Study of Dynamic Characteristics of High speed Catamaran Hull Form at sea waves

Mehdi Rowshan [1], Mohammad Javad Ketabdari [2], Mehdi Behzad [3]

Shiraz Air Naval Research Center. PO: 71949-15685
(me_rowshan@yahoo.com)

Abstract
In the new millennium, significant changes can be seen in the form of novel hull forms suitable for high-speed operation. Several authors have made significant contributions over the last few years tothe evaluation and analysis of dynamic performance of high-speed multihull forms. In this paper, an attempt has been made to present the dynamic characteristics of a high-speed catamaran hull form. The two-dimensional strip theory method (using Lewis-form sections) has been used to predict the heave and pitch motions in frequency domain. Finally the response amplitude operators (RAO) at different directions (wave entrance ahead and laterally) are obtained.

Keywords
Catamaran;dynamic characteristics; frequency domain

Introduction

Min et al (1993) [1] carried out a dynamic study on the development of a mid-size high-speed catamaran ferry based on the theoretical methods of strip theory and a three-dimensional source distribution; although the study concluded that strip theory is inaccurate in the high-speed region, no noticeable differences have been observed in both methods. The authors emphasize that the strip-theory method could be utilized as a practical tool to estimate dynamic Performance of catamarans. A further paper by Fang et al (1997) [2] introduced an extension of the linear frequency domain theory to a quasi-non-linear time-domain technique to compute the large-amplitude motions in regular waves. The authors have solved the coupled heave and pitch equations in time domain by the Runge-Kutta method and have experimented with a catamaran in head seas to compare the linear and nonlinear methods. Varyani et al (2000) [3] have presented the behavior of a catamaran hull form with and without forward speed. Like the previous authors, two different methods have been used, namely, strip theory and the three-dimensional pulsating-source method. Minor differences have been noted at zero forward speed in both methods. Monohull and catamaran hull configurations showed similar responses at higher speeds and higher frequencies. This was attributed to decrease interferences between the demihulls at high speeds for certain values of the hull spacing and the wave frequency. In this paper, we present results for heave and pitch motions in two main directions of wave entrances (heading and laterally) for typical catamaran hull form generally used in the high-speed ferry industry. The hydrodynamic coefficients in equations of motion are estimated by conformal mapping using Lewis-form sections and numerical method used to predict the heave and pitch motion is the two-dimensional strip theory method in frequency domain. Finally the response amplitude operators (RAOs) are obtained for different velocities and encounter wave frequencies.

1- Vessel specifications

The catamaran (two hulls) form has been designed to be able to operate in a wide variety of conditions, from 5 knots in survival sea conditions to 40 knots in calm seas. Table 1 provides the main particulars of the vessel and the body plan is brought in figure 1.

2-Characterizing Vessel Response

A vessel may be considered as a complex vibratory system with six degrees of freedom; these are often termed the rigid body modes. The motions of a ship in response to waves may be considered as a forced damped-spring-mass system. Here we only deal with the coupled motions of pitch and heave. The ship

Motions of heave, pitch and roll are oscillatory in nature; this is due to the restoring force created by changes in buoyancy involved in these motions. The two relevant equations of motion are:

For heave:

$$(M + A_{33})\ddot{\eta}_3 + B_{33}\dot{\eta}_3 + C_{33}\eta_3 + A_{35}\ddot{\eta}_5 + B_{35}\dot{\eta}_5 + C_{33}\eta_5 = F_3 e^{i\omega_e t}$$

[1]

And for pitch:

$$(I_5 + A_{55})\ddot{\eta}_5 + B_{55}\dot{\eta}_5 + C_{55}\eta_5 + A_{33}\ddot{\eta}_3 + B_{53}\dot{\eta}_3 + C_{53}\eta_3 = F_5 e^{I\omega_e t}$$

[2]

The solutions to the coupled heave and pitch equations are found using the method, which is outlined below:

$$P = C_{33} - (m + A_{33})\omega_e^{\ 2} + iB_{33}\omega_e$$

$$Q = C_{35} - A_{35}\omega_e^{\ 2} + iB_{35} - \omega_e$$

$$R = C_{53} - A_{53}\omega_e^{\ 2} + iB_{53}\omega_e$$

$$S = C_{55} - (I_{55} + A_{55})\omega_e^{\ 2} + iB_{55}\omega_e$$

[3]

$$Z_3 = \frac{F_5 Q - F_3 S}{QR - PS} = Z_{30} e^{i\varepsilon_3}.$$ Heave response

[4]

$$Z_5 = \frac{F_3 R - F_5 P}{QR - PS} = Z_{30} e^{i\varepsilon_5}$$ Pitch response

[5]

2-2- Wave Excitation Force and Moment

The wave excitation force and moment drive the motions of the vessel. For solutions of the coupled heave and pitch equations of motion, only the global force and moment are required; however, for solution of the wave induced shear force and bending moment, the forces must be divided into the sectional Froude Kriloff and diffraction forces. The method used here for the evaluation of the Global Wave Excitation Force and Moment is the sectional Froude Kriloff and diffraction forces for arbitrary wave angles, which are given by:

$$F_3 = \rho\zeta_0 \int (f_3 + h) d\xi + \rho\varsigma_0 \frac{U}{i\omega} h_3{}^A$$

[6]

$$F_5 = -\rho\varsigma_0 \int \left[\xi(f_3 + h_3) + \frac{U}{i\omega} h_3 \right] d\xi - \rho\varsigma_0 \frac{U}{i\omega} x_A h^A$$

[7]

f_3 : Is the sectional Froude krioloff force.

h_3 : Is the sectional diffraction force.

The vessel is considered to be a rigid body, floating in the surface of an ideal fluid, which is homogeneous, incompressible, and free of surface tension, irrotational and without viscosity. It is assumed that the problem of the motions of this floating body in waves is linear or can be linearised. Consequently, only the external loads on the underwater part of the ship are considered here and the effect of the above water part will be fully neglected. Strip theory by using conformal mapping is used for the calculation of the sections' hydrodynamic properties. The vertical motions of a vessel (pitch and heave) are most readily calculated by subdividing the vessel into a number of transverse strips and finally considering the forces on each of those strips. The two-dimensional added mass, damping and restoring coefficients are calculated for each strip, and the respective global coefficients are then found by integrating along the length of the hull. It is assumed that the amplitude of oscillation is sufficiently small that the response of the vessel will remain linearly proportional to the amplitude of the waves. The encounter frequency may be calculated by considering the component of vessel velocity in the direction of the waves and subtracting the wave phase velocity c. Often the vessel is assumed to be operating in deep water. Thus using the deep-water wave speed relationship, the encounter frequency simplifies to:

$$\omega_e = \omega - \frac{\omega^2 U}{g} \cos\mu$$

[8]

3 - Response Amplitude Operator

In this work the heave and pitch motions are coupled together. The response amplitude operators (or transfer functions) of a vessel are such as that describing a forced spring, mass and damper system. In general for each motion the mass; damping and stiffness coefficients will be different, thus changing the exact shape of the curve. It is normal practice to non-dimentinalise the various motions as follows:

Linear motion-wave amplitude; linear motion transfer function: $RAOz = \frac{z_0}{\varsigma_0}$

Angular motion-wave slope; Angular motion transfer function: $RAO_\theta = \frac{\theta_0}{k\varsigma_0}$

4- Conclusion

In this paper the motions for a modern catamaran hull form for two moderate and high speeds (V=20 knot and V=40 knot) is determined numerically and the diagrams of response amplitude operators are calculated and drawn for two wave entrances ($\mu = 90^0$ and $\mu = 180^0$) (figures 2-5). The behaviors of the vessel for two velocities are nearly the same with differences in resonance frequencies and the magnitudes of RAOs. The hydrodynamic coefficients are calculated with the maxsurf program. In heave motions for the wavelengths more than ship length the vessel exactly follows the wave entrance (RAO=1). And in the pitch motion for Heading Sea will be increased with respect to increase of wavelength. The RAO tends to zero with the increase of encounter frequency. The table below shows the resonance frequencies at different wave entrances and velocities.

Velocity & Wave Entrance angle	Resonance frequency at Heave (Hz)	Resonance frequency at Pitch (Hz)
Heading: $\mu = 180^0$ V=20 Knot	0.75	0.81
Laterally: $\mu = 90^0$ V=20 Knot	1	0.97
Heading: $\mu = 180^0$ V=40 Knot	1.35	1.25
Laterally: $\mu = 90^0$ V=40 Knot	1.32	1.28

References:

[1]: A study on the prediction Method of Motion Characteristics for high speed Catamaran Ship Min, K.S., Yum, D.J., and Song, K.J. Fast 93, Yokohama, Vol. 1, PP 127-137.

[2]: Fang, C.C., Chan, H.S. and Inceeik, A. (1997). "Investigation of Motions of catamarans in Regular waves-II", Ocean Engineering, Vol.24, No.10, pp949-966.

[3]: Varyani, K.S., Gitiganti, R.M., and Gerigk, M. (2000). "Motion and Slamming Impact on Catamaran", Ocean engimeering, Vol. 27,pp 729-744.

[4]: Sea loads on ships and offshore structures, O.M Faltinsen, Cambridge University Press

Table 1: Vessel Characteristics

Length	96.35 m
Beam	45 m
Depth	15.113 m
draught	5.5 m
Waterline length	92.117 m
Prismatic coefficient	0.767

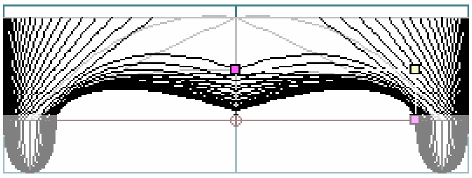

Figure 1: Body plan of the vessel

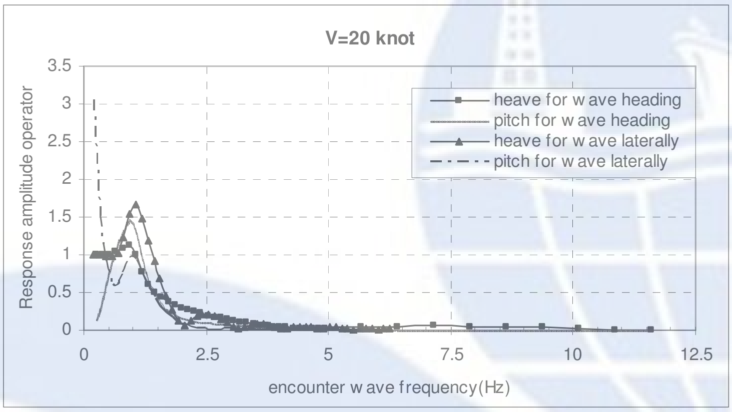

Figure2): heave and pitch responses for wave heading: $\mu = 180^0$ and laterally wave Entrance: $\mu = 90^0$ with respect to encounter wave frequency. (V=20 Knot)

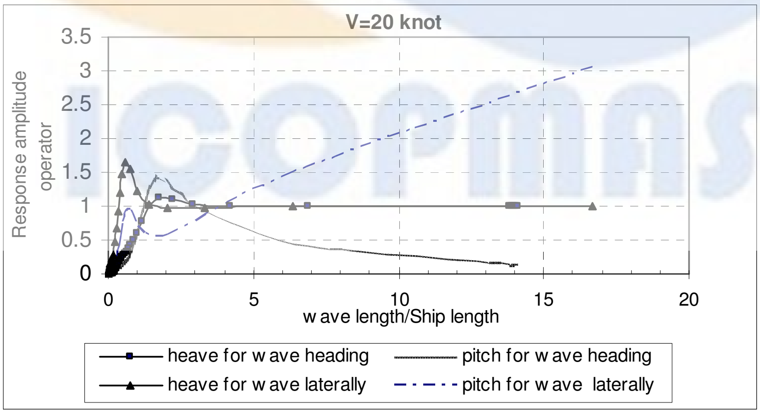

Figure3): heave and pitch responses for wave heading: $\mu = 180^0$ and laterally wave Entrance: $\mu = 90^0$ with respect to wave length/Ship length. (V=20 Knot)

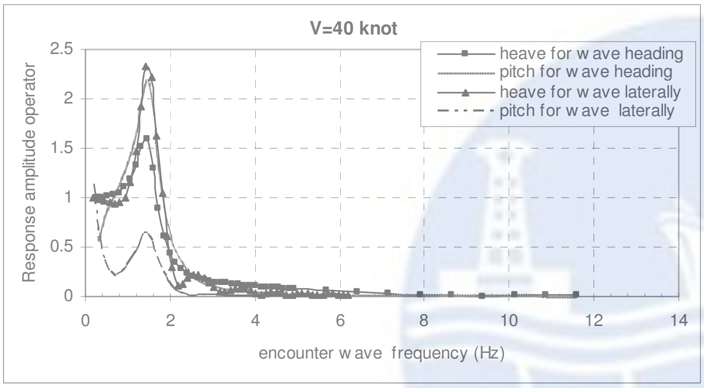

Figure4): heave and pitch responses for wave heading: $\mu = 180^0$ and laterally wave Entrance: $\mu = 90^0$ with respect to encounter wave frequency. (V=40 Knot)

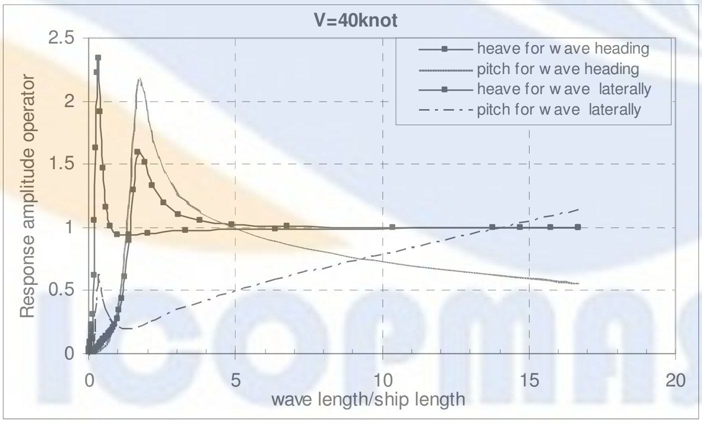

Figure5): heave and pitch responses for wave heading: $\mu = 180^0$ and laterally wave Entrance: $\mu = 90^0$ with respect to wave length/Ship length. (V=40 Knot)

1-MSc in Naval Architecture
2-Assistant Professor Amirkabir University of Technology
3-Associate Professor of Sharif University of Technology