaluating the ocean surface elevation. Figures 7 and 8 show heave acceleration of the RHIB on its own and when near the frigate. Hydrodynamic interaction effects somewhat influence heave accelerations for the RHIB. Figures 9 and 10 show roll of the RHIB on its own and when near the frigate. Hydrodynamic interaction effects have a dramatic influence on roll of the RHIB, especially in the vicinity of head seas. Note that the experiments by McTaggart, Cumming, Hsiung, and Li [4] revealed a similar physical phenomenon, in which the presence of a supply ship induced significant roll motions on a nearby frigate in head seas. The high roll motions of the RHIB at higher speeds in the vicinity of head seas are also due to wave encounter periods being near the RHIB natural roll period of 2.4 s. Due to the large magnitude of the roll motions in Figure 10, they would be significantly influenced by nonlinear effects; however, these nonlinear effects haven't been modelled in the present frequency domain computations. It is recommended that time domain methods

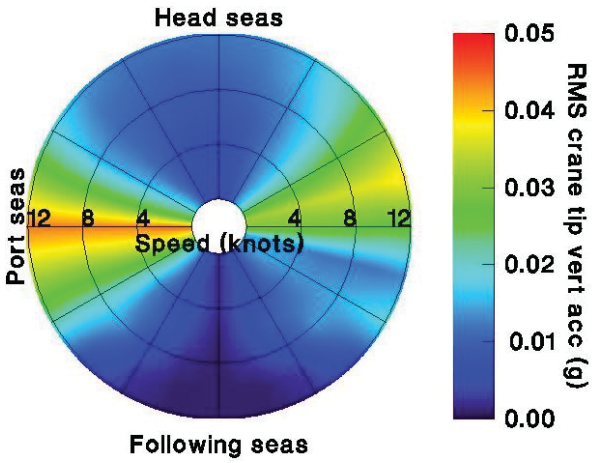

Figure 5: RMS Vertical Acceleration of Crane Tip in Upper Sea State 3

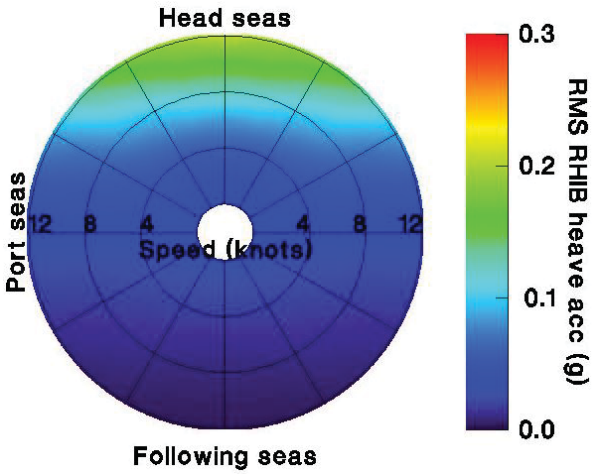

Figure 7: RHIB Heave Acceleration in Upper Sea State 3 without Interaction

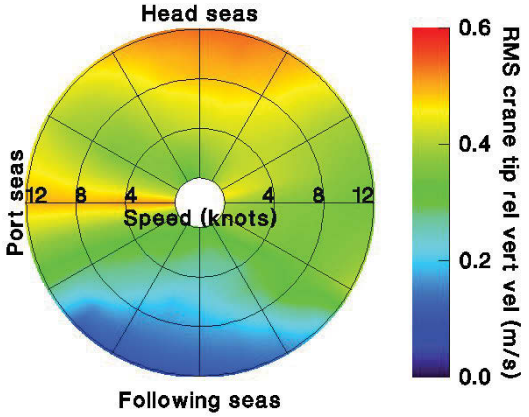

Figure 6: RMS Relative Vertical Velocity between Crane Tip and Ocean Surface in Upper Sea State 3

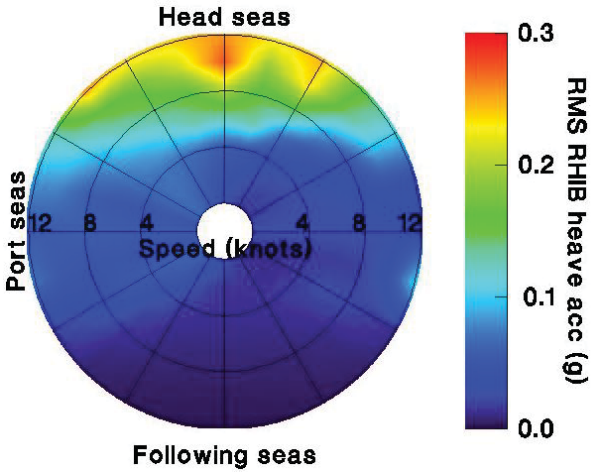

Figure 8: RHIB Heave Acceleration in Upper Sea State 3, 1.5 m Gap between Generic Frigate and RHIB

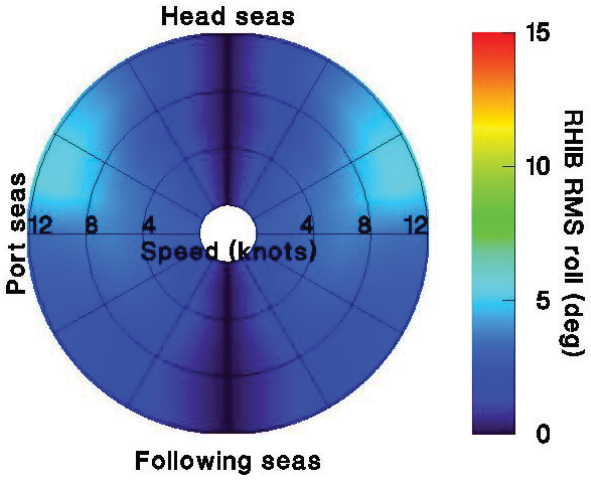

Figure 9: RHIB Roll in Upper Sea State 3 without Interaction

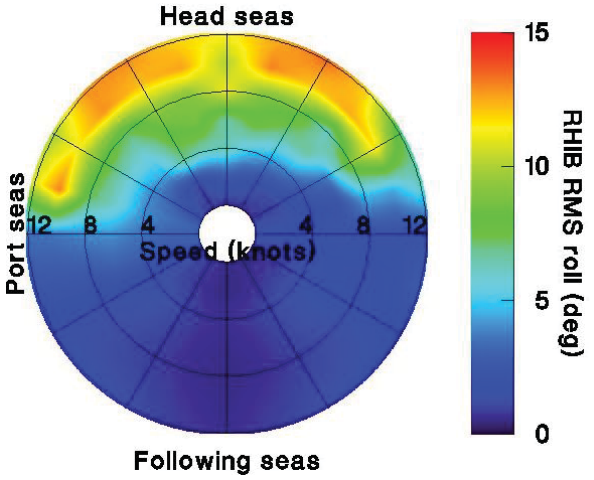

Figure 10: RHIB Roll in Upper Sea State 3, 1.5 m Gap between Generic Frigate and RHIB

be investigated for modelling these large amplitude motions.

Figures 5 to 10 suggest that following seas could be an excellent heading for launch and recovery; however, steering can be challenging in following seas. Furthermore, no results have been presented for other quantities which might significantly influence launch and recovery operations. Greater understanding of launch and recovery operational limits would assist in determining which parameters should be investigated in greater detail.

CONCLUSION

Frequency domain predictions of vessel motions in waves have been extended to predict motions for two vessels, including hydrodynamic interaction effects. Example computations for launch and recovery of a RHIB from a frigate indicate that the presence of the frigate can induce large motions on the RHIB. The highest RHIB motions occur at higher speeds in the vicinity of head seas, for which wave encounter periods are near the RHIB natural roll period. For the large amplitude RHIB motions observed in the example computations, it is recommended that time domain methods be investigated for modelling associated nonlinear effects. Validation of the RHIB motion predictions is recommended due to the high Froude numbers for the RHIB.

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