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Unsteady Hydrodynamic Interactions between Ships in Shallow Water

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SUMMARY A model is developed for the unsteady hydrodynamic interactions between two ships moving along parallel paths in shallow water. The problem is analogous to that for two porous airfoils passing each other. A system of singular integral equations is derived and solved numerically. The sway force and yaw moment may then be calculated for each ship. To test this model and numerical procedure, comparisons are made with published experimental results and theoretical results for the far field.

1 INTRODUCTION

The forces and moments occurring during ship-ship interactions have been the subject of several investigations in the past few years. This interest results from the number of ship collisions occurring each year and through further study it is hoped that additional information about hazardous situations will be obtained.

A ship is usually in close proximity to another ship or some obstacle when it is moving in restricted waterways such as harbours or canals. Ship-ship interactions can be divided into two classes, the simpler steady case and the unsteady case. Tuck and Newman (1974) formulated the shallow water problem for steady interactions by the use of results obtained from slender body theory. More recently, Tuck (1976) gave a general formulation for ships moving in shallow water.

Most ship manoeuvres are inherently unsteady and some types of unsteady manoeuvres have been investigated by Dand (1976), King (1977) and Yeung (1977). King examines unsteady interactions without bottom clearance by using thin-wing theory and provides a numerical procedure for solving such problems. Yeung has derived an analytic solution for the far field. The above two papers include the affects of circulation, whereas Dand does not.

In the present paper, by use of results obtained from slender body theory, unsteady ship interactions, with underkeel clearance for the ships, are studied. The numerical results obtained give reasonable agreement with experimental measurements. Particular manoeuvres to which this model can be applied include ships passing each other in opposite directions, the overtaking of one ship by another, and a ship passing a submerged sandbank or a stationary moored vessel.

2 MATHEMATICAL FORMULATION

The motion of n ships moving with possibly time-varying velocities parallel to the x-axis is considered. It is useful to investigate this problem in an absolute frame of reference (i.e. fluid at rest at infinity). The geometry of the j^{th} ship when it is moving to the left in a fluid of depth h is given in Figure 1. The ship segment B_j is represented by the interval $a_j(t) < x < b_j(t)$ and, for a ship moving to the left, the wake segment W_j by the interval $b_j(t) < x < \infty$.

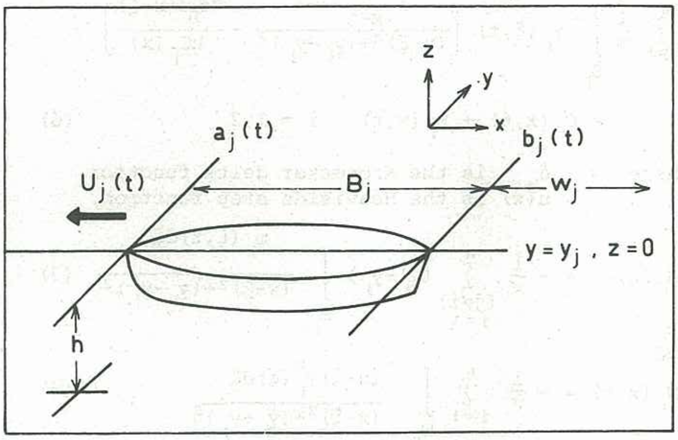

Figure 1 Geometry of j^{th} ship

In this paper only symmetric ships which are not yawed to their direction of motion will be considered, so that camber need not be included. Tuck (1976) has shown that the appropriate boundary condition on an uncambered slender ship j is

$$\frac{\partial}{\partial y}(\phi_y(x,y_j+0,t)+\phi_y(x,y_j-0,t))$$
$$= \frac{1}{hC_j(x)}(\phi(x,y_j+0,t)-\phi(x,y_j-0,t)) \qquad (1)$$

where $\phi(x,y,t)$ is the velocity potential and $C_j(x)$ is the non-dimensional blockage coefficient at station x (see Taylor (1973)). The flow is equivalent to that of a porous airfoil in unsteady motion, and $1/C_j$ plays the role of the permeability.

As in conventional wing theory, the lifting effects are modelled by vortices of strength $\gamma_j(x,t)$ on B_j+W_j, and thickness effects by sources of strength $m_j(x,t)$ on B_j. If the vortex strength is chosen as

$$\gamma_j(x,t) = -\frac{\partial}{\partial t}(\phi(x,y_j+0,t) - \phi(x,y_j-0,t)) \qquad (2)$$

then

$$\gamma_j(x,t) = \begin{cases} 0 & \text{ahead of } B_j \\ \text{unknown on } B_j \\ \gamma_j^w(x) & \text{on } W_j \end{cases} \qquad (3)$$

which means that once a vortex has been shed into the wake, its strength remains constant. Hence the disturbance velocity potential due to two ships has the representation

$$\phi(x,y,t) = \sum_{j=1}^{n} \left\{ \int_{B_j} m_j(\xi,t)\frac{1}{2\pi} \log \sqrt{(x-\xi)^2+(y-y_j)^2}\,d\xi + \int_{B_j+W_j} \gamma_j(\xi,t)\frac{1}{2\pi} \arctan\left(\frac{y-y_j}{x-\xi}\right)d\xi \right\} \quad (4)$$

where the branch of the arctan function must be chosen so that any jump in the velocity potential occurs across a wake or a ship.

By proceeding from the above formulation in a similar manner to Tuck (1976) and King (1977), it can be shown that the source distribution is given by

$$m_j(x) = u_j\, S_j'(x)/h \quad (5)$$

where $S_j(x)$ is the cross-sectional area of ship j at station x. The vortex distribution satisfies the system of integral equations

$$\sum_{j=1}^{n} \frac{1}{\pi} \int_{B_j} \gamma_j(\xi,t) \left[\frac{x-\xi}{(x-\xi)^2+(y_i-y_j)^2} - \frac{\pi\delta_{ij}u(x-\xi)}{hC_j(x)}\right] = G_i(x,t) + H_i(x,t) \quad i = 1,2 \quad (6)$$

where δ_{ij} is the Kronecker delta function, $u(x)$ is the Heaviside step function,

$$G_i(x,t) = -\frac{1}{\pi} \sum_{\substack{j=1\\(j\neq i)}}^{n} (y_i-y_j) \int_{B_j} \frac{m_j(\xi,t)\,d\xi}{(x-\xi)^2+(y_i-y_j)^2} \quad (7)$$

and

$$H_i(x,t) = -\frac{1}{\pi} \sum_{j=1}^{n} \int_{W_j} \frac{(x-\xi)\gamma_j^w(\xi)\,d\xi}{(x-\xi)^2+(y_i-y_j)^2} \quad (8)$$

All the functions on the righthand side of (6) are known provided that $\gamma_j^w(x)$, $x \in W_j$ is known. The righthand side has been divided into two terms to show the two different types of lift on each body. G_i is the lift due to the thickness of the other ship, and H_i is the lift due to the wakes of both ships. If cambered or yawed bodies are considered, a third term, involving camber-induced lift, occurs on the righthand side.

The system of integral equations does not possess a unique solution, so a trailing edge or Kutta condition is required on each body. The appropriate condition for a moving ship is that the vorticity at the trailing edge of each ship is equal to the vorticity in the wake adjacent, i.e.

$$\gamma_j(b_j(t),t) = \gamma_j^w(b_j(t)) . \quad (9)$$

For a stationary ship, the circulation around the ship must be zero, i.e.

$$\int_{B_j} \gamma_j(\xi,t)\,d\xi = 0 . \quad (10)$$

By using (9) and (10) when required, the unique solution for a given problem may be determined.

A numerical technique for solving the system of integral equations and finding the appropriate solution has been given by King (1977).

3 FORCES AND MOMENTS

For two ships in an interaction situation, the quantities of most interest are the sway force and yaw moment on the ships. These are determined by integrating the pressure jump across each ship. If the sway force is positive to starboard and the yaw moment positive for the bow turning starboard, the y-directed sway force on ship j is

$$Y_j(t) = -\rho h \int_{B_j} \frac{\partial}{\partial t} \int_{a_j(t)}^{x} \gamma_j(\xi,t)\,d\xi\,dx \quad (11)$$

and the net yaw moment about the centre of ship j is

$$M_j(t) = \tfrac{1}{2}\rho h \int_{B_j} (a_j(t)+b_j(t)-2x)\frac{\partial}{\partial t} \int_{a_j(t)}^{x} \gamma_j(\xi,t)\,d\xi\,dx . \quad (12)$$

4 RESULTS

To test the above formulation and suggested numerical technique, numerical results were obtained and compared with the experimental results of Remery (1974). The blockage coefficient is calculated using the formula derived by Taylor (1973). To simplify the calculation, the blockage coefficient is assumed to be constant along the whole ship. The term involving the blockage coefficient in (6) may then be evaluated analytically.

The experiments of Remery (1974) which are used for comparison consist of a model of a moored 100 MDWT vessel being passed by a 30 MDWT vessel. The depth of water for all experiments was equivalent to a full scale depth of 18 metres.

	Symbol	Unit	Moored Vessel	Passing Vessel
Deadweight	MDWT	1000 ton	100	30
Length	L	m	257	183
Beam	B	m	36.8	26.1
Draught	d	m	15.7	10.5

Table 1 Relevant Dimensions of Ships

Figures 2 and 3 show the results obtained for the passing manoeuvre with a separation of 61.4 metres between the parallel paths. The graphs show that satisfactory agreement is obtained with the experiments but that the magnitude of both the sway force and yaw moment on the stationary ship are slightly underestimated. When compared with the far field results of Yeung (1977) the graphs are also quite similar, showing that the far field results are a good approximation even for close interactions. Although both theoretical computations underestimate the force and moment, Beck (1976) found a similar phenomenon for a ship in a canal, and found that when the forces for the interactions between the source distributions were

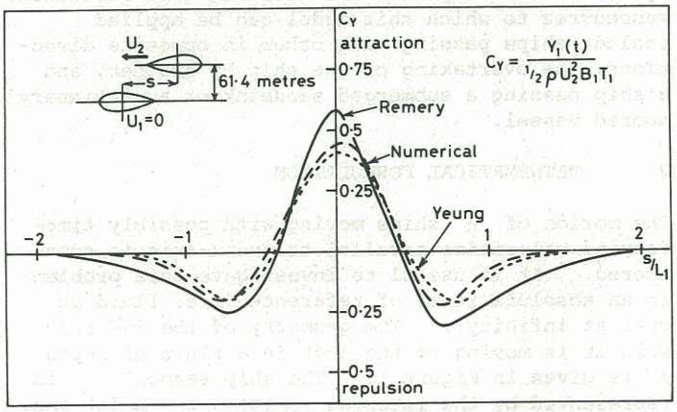

Figure 2 Sway force on a stationary ship for a separation of 61.4 metres.

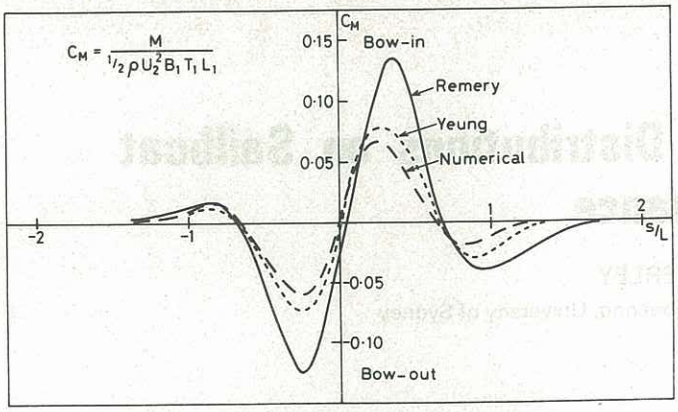

Figure 3 Yaw moment on a stationary ship for a separation of 61.4 metres.

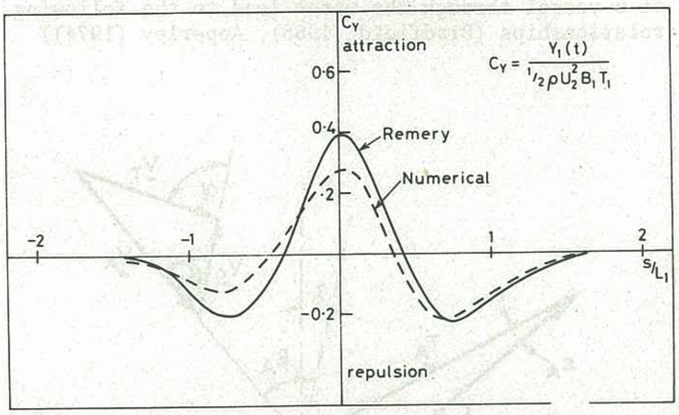

Figure 4 Sway force on a stationary ship for a separation of 96.4 metres.

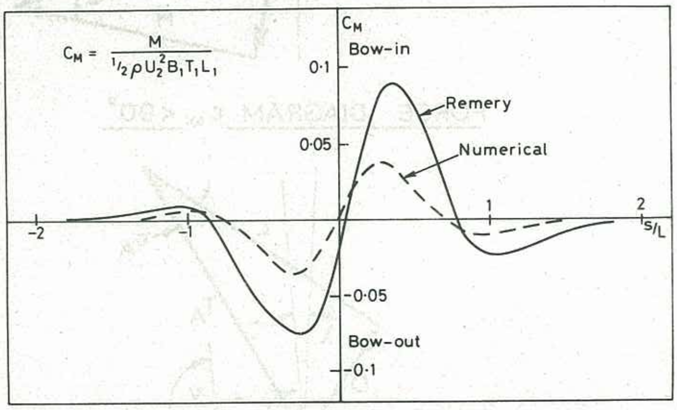

Figure 5 Yaw moment on a stationary ship for a separation of 96.4 metres.

added, a correction was obtained which gave better agreement.

Figures 4 and 5 show the results obtained when the separation is 96.4 metres, and again it can be seen that both the magnitude of the sway force and the yaw moment are underestimated. When comparing the two different experiments it is significant that the force and moment decrease quite rapidly as the separation increases.

5 CONCLUSION

For the limited number of available comparisons with experiments, it was found that the present formulation and numerical technique produce satisfactory results. As the qualitative agreement is good the approach in this paper should be useful for giving predictions for ship interactions which are difficult to model by experiment. Many different simulations can be carried out by this method, such as investigating the effect of varying the depth of the water, which can cause large changes in the force and moment.

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