WAVE INDUCED MOTIONS OF SURFACE EFFECT SHIPS

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INTRODUCTION

A computer program for computation of the motions of and loads on high speed vessels has been developed. The program is based on linear theory and the interaction between the hulls is neglected. The program can be used for a variety of vessels type including catamarans, foil-catamarans and Surface Effect Ships. In this study we describe the theory and some results for Surface Effect Ships.

MATHEMATICAL FORMULATION

The velocity potential is written as the sum of a steady and an unsteady part

$$\Phi(x,y,z,t) = Ux + \phi_s(x,y,z) + \Phi(x,y,z,t) \tag{1}$$

Within linear theory the unsteady potential is decomposed as follows:

$$\phi(x,y,z,t) = [A(\phi_I + \phi_D) + \sum_{j=1}^{7} \eta_j \phi_j(x,y,z)]\, e^{i\omega_e t} \tag{2}$$

where A is the wave amplitude, ω_e the frequency of encounter, and the indices I,D and $j=1,7$ denote incident, diffraction and radiation respectively. The seventh degree of freedom is the pressure variation Δp in the cushion which is represented by

$$\Delta p / p_0 = \hat{\eta}_7 e^{i\omega_e t} \tag{3}$$

where p_0 is the mean excess pressure in the cushion. The corresponding potential, the pressure potential satisfies the following boundary conditions;

$$\frac{\partial \phi_7}{\partial n} = 0 \quad \text{on wetted hulls} \tag{4}$$

$$(i\omega_e + U\frac{\partial}{\partial x})^2 \phi_7 + g\frac{\partial \phi_7}{\partial z} = -\frac{1}{\rho}(i\omega_e + U\frac{\partial}{\partial x})p_0 \quad \text{on the free surface} \tag{5}$$

Outside the cushion, $p_0 = 0$. The boundary value problem for ϕ_7 is solved by writing it as a sum of two parts

$$\phi_7 = \phi_7^1 + \phi_7^2 \tag{6}$$

The potential ϕ_7^1 satisfies the free surface condition, but no boundary condition on the body is imposed. Assuming a rectangular pressure patch, this potential can be obtained in closed form (Kim & Tsakonas [1]). The potential ϕ_7^2 will then satisfy the homogeneous free surface condition and the condition

$$\frac{\partial \phi_7^2}{\partial n} = -\frac{\partial \phi_7^1}{\partial n} \tag{7}$$

on the body. The boundary value problem for ϕ_7^2 is analogous to the diffraction problem and it is solved by the same method. The radiation and diffraction problems are solved by using the high speed slender body approximation of Faltinsen & Zhao [2].

$$\phi(x,y,z) = \exp[-i(\omega_e/U)x]\Psi(x,y,z) \tag{8}$$

The equation for Ψ is parabolic in x and the solution can be found by stepping from the bow along the ship and solving a 2-dimensional problem at each section.

The equation of motion for the SES will have some extra contributions to the stiffness matrix from the cushion which are given by:

$$C_{37} = -p_0 A_0 \quad , \; C_{57} = p_0 A_1 \quad \text{and} \quad C_{44} = -\frac{1}{2}\rho g \left(\frac{p_0}{\rho g}\right)^2 \tag{9}$$

where A_0 and A_1 are the zeroth and first order longitudinal moments of the waterplane area. There are also contributions from the seals to the damping and stiffness matrices.

The equations of motion are supplemented by the continuity equation for the air cushion(s) which may be written in a similar form as the equation of motion:

$$\sum_{j=1}^{7} [-\omega_e^2 a_{7j} + i\omega_e b_{7j} + c_{7j}]\hat{\eta}_j = AX_7 \tag{10}$$

where

$$a_{7j} = \frac{1}{\omega_e} \mathrm{Im} \iint_{\bar{s}_A} \varsigma_j dxdy \tag{11}$$

$$b_{7j} = -\mathrm{Re} \iint_{\bar{s}_A} \varsigma_j dxdy + A_0\delta_{3j} - A_1\delta_{5j} + \frac{V_0}{\gamma(1 + p_a/p_0)} \tag{12}$$

$$c_{7j} = \left[\frac{1}{2}Q_0 - p_0\left(\frac{\partial Q}{\partial p}\right)_0\right]\delta_{7j} \tag{13}$$

$$X_7 = i\omega_e \iint_{\bar{s}_A} (\varsigma_I + \varsigma_D) dxdy \tag{14}$$

where ς_j , ς_I and ς_D are the surface elevation corresponding to the radiation, incident and diffraction potentials respectively, V_0 is the cushion volume, γ is the ratio of spesific heats for air (=1.4), p_a the atmospheric pressure, Q_0 the mean leakage flux and $\left(\frac{\partial Q}{\partial p}\right)_0$ is the inverse slope of the fan characteristic curve. An approximate solution, here called the simplified model, is obtained by omitting the integral terms in a_{7j} and b_{7j} and the contribution from the diffracted wave in X_7. This approximation will in general have minor influence on the response, but the more detailed description of the pressure field is of importance for the shear forces and bending moment. Some results for the response are given in McHenry et al. [3].

NUMERICAL RESULTS

Using the simplified model, the effect of dividing the air cushion in two by a seal mid-ships, was studied. The objective of such a design would be to increase the pitch stiffness (cf. fig. 1) and thereby move the resonance frequency out of the region with significant wave energy in a typical sea state. In addition one may expect that this change will reduce the magnitude of the response away from the resonance frequency. Figures 3 and 4 show that this is not the case. The resonance peak has been removed, but the magnitude of the response is larger for a considerable interval of frequencies. The reason for this is that for two cushions the excitation force will be considerably increased for wavelengths comparable to the ship length (cf. fig. 2) since the air can not escape from one cushion to the other. In a typical sea state these wavelengths have considerable energy and will therefore give an increase in the response.

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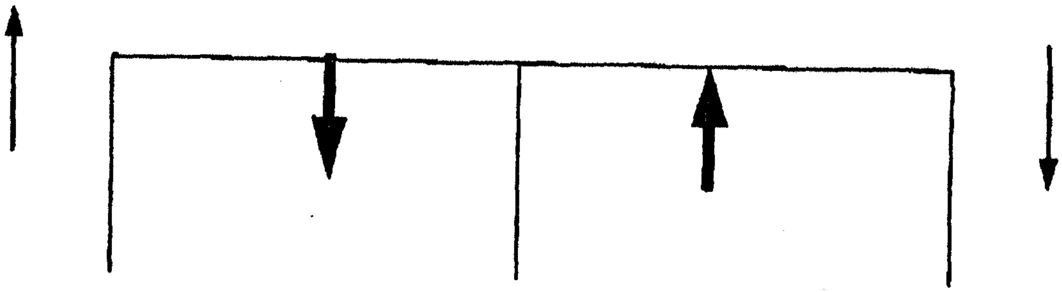

Figure 1:
Effect of two cushions: Additional restoring moment in pitch.

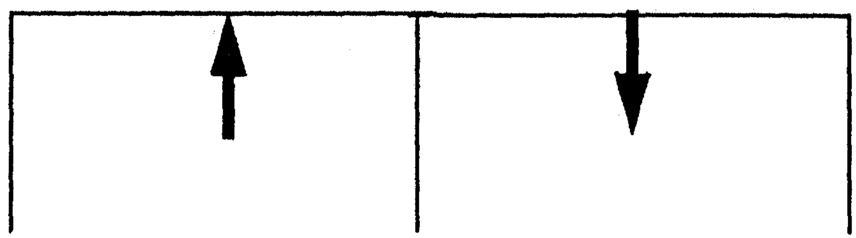

Figure 2:
Effect of two cushions: Increased exciting moment in pitch

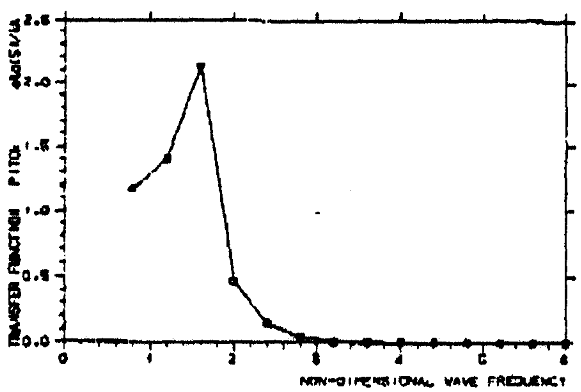

Figure 3:
Pitch response in head sea for Fn=1.22, one cushion

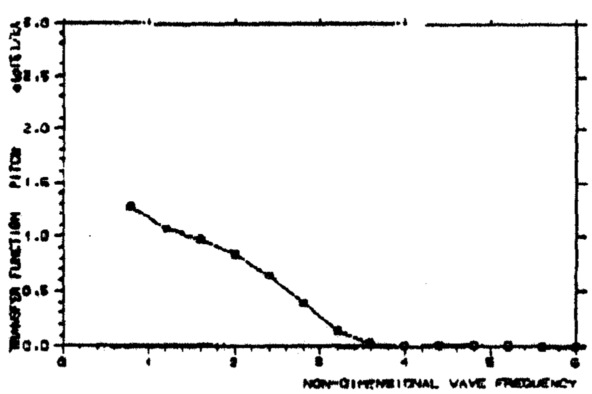

Figure 4:
Pitch response in head sea for Fn=1.22, two cushions