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Ship–ship interactions in calm water and waves. Part 1: Analysis of the experimental data

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ABSTRACT

Part 1 of this two-part paper presents detailed analysis of the previously conducted ship–ship experiments for Bob Hope and Bobo free to heave and pitch in deep calm water and waves (Van't Veer and Van Engelenburg, 2006). Interactions are quantified, recommendations for future experiments are provided, and the results are used as basis for selection of simulation conditions in Part 2. Calm water interactions include induced side forces and rolling and yawing moments on both ships. Effects of changing the configuration, decreasing the spacing, and increasing the speed are to intensify or diminish these induced effects, depending on the variable and the test conditions. In waves, the important effects include increased interactions in resonance region, sheltering of one ship by the other in oblique waves, and elevated amplitudes of forces and moments at high frequencies where the motion amplitudes are nearly zero. Effects of configuration, speed, and heading are studied both on trends with frequency and averaged over all frequencies, showing different effects depending on the test conditions. Part 2 provides validation studies for selected conditions, as well as further investigation of the physics through comparison with single-ship simulations and analysis of the global and local flow variables.

1. Introduction

Ship–ship interactions occur in waterways with dense shipping traffic, for moored ships affected by passing ships, between tugs and vessels, and in ship to ship operations for cargo transfer. Understanding these interactions is important to avoid collisions since due to increasing ship dimensions these effects are unavoidable in channels and harbors. Also cargo transfer in waves and other environmental conditions require reliable and accurate predictions of these effects for developing design criteria and a safe envelope of operation. Reviews of ship–ship interaction studies are included in the ITTC reports by the Maneuvering Committee (ITTC, 2011). The problem has been studied using experiments, system-based methods, potential flow solvers, and viscous CFD simulations. The global variables including forces, moments, and motions are studied. The interactions are found to be functions of ship geometries and length ratio, shallow and confined water conditions, type of maneuver (overtaking, encountering, side-by-side replenishment, etc.), spacing between the ships, ship speeds, and waves and other environmental conditions. Trapping waves in the gap between two floating structures are identified, present when the spacing is a multiple of half the wavelength of the incoming waves (Mciver and Newman, 2003). Most of the previous work are for shallow calm water conditions, while this paper focuses on deep calm water and waves.

Previous experiments are reviewed herein, while simulation studies are addressed in Part 2. All experimental studies are carried out for captive conditions only. Overtaking and encountering experiments in shallow calm water conditions are carried out systematically by a few studies (e.g. Dand, 1981; Vantorre et al., 2002) and are used to develop simplified theoretical and computational methods (e.g. Fang and Kim, 1986; Kaplan and Sankaranarayanan, 1987) and empirical formulas (e.g. Brix, 1993; Vantorre et al., 2002; Varyani et al., 2004). The effects of passing ships on moored ships in restricted water depth are tested by Pinkster and Ruijter (2004). Captive side-by-side experiments are carried out in shallow calm water for varying conditions including water depth, drift angle, and spacing (Lataire et al., 2009) and provided as benchmark data for the 2nd International Conference on Ship Manoeuvring in Shallow and Confined Water, 2011, Norway. The only experimental study in waves is carried out by Van't Veer and Van Engelenburg (2006) which is the data analyzed in the current work. The experimental matrix is extensive and includes systematic experiments for replenishment and overtaking in deep calm water and waves for Bob Hope and Bobo. The experimental report did not include thorough investigation of the data to quantify and explain the ship–ship interactions including the effects of configuration, spacing, speed, and wave heading. These analyses of the data are provided in the present Part 1 paper. The data are also previously used for

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Nomenclature

a	Wave amplitude
B	2nd Lt. John P. Bobo (T-AK 3008)
b-m	bow-to-amidships configuration
CFD	Computational fluid dynamics
D	Data value
DR	Dynamic range (for data values)
E	Error value
f_e	Encounter frequency
f_n	Natural frequency
Fr	Froude number
Fr_c	Coincidence Fr
H	Bob Hope (TAKR 300); Wave height
K	Roll moment
k	Wave number
L	Ship length
m-m	amidships-to-amidships configuration
N	Yaw moment
PF	Potential Flow
RAO	Response amplitude operator
S	Spacing between ships; Simulation value
t	Time
T	Wave period
URANS	Unsteady Reynolds Averaged Navier Stokes
V	Ship velocity
X	Surge force
Y	Sway force
z	Heave motion
α	Wave incidence angle
θ	Pitch motion
λ	Wavelength
σ	Calm water sinkage
τ	Calm water trim

evaluating a set of potential flow-based computational tools, as summarized in Part 2.

The objectives of this Part 1 paper are to perform detailed analyses of the experimental data by Van't Veer and Van Engelenburg (2006) to quantify the ship–ship interactions, provide recommendations for future experiments, and provide a basis for selection of simulation conditions in Part 2. The post-processing procedures for analysis of the data are discussed in Section 3.

2. The experimental data

Tests were performed for the 45th scale models of the T-AKR 300 class (Bob Hope) and the T-AK 3008 (Bobo) with main particulars shown in Table 1. All the results in this paper are in the model-scale dimensions. The length ratio of the models is $L_H/L_B = 1.536$. Both models were free to pitch and heave and constrained in all other motions. Time histories of z, θ, X, Y, K, and N were measured. Fig. 1 shows the experimental coordinate system, m-m and b-m configurations, and definition of wave heading angles. The tests were run for three separations and four speeds. Table 2 provides a complete list of all experimental tests. Each set of regular wave tests include 6 wave frequencies/wavelengths in side-by-side configurations and 3 in overtaking, for which the wave conditions are summarized in Table 3. None of these conditions correspond to the conditions where the trapping waves system is present.

3. Post processing procedures

3.1. Analysis of time histories

For calm water results the time histories of resistance, sinkage, and trim are evaluated to ensure steady state condition is achieved, and the values are obtained by averaging over the steady portions.

Table 1
Main particulars of Hope and Bobo.

	Full scale		Model scale	
	H	B	H	B
L_{WL} (m)	279.16	181.689	6.20	4.04
B (m)	32.258	32.156	0.72	0.71
T_F (m)	7.83	5.19	0.17	0.12
T_A (m)	9.76	8.18	0.22	0.18
Δ (tons)	50396.7	30784.9	0.55	0.34
C_B	0.643	0.746	0.643	0.746

For seakeeping in waves, the time history of each parameter $P(X, Y, K, N, z, \theta)$ is transferred into frequency domain using Fourier series, and the amplitudes (P_n) and phases (γ_n) are determined as:

$$P(t) = \frac{P_0}{2} + \sum_{n=1}^{N} P_n \cos(2\pi f_e t + \gamma_n)$$

$$a_n = \frac{2}{T}\int_0^T P(t)\cos(2\pi f_e t)dt$$

$$b_n = \frac{2}{T}\int_0^T P(t)\sin(2\pi f_e t)dt$$

$$P_n = \sqrt{a_n^2 + b_n^2}$$

$$\tan(\gamma_n) = -\frac{b_n}{a_n} \quad (1)$$

Streaming value is defined as the difference between steady calm water and 0th harmonic amplitude in waves. Following G2010 (Stern et al., 2014), only 0th and 1st harmonics are considered and 2nd and higher harmonics are not included for seakeeping in regular waves.

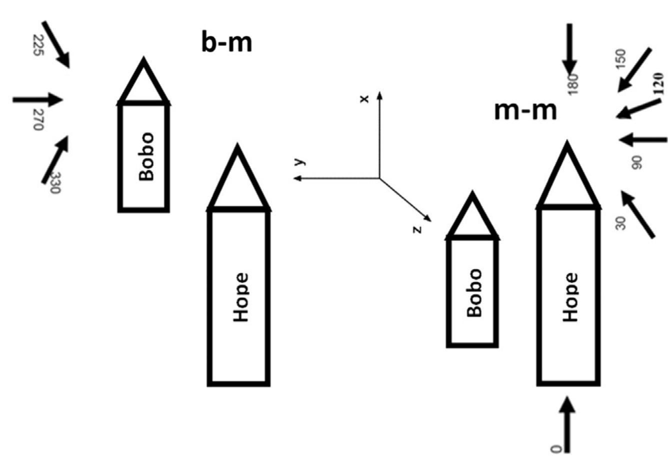

Fig. 1. Definitions of m-m and b-m configurations, coordinates, and wave heading directions.

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