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Dependence of SWATH Ship Response in Waves on Choice of Viscous Coefficients

by

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1 Introduction

Analytical methods to predict motions and wave induced loads of SWATH ships in a seaway need to account for effects of viscous lift and damping on hulls and lift and drag on stabilizing fins. This is because SWATH ships have a small waterplane area and do not generally generate large waves when oscillating in the vertical plane. Potential (wave making) damping, therefore, is relatively small, and viscous effects contribute significantly to damping, specially at resonance conditions. We developed an improved model to account for effects of viscous force components that act on the hulls and produce lift and drag on stabilizing fins. Similar to earlier models developed by, e.g., Lee and Curphey (1977) and extended by McCreight (1987), our model is based on semi-empirical expressions that utilize experimental data from a range of sources.

In developing this model, it was necessary to assure that the resulting forces due to viscous effects are valid also for the zero speed case. This case is of practical importance because, in general, SWATH ships experience their most severe wave loading under zero speed beam sea conditions.

Our calculations are based on formulating the equations of motion as rigid body dynamic responses of the ship to harmonic exciting forces and moments caused by free surface waves (Schellin and Rathje, 1995). We consider the ship advancing at constant mean forward speed on the free surface in small amplitude waves. The resulting six coupled linear motion equations include two groups of hydrodynamic forces. One group is obtained under the assumption of potential flow, while the other group, comprising suplemental damping and lift forces on hulls and stabilizing fins, is associated with the viscous nature of the flow. It is the latter group that is of interest here. We adopt an empirical approach according to experimental results of side forces generated on slender bodies proportional to viscous drag and lift coefficients and of lift forces on wing sections.

We are currently in the process of conducting systematic calculations to demonstrate the effect on predicted ship motions and wave induced loads by assuming different input values of viscous drag and lift coefficients. The purpose is to determine the sensitivity of selecting appropriate coefficients.

2 Viscous Lift and Damping on Hulls

For a harmonically oscillating slender body advancing with constant forward speed in regular waves, we express the fluid force Q due to viscous lift and cross flow drag as

$$Q = \frac{\rho}{2} \int_{A^H} V^H \sin\alpha^H \left(C_L^H \left| V^H \cos\alpha^H \right| + C_D^H \left| V^H \sin\alpha^H \right| \right) dA^H \tag{1}$$

where α^H is the angle of incidence of flow at a cross section of the body, V^H is the relative fluid velocity at the section, and C_L^H and C_D^H are the viscous lift gradient and the cross flow drag coefficient, respectively. The density of water is ρ. The strip concept is introduced in this expression, where A^H is the projected plane area along an incremental length of the body. Expression (1) is not restricted to small angles of incidence.

The first term of (1) accounts for hydrodynamic lift due to vortex shedding around a slender body at steady state translation. The second term arises from boundary layer growth and flow separation. Values of C_L^H and C_D^H depend on the body's geometry, its mode of motion, and the frequency of oscillation encountered. In practice, these coefficients have to be obtained experimentally. Experiments on airship models with circular and polygonal cross sections in uniform flow at small angles of incidence resulted in lift force gradients of about 0.007, while drag coefficients were found to be between 0.4 and 0.7 (Thwaites, 1960).

Assuming pseudo steady state conditions, we let the relative cross flow velocity at an oscillating ship section act at the angle of attack. To determine wave particle velocities for the relative velocity, we consider only the incident wave potential. The longitudinal components of the relative velocity are approximated by the ship's mean forward speed. Viscous forces in the longitudinal direction of the body are neglected.

To calculate the fluid force due to viscous effects on the hulls based on (1), each hull is subdivided into transverse strips. Viscous interaction between hulls is neglected. The cross flow drag term in (1) is nonlinear and cannot be directly introduced in linear motion equations. We use the principle of harmonic balance to obtain a linearized approximation. The resulting viscous forces and moments on the hulls are separated into viscous damping, viscous restoration and viscous excitation and inserted as added terms of hydrodynamic response and wave exciting force in the motion equations.

3 Lift and Drag on Stabilizing Fins

For stabilizing fins fixed to the hulls, the angle of attack is estimated from the ship's pitch angle and the relative fluid velocity with respect to the fins. Obtaining the relative velocity components involves solving for the motion of the fins with respect to the fluid motion caused by the incident and refracted waves as well as the forward speed of the ship. There are several important hydrodynamic effects that should be considered when predicting forces on fins, such as body-fin interactions, blockage of the other hull, upwash and downwash between fins, free surface influence on fins, etc. We neglect all but the body-fin interaction and account for this effect based on the procedure documented by Lee and Curphey.

The vertical force acting on a stabilizing fin comprises the three force components hydrodynamic lift, cross flow drag and virtual inertia. Lift L is calculated from

$$L = \frac{\rho}{2} A^F V^F \sin\alpha^F \left(C_L^F \left| V^F \cos\alpha^F \right| \right) \tag{2}$$

where A^F is the plane area of the fin, C_L^F is the lift curve slope, and V^F is the relative velocity of the fin's center of pressure, assuming the flow not to be influenced by the fin's presence. The center of pressure of a thin fin is assumed located a quarter chord length behind its leading edge and somewhat closer to the hull than its areal centroid. The influence of incident waves on fin forces is accounted for by letting the relative fluid velocity vector at the fin's center of pressure act over the entire fin area. Radiated and diffracted waves from fins are neglected. The relative fluid velocity components at the fin's center of pressure are thus a function of the wave particle velocities, the translational and rotational motions of the fins due to ship motions, and the ship's forward speed. Expression (2) is not restricted to small angles of incidence.

Drag force D on a vertically oscillating fin, linearized according to the principle of harmonic balance, is calculated from

$$D = \frac{\rho}{2} A^F V^F \sin\alpha^F \left(C_D^F \left|V^F \sin\alpha^F\right|\right) \tag{3}$$

where C_D^F is the cross flow drag coefficient of the fin.

Unless the mass of a fin is specified, it is approximated by taking the fin section as a neutrally buoyant ellipse. A fin's added mass is approximated by a cylinder of fluid with length equal to its span and diameter equal to its chord. Expressions for vertical force on fins are separated into damping, restoration and excitation and inserted as added terms of hydrodynamic response and wave exciting force in the motion equations.

4 Results and Discussion

Using a three-dimensional panel method (Schellin and Rathje), we performed numerical computations to predict motions and structural response of the two single strut SWATH ships AEGEAN QUEEN and WFS-752 in regular waves at different Froude number F_n. Both ships are equipped with two pairs of stabilizing fins located at the fore and aft ends of their hulls. Lift and drag coefficients were carefully chosen from available literature. For the AGEAN QUEEN in head waves, transfer functions of heave and pitch motions, plotted against nondimensionalized frequency of encounter $\omega\sqrt{L/g}$, are shown in Fig. 1. For the WFS-752 in beam waves, transfer functions of heave and roll motions and wave induced sectional loads in the cross deck structure, plotted against wave period T, are shown in Fig. 2. Comparative model test measurements are shown as well. In these figures, motions are nondimensionalized with wave amplitude ζ; transverse forces and moments in the cross deck structure, with $g\Delta\zeta/L$ and $g\Delta\zeta$, respectively. Here g is acceleration of gravity, Δ is the ship's displacement, and L is the ship's characteristic length.

Agreement between our predictions and test results is seen to be favorable. Even peak values at resonance conditions are close to experimental results. To a large extent, this favorable agreement is due to the choice of lift and drag coefficients. To ascertain the importance of chosing these values "correctly," we are in the process of performing a series of systematic calculations, whereby the values of these coefficients are varied to cover the range of uncertainty commonly encountered in practice.

5 References

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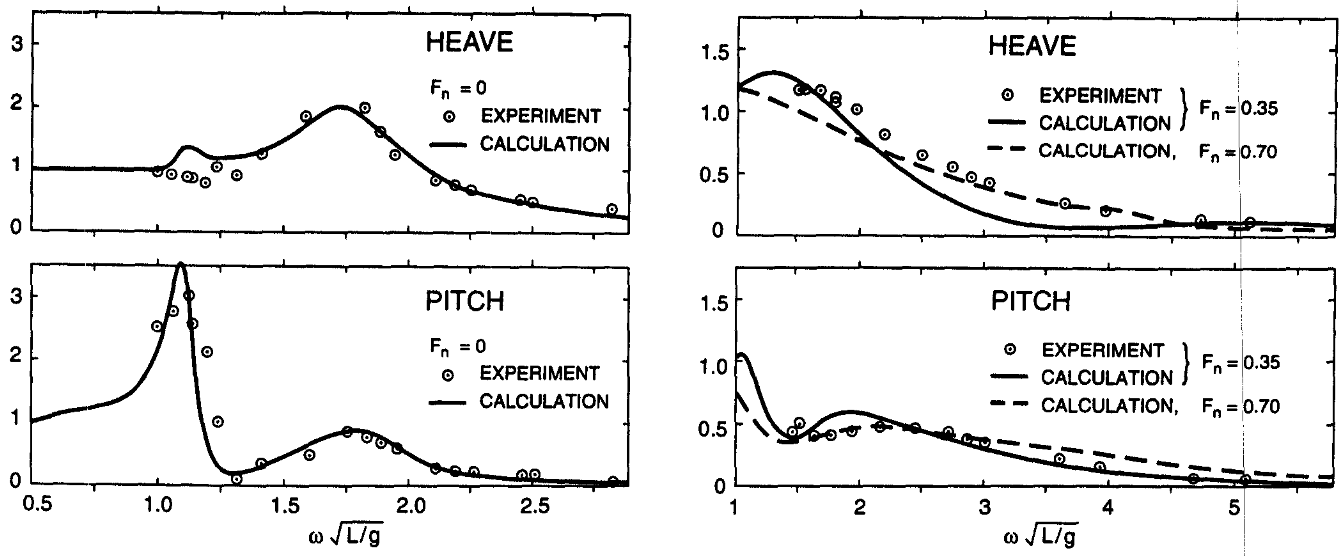

Fig. 1: Motions of AEGEAN QUEEN in head waves (Schellin and Rathje, 1995)

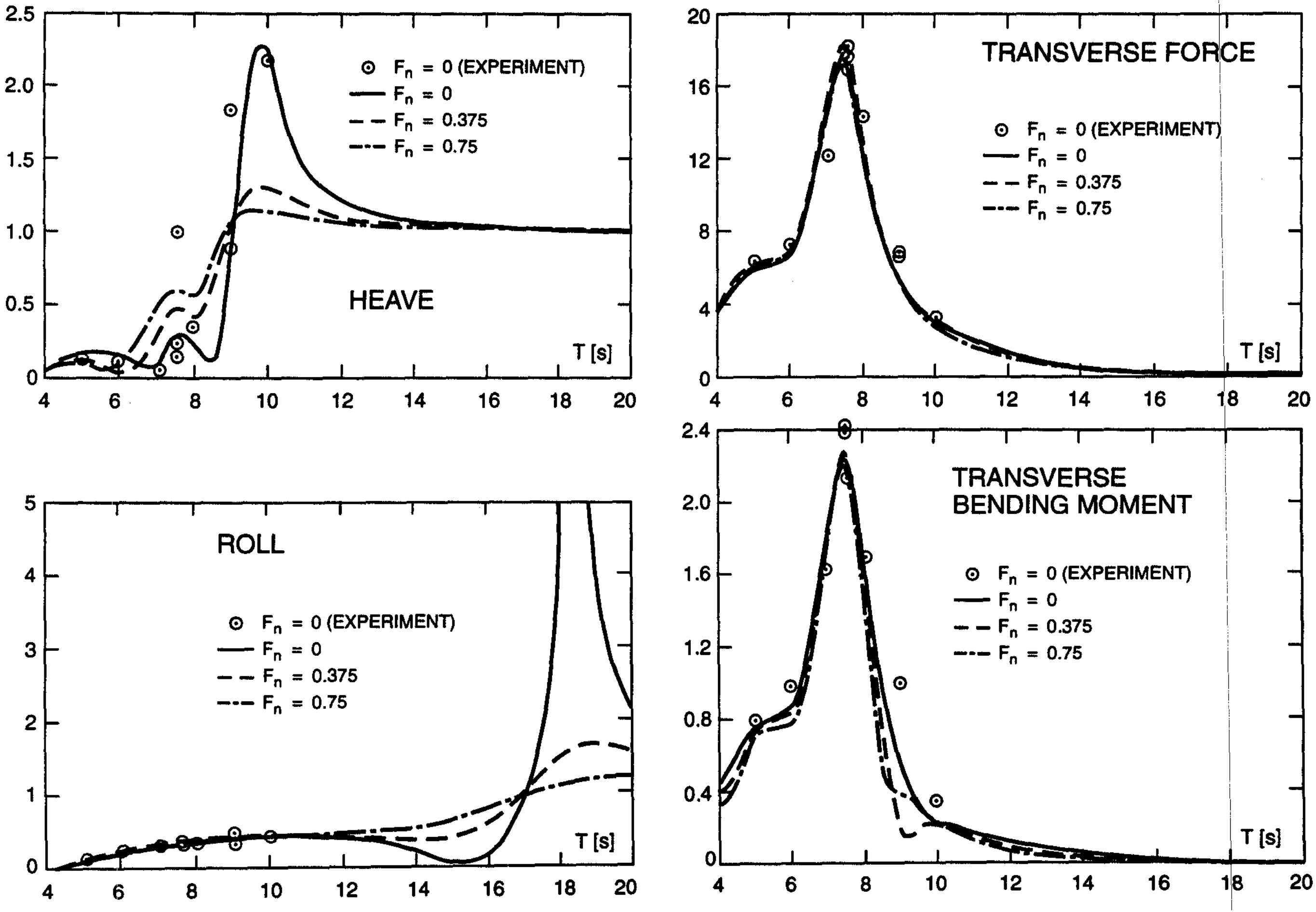

Fig. 2: Motions and sectional loads of WFS-752 in beam waves (Schellin and Rathje, 1995)