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Hydrodynamic Coefficients of Rolling Rectangular Cylinders

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ABSTRACT

Fluid viscosity is known to influence hydrodynamic forces on an oscillating body when its motion amplitude is large and its shape is bluff. An experimental program is developed to measure the roll inertia and damping of a floating rectangular cylinder, a problem of intrinsic interest in evaluating the resonant motion of ships in waves. Results from the experiments are compared with those from a recently developed method for modeling vortical flow in the presence of a free surface. This free-surface random-vortex method (FSRVM, Yeung and Vaidhyanathan, 1994) is observed to yield predictions consistent with the measured results for the "diagonal" terms. However, cases exist where both results produce added roll inertia that differ from those measured by Vugts (1968). A promising roll hydrodynamic loading model that includes both linear (wave-related) and nonlinear (flow-separation related) damping is also proposed and evaluated in the paper.

INTRODUCTION

In order to predict the roll motion of marine vehicles with accuracy, viscous-flow models need to be developed. While a number of empirical methods exists for engineering purposes (see Himeno, 1981), predictions based on rational-mechanics methods are only emerging. When a vehicle undergoes large-amplitude motion, separation occurs around the bilges, and it is conceivable that this would change the hydrodynamic character of the flow from what is normally predicted by inviscid-fluid flow theory (Wehausen, 1971). The nature of this inviscid and viscous coupling has received some attention (Downie et al., 1990; Yeung and Wu, 1991; Yeung and Ananthakrishnan, 1992; Gentaz et al., 1997), even though a complete understanding is yet to be achieved. In a sequel of works (see Yeung and Cermelli, 1998, for a short review), an effective grid-free numerical method was developed to model viscous flow in the presence of a free surface. The method is based on the Random Vortex algorithm, but properly improved to accommodate bodies of arbitrary shapes and reformulated to include the effects of free surface. There has been considerable success in applying this methodology, called FSRVM (Free-Surface Random Vortex Method), to modeling heave and sway motion of bodies (see Yeung and Vaidhyanathan, 1994). Its effectiveness to model flow associated with rolling motion has been rigorously investigated (Yeung et al., 1996) by examining the flow about a rolling plate and comparing predictions with detailed experimental data involving DPIV (Digital Particle Image Velocimetry). This last work indicated that not only forces and moments were well predicted, but the vortical patterns associated with such flows were also well reproduced.

Only a limited amount of applications of FSRVM has been applied to realistic ship-like sections. A classical test shape is rectangular cylinders. In Yeung et al. (1996), it was found that the computed added roll inertia did not appear to uniformly agree with the results measured by Vugts (1968). Vugts himself felt uncertain about his measured hydrodynamic properties due to roll. Among other causes of difficulties, roll characteristics are inherently difficult to measure because of the large mass inertia and hydrostatic moment of a typical model. In order to establish more credibility of the experimental data, and to validate our FSRVM model, a synergistic effort involving both experiments and theoretical predictions would be appropriate. In this set of experiments, particular care was taken based on Vugts' experience. Even so, limitations on the capability of our apparatus have prevented us from covering the full range of frequency that is of practical interest, particularly at the largest roll amplitude being considered.

Our experiments showed that viscosity causes higher damping, which is to be expected, but lower added-moment of inertia coefficients. This is similar to what Vugts had found. However, when the amplitude of roll is greater than 5°, the added-moment coefficients seem to saturate and are not affected by further increase in the amplitude. This behavior disagrees with Vugts' results but was substantiated by the computations of FSRVM.

Because flow separation clearly affects the hydrodynamic moment on the oscillating body significantly, we propose, in the last section of the paper, a composite model to represent this effect. Unlike traditional models, the hydrodynamic moment is expressed as the sum of three terms: the added inertia, a linear damping associated with surface wave generation, and a quadratic damping term related to vortex generation. A method of separating these terms based on the roll-moment time history is developed and illustrated.

EXPERIMENTAL INVESTIGATION

Setup

The experiments were conducted at the conducted at the Ship Model Testing Facility of the University of California at Berkeley. An 8' × 1' × 1' rectangular acrylic cylinder as shown in Fig. 1 was hinged at the water level by the sides of the tank. The model is geometrically similar to the one used by Vugts (1968) and the bilge radius was determined accordingly. A hydraulic cylinder that can accept random-motion input (Random Motion Mechanism, Hodges and Webster, 1986) was used to oscillate the model at various frequencies. The RMM is a piston driven by a servo-valve actuator capable of an axial load of ±1000 lbs. The position

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