Motions and Loads of a Catamaran Ship of Arbitrary Shape in a Seaway

C.H. Kim*

Stevens Institute of Technology, Hoboken, N.J.

An analytical method is presented for predicting the motions and loads of a catamaran of arbitrary shape running in oblique regular waves. Numerical calculations were carried out for the ASR catamaran and a semisubmersible. Correlations between the theoretical and experimental values are shown and a brief discussion is given.

Nomenclature

A_w = waterplane area
a = wave amplitude
B = beam ($\otimes$) of a single hull or buoyancy
B_m = overall beam ($\otimes$) of a twin hull
C = contour of a cross section
f = sectional wave-exciting force (or moment)
g = gravitational constant
G = center of gravity (c.g.)
G_a = center of gravity of hull "a"
h = wave elevation or incident wave
i = $(-1)^{1/2}$
I = inertial moment
ℓ_1 = length between LCG and FP
ℓ_2 = length between LCG and AP
L = length between perpendiculars
M = mass
M'' = added mass
K = symbol indicating keel
N = damping coefficient
S = section of bridging structure, or hull separation
T = period (or draft)
t = time or transverse distance
U = ship speed
x,y,z = moving coordinates on ship
X,Y,Z = fixed coordinates in space
ζ = heave amplitude
ρ = water density
Δ = displacement
∇ = displaced volume
ϵ = phase angle
η = sway amplitude
λ = wavelength
μ = wave incidence
ν_0 = wave number
ω_0 = circular frequency of wave
ω = circular frequency of encounter
Φ = velocity potential
φ = velocity potential or roll
ψ = pitch amplitude
χ = yaw amplitude

I. Introduction

OHKUSU and Takaki[1] reported on the heaving and pitching motions and transverse loads in head seas, and swaying, rolling, and heaving motions and transverse loads in beam seas of a twin hull. The twin hull is longitudinally symmetric and the sections of each hull are also symmetrical about its own longitudinal centerplane.

Wahab, Pritchett, and Ruth[2] reported the experimental results of motions and loads of the ASR catamaran in waves. The sections of each hull of the ASR catamaran are mostly asymmetrical about the longitudinal centerplane.

Lee, Jones, and Curphey[3] carried out an analytical prediction of heave and pitch of various catamarans (including ARS) moving in head seas, and heave and roll motions as well as the vertical shears and bending moment in regular beam waves for zero speed. Based on the assumption that the pitching and yawing motions are negligibly small in the beam sea responses, the three-dimensional motion and loading problem was simplified to one of finding the motion and loading of an equivalent two-dimensional body. The equivalent two-dimensional hull form is generated from the midship section of the catamaran in question. The midship section is then taken to be uniform over an equivalent length such that the actual displacement of the ship is obtained. The analysis shows that the heaving affects only the bending moment, and the vertical shear is affected by roll and sway.

The present study, on the other hand, is more general and describes an analytical method for prediction of motion (five degrees of freedom) and load (five components) of a catamaran of arbitrary shape uniformly advancing in oblique regular waves. The procedure is based on the strip method[4,5] developed for monohull ships and the two-dimensional method[6,7] developed for two hydrodynamically interacting cylinders of arbitrary shape floating in beam waves.

The analytical predictions of wave-exciting forces and moments, motion-induced forces and moments, as well as the motions of a catamaran, were reported in part in a recent paper[4] in which it was shown that the strip method devised for monohull ships could also be well applied to the catamaran-type ship.

In the investigation of the hydrodynamic interaction between two cylinders ("a" and "b") of arbitrary shape floating in beam sea,[6,7] it was pointed out that the heaving motion in calm water induces lateral and vertical forces on each body. Similarly, the swaying and rolling motions in calm water also induce lateral and vertical forces on each body. Some of these forces acting on bodies "a" and "b" are equal and opposite and therefore do not contribute to the resultant forces and moments on catamaran boats.

However, it should be kept in mind that all the forces on a section of each hull which are generated by its heave, sway and roll contribute to the loads at the bridging structure of the catamaran. In addition, it should be emphasized that in the defraction problem the wave-exciting forces on a section of each hull must be the vector sum of the corresponding forces due to both even and odd components of the incident waves. Therefore the loading at the bridging section is determined by summing up vectorially all the forces and the moments in-

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*Research Engineer.

duced by the motions (heave, pitch, sway, roll and yaw) and wave-exciting forces and moments on the starboard or port hull. The formulas for loads were derived on the basis of the previously mentioned considerations.

To confirm the reliability of the present method, extensive calculations of the motions and loads of the ASR catamaran were carried out, since extensive experimental information is available.[2] The comparison betweeen theoretical and experimental values shows fairly good agreement. As a second application of the present method, a semi-submersible catamaran of unusual shape which has been designed for Harbor Branch Foundation, Inc. and tested at Davidson Laboratory has also been employed.

It can be concluded that this method can be utilized to furnish required information at the preliminary design stage on the seakeeping qualities of a platform or arbitrary configuration such as a semi-submersible catamaran which is an appropriate configuration for self-propulsion at sea.

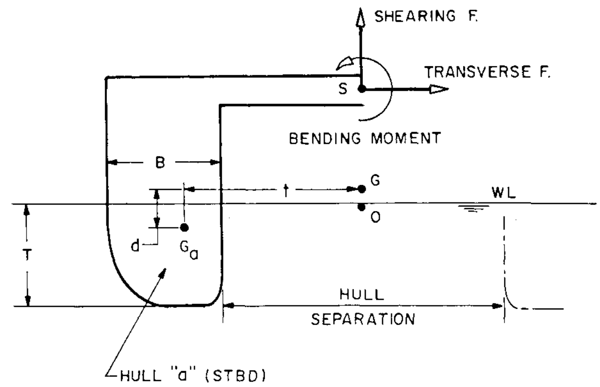

Fig. 1 Definition of loads.

II. Motions and Loads

As mentioned in Sec. I, the strip method devised[4,5] for conventional ship forms was successfully applied to the prediction of hydrodynamic forces and moments as well as motions of a catamaran of arbitrary shape. The formulas of the strip method can be obtained from Refs. 4 and 5.

The coupled heaving and pitching equations and the swaying, yawing, and rolling equations are given below. The hydromechanical coefficients are defined in Appendix A of Ref. 5.

$$\begin{bmatrix} \{(B_{\zeta\zeta}-\omega^2 M_{\zeta\zeta})-i\omega N_{\zeta\zeta}\} & -\{B_{\psi\zeta}-\omega^2 M_{\psi\zeta})-i\omega N_{\psi\zeta}\} \\ -\{(B_{\psi\zeta}-\omega^2 M_{\psi\zeta})-i\omega N_{\psi\zeta}\} & \{B_{\psi\psi}-\omega^2 M_{\psi\psi})-i\omega N_{\psi\psi}\} \end{bmatrix} \times \begin{bmatrix} \zeta/a \\ \psi/a \end{bmatrix} = \begin{bmatrix} F_{\zeta h}/a \\ F_{\psi h}/a \end{bmatrix} \tag{1}$$

and

$$\begin{bmatrix} (-\omega^2 M_{\eta\eta}-i\omega N_{\eta\eta}) & (-\omega^2 M_{\chi\eta}-i\omega N_{\chi\eta}) & (-\omega^2 M_{\phi\eta}-i\omega N_{\phi\eta}) \\ (-\omega^2 M_{\eta\chi}-i\omega N_{\eta\chi}) & (-\omega^2 M_{\chi\chi}-i\omega N_{\chi\chi}) & (-\omega^2 M_{\phi\chi}-i\omega N_{\phi\chi}) \\ (-\omega^2 M_{\eta\phi}-i\omega N_{\eta\phi}) & (-\omega^2 M_{\chi\phi}-i\omega N_{\chi\phi}) & (B_{\phi\phi}-\omega^2 M_{\phi\phi}-i\omega N_{\phi\phi}) \end{bmatrix} \begin{bmatrix} \eta/a \\ \chi/a \\ \phi/a \end{bmatrix} = \begin{bmatrix} F_{\eta h}/a \\ F_{\chi h}/a \\ F_{\phi h}/a \end{bmatrix} \tag{2}$$

The time factor $e^{-i\omega t}$ is omitted in both cases. As we can see in Eqs. (1) and (2), the motions consist of sway η, heave ζ, roll φ, pitch ψ, and yaw χ. It is, as usual, assumed that the motions η, ζ are the translatory motions of the center of gravity G about its midposition of oscillation and that φ, ψ, χ are the rotational motions about the axes through G at its midposition of oscillation.

As mentioned in Sec. I, the loads on the bridging section through S (midpoint on the neutral axis) as shown in Fig. 1 are determined by the motion- (heave, pitch, sway, yaw and roll) induced forces and moments and wave-exciting forces and moments acting on Hull "a" (starboard hull).

The loads which will be evaluated on the section through S (see Fig. 1) are: 1) transverse force, F_η; 2) vertical shear force, F_ζ; 3) vertical bending moment, M_φ; 4) torsional moment, M_ψ; and 5) yawing moment M_χ. These designations were adopted from Ref. 2. If the calculations of forces and moments are all about the x-, y-, and z-axes fixed at the CG of the ship, the vertical bending moment about the section through S is expressed by

$$\bar{M}_\varphi = M^o_\varphi \pm \overline{GS}\, F_\eta \tag{3}$$

where the superscript "o" refers to bending moment about the axis through G.

Since all modes of motion (η, ζ, φ, ψ, χ) contribute to the loads (F_η, F_ζ, M_φ, M_ψ, M_χ) and since both the odd and even components of the wave-exciting forces and moments act on one body "a" the total is obtained by the superposition of all of the motion-induced and wave-exciting forces and moments acting on body "a." The devised strip method is applied to hull "a" by utilizing the two-dimensional hydrodynamic forces and moments.[5,6] The resulting formulas of the various loads are given in Apprneix A of Ref. 8. As an instance, F_η is expressed in the following form:

$$\begin{aligned} F_\eta = & \{\omega^2 (M_{\eta\eta})_a + i\omega (N_{\eta\eta})_a\}\eta \\ & + \{\omega^2 (M_{\varphi\eta})_a + i\omega (N_{\varphi\eta})_a\}\varphi \\ & + \{\omega^2 (M_{\chi\eta})_a + i\omega (N_{\chi\eta})_a\}\chi \\ & + \{\omega^2 (M_{\zeta\eta})_a + i\omega (N_{\zeta\eta})_a\}\zeta \\ & + \{\omega^2 (M_{\psi\eta})_a + i\omega (N_{\psi\eta})_a\}\psi + (F^{(o+e)}_{\eta h})_a \end{aligned}$$

where, for example,

$$(M_{\zeta\eta})_a = \int_{-\ell_2}^{\ell_1} (m''_{HS})_a \mathrm{d}x - \frac{U}{\omega^2} (N^{*}_{HS})_a$$

$$(N_{\zeta\eta})_a = \int_{-\ell_1}^{\ell_2} (N_{HS})_a \mathrm{d}x + U(m''^{*}_{HS})_a$$

and $(m''_{HS})_a$, $(N_{HS})_a$, etc. indicate the heave-induced sway added mass and damping coefficients on body "a," etc. The above integral is to be carried out from AP to FP. The sectional term with superscript * indicates the term for the aft end section which has a nonzero sectional area such as a transom stern.

The sectional wave-exciting forces and moments given by Eqs. (34, 38, 39, and 43) of Ref. 5 should be modified as follows:

$$\begin{Bmatrix} f^k_H(x) \\ f^k_S(x) \\ f^k_R(x) \end{Bmatrix} = \rho g a \int_{c(x)} e^{\nu_0 z} e^{i\nu_0 y \sin\mu} \times \begin{Bmatrix} \mathrm{d}y \\ -\mathrm{d}z \\ y\mathrm{d}y + z\mathrm{d}z \end{Bmatrix} \quad \text{on body "}a\text{"}$$

$$\begin{Bmatrix} f_H^D(x) \\ f_S^D(x) \\ f_R^D(x) \end{Bmatrix} i\rho\omega \int_{c(x)} \varphi_D^{(o+e)}$$

$$\times \begin{Bmatrix} dy \\ -dz \\ ydz+zdz \end{Bmatrix} \quad \text{on body ``}a\text{''}$$

where superscript $o+e$ indicates the sum of the velocity potentials satisfying the kinematical boundary conditions in the diffraction problem corresponding to odd and even incident wave components, respectively:

$$\varphi_D^{(o+e)} = \varphi_D^{(o)} + \varphi_D^{(e)}$$

In the formulas in Appendix A,[8] the longitudinal center of gravity of the starboard hull was assumed to be at the longitudinal center of gravity G of the entire ship. Since the effect of the vertical distance d between G and G_a and the rolling motion φ on F_η as well as the effect of d and the swaying motion η on M_φ were negligibly small, they are omitted in the formulas.

III. Confirmation of the Reliability of the Method

The reliability of this method can only be confirmed by an extensive comparison of the numerical calculations with the model test results of a typical platform. For this purpose, as mentioned above, extensive calculations of the response motions and loads of the ASR catamaran[2] were carried out. The ASR catamaran (Model 5061) is a typical catamaran ship of arbitrary shape, the main particulars of which are as shown in Table 1. The number of input points which will approximately represent the contours of each of the 13 sections into which the catamaran ship is divided is shown in Table 2.

Table 1 Main particulars of the preliminary design of the ASR catamaran

Model number	5061
Length (between perpendiculars), L, ft	210.0
Beam (overall) B_m, ft	86.0
Beam (each hull) B, ft	24.0
Draft, T, ft	18.0
Hull separation, ft	38.0
Displacement of each hull, long tons	1397 SW
Longitudinal c.g. aft of FP, ft	105.5
Longitudinal radius of gyration	0.25L
Vertical c.g., KG, ft	21.0
Transverse metacentric height, $\overline{GM}$, ft	59.0
Vertical distance of the neutral axis, $\overline{GS}$ above the VCG, ft	20.0
Transverse distance of the c.g. of the starboard hull form G, t, ft	29.5

Table 2 Number of input points on sections

Station	No. of input points on section contour of hull "a"
1	0
1.5	9
2	11
3	13
4	13
5	13
6	13
7	13
8	13
9	13
10	13
10.5	9
11	0

In the course of this work, an investigation has been made of the effect of the number of input points representing a typical cross section. It was found that the heave added masses were quite sensitive to the number of input points. For 19 and 11 input points, the results were quite different although they showed the same trend as a function of frequency. On the other hand, the sway added masses for the two sets of data were very close to each other. Adoption of the numbers of input points, shown in Table 2, may not be sufficient to obtain accurate results; nevertheless, this set of calculations exhibits at least the proper trends of the various responses.

The calculated results for heave- and pitch-exciting forces and moments by the present theory and by that of Ref. 3 are exhibited in Figs. 2a and 2b, together with the results of experiments. The agreement between theory and experiment for the heave-exciting forces excels that for the pitch-exciting moments. Similar behavior was also observed in the prediction of the heave- and pitch-exciting forces and moments of a monohull ship (Series 60) in Ref. 4.

Figures 3a to 3e depict the theoretical values (no experiments are available) of the heave- and sway-exciting for-

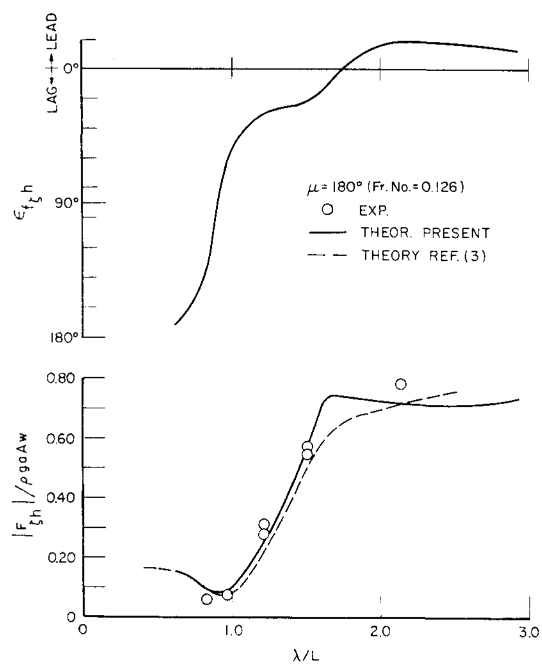

Fig. 2a Heave-exciting force of ASR catamaran.

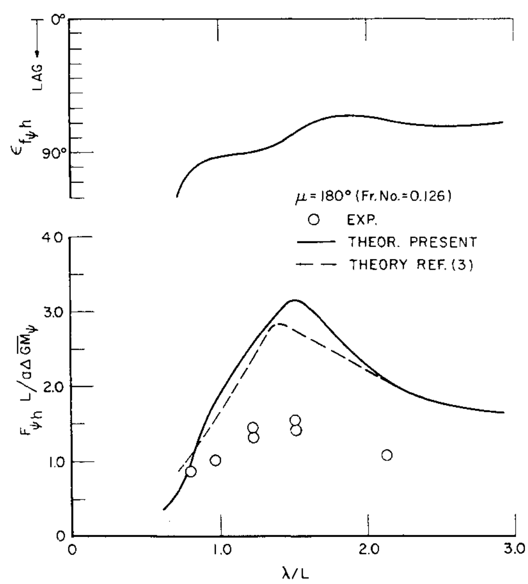

Fig. 2b Pitch-exciting moment of ASR catamaran.

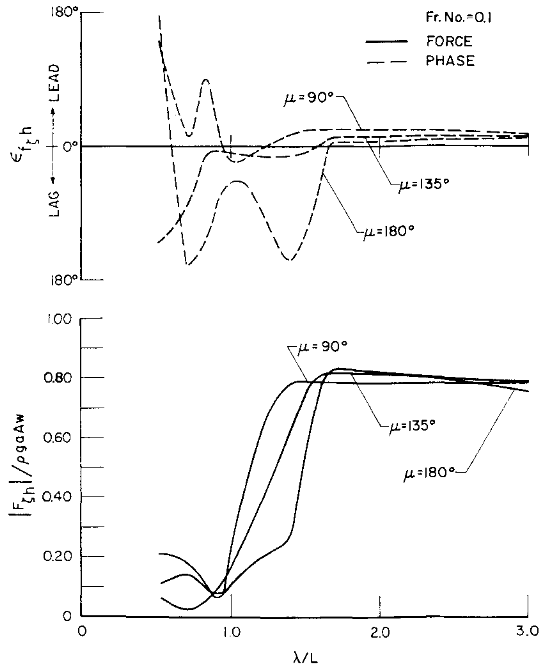

Fig. 3a Heave-exciting force of ASR catamaran.

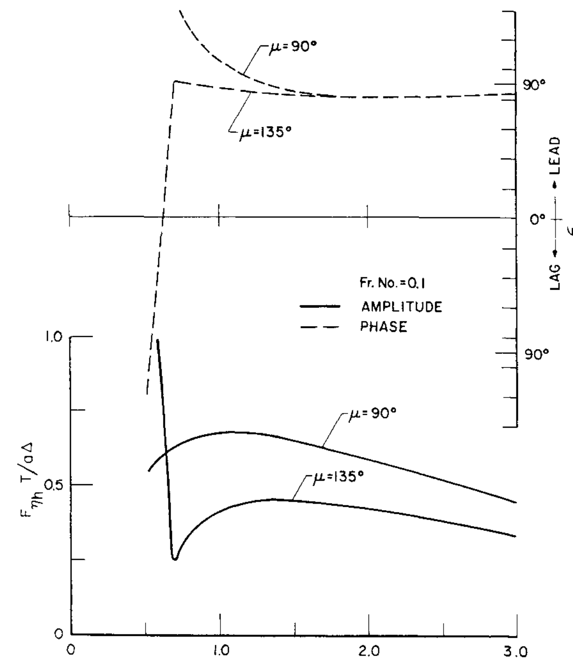

Fig. 3c Sway-exciting force of ASR catamaran.

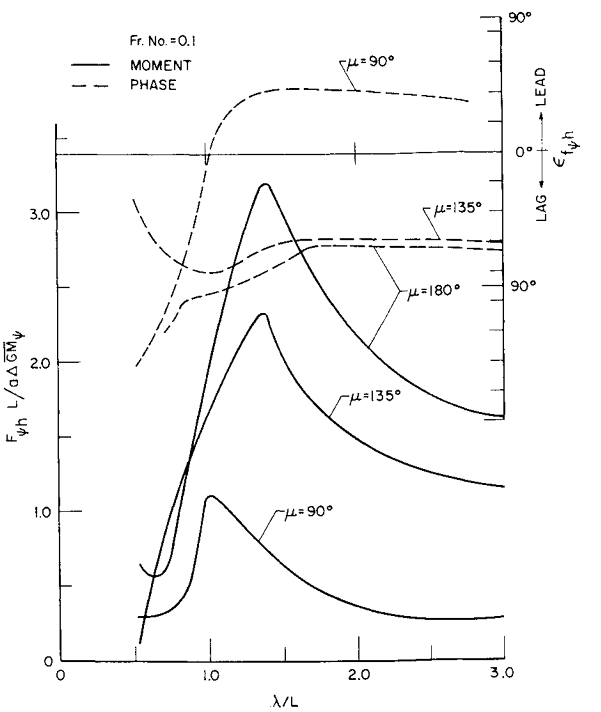

Fig. 3b Pitch-exciting moment of ASR catamaran.

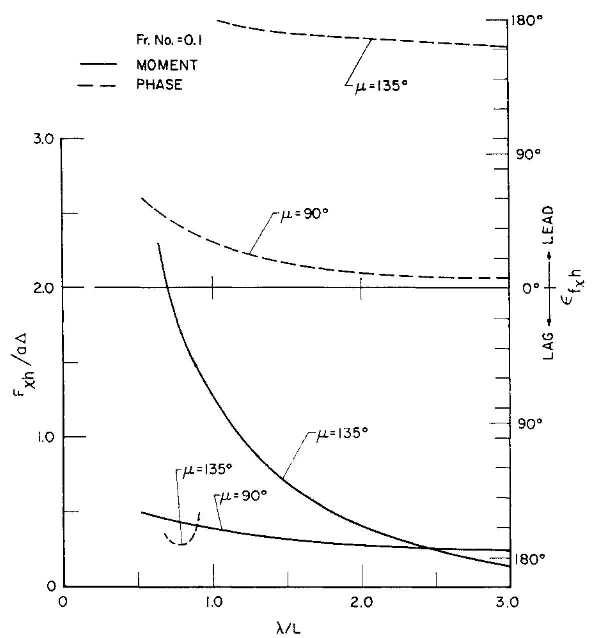

Fig. 3d Yaw-exciting moment of ASR catamaran.

ces and yaw-, pitch-, and roll-exciting moments of the ASR catamaran in oblique regular waves ($\mu=90°$, 135°, 180°) at Froude (F_r) = 0.10.

The results of the present theory for heave, pitch and roll responses are exhibited in Figs. 4-6 together with corresponding experimental values, when available, as given in Ref. 2. This comparison shows fair agreement in all responses at all headings. The heave and roll predictions show better correlation with the experiments than do pitch response especially in long waves where the accuracy of the measurements becomes questionable.

The various wave loads through section S were also calculated for the same ASR-5061 model[2] which has been used for prediction of the responses, with a ratio of hull separation to beam equal to 1.58. This is the mean value of the ratios of 1.76 and 1.41 for the model 5061 tested in Ref. 2. It should be mentioned that the value of the vertical distance $\overline{GS}$ above G was obtained from the information given in Ref. 3. These data are also given in Table 1.

The comparison of theoretical and experimental values of the loads is presented in Figs.7 and 8. The results are obtained for two headings, $\mu=90°$ and 120°, and for two Froude numbers, $F_r=0$ and 0.253. The comparison of predicted and experimental transverse forces in Figs. 7a and 8a shows rather fair agreement. The transverse force at $\mu=120°$ and $F_r=0.253$ (Fig. 8a) exhibits the characteristically fluctuating behavior which was shown in Figs. 10 and 16 of Ref. 1. The comparison of theoretically calculated and experimental shear forces indicates fair correlation for the beam sea case at both $F_r=0$ and 0.253, whereas at $\mu=120°$ for both Froude numbers the correlation is rather poor.

The shearing force in beam seas at zero speed can also be compared with the corresponding theoretical curve reported

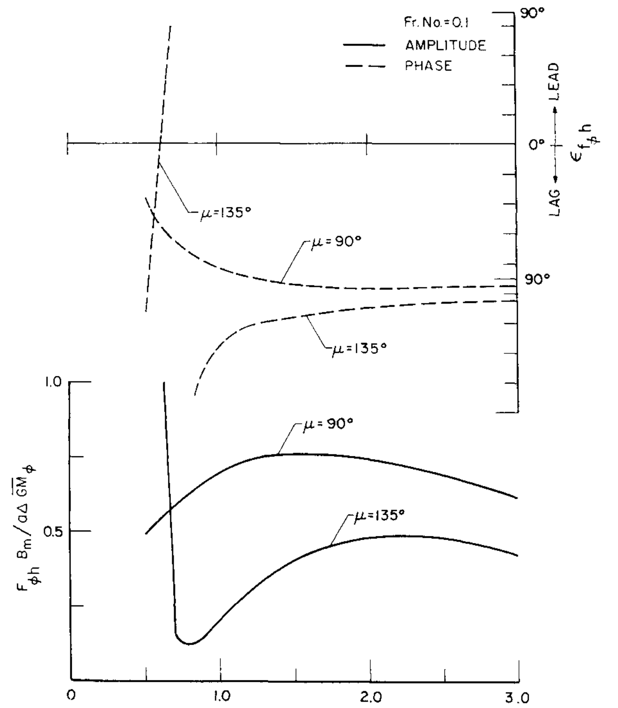

Fig. 3e Roll-exciting moment of ASR catamaran.

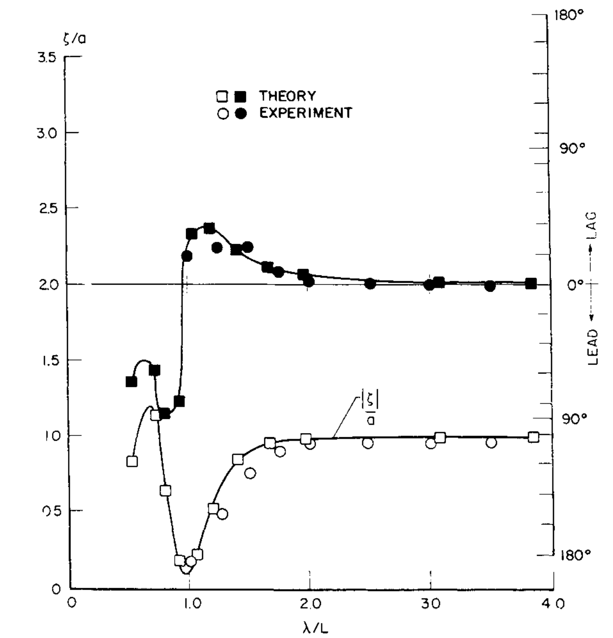

Fig. 4a Heave response of ASR catamaran: Fr No. = 0.1; μ = 90°.

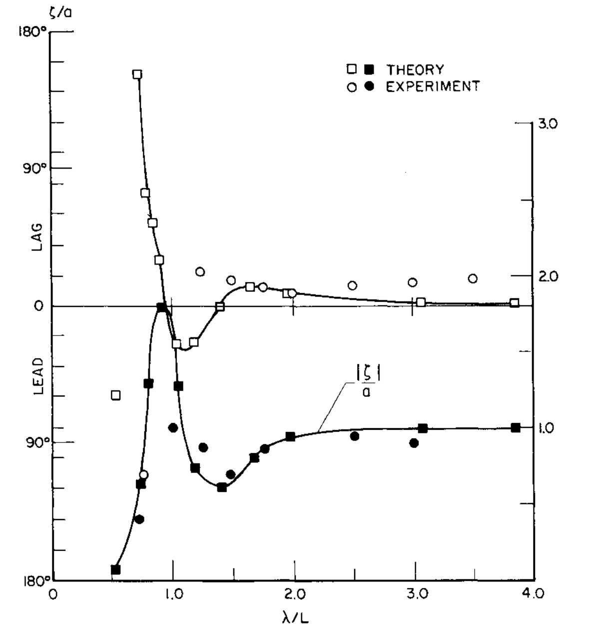

Fig. 4b Heave response of ASR catamaran: Fr. No. = 0.1; μ = 135°.

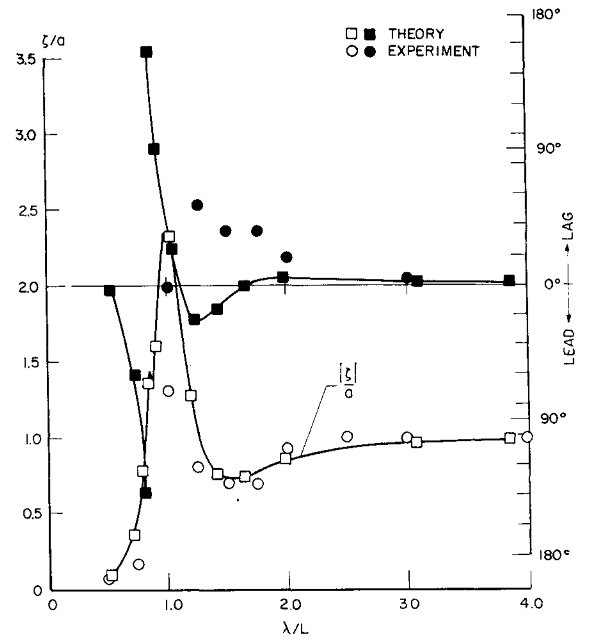

Fig. 4c Heave response of ASR catamaran Fr. No. = 0.1; μ = 180°.

in Ref. 3. The latter curve shows a trend similar to that of rolling motion whereas the present results indicate a trend similar to that of heaving motion. The analysis[3] based on the assumption as described in the Introduction of this paper shows that the vertical shear is affected by sway and roll. The present calculation assumes that each load is affected by all motions, heave, sway, roll, yaw and pitch.

The bending moments are illustrated in Figs. 7c and 8c for both headings and Froude numbers. The bending moment curve for $\mu = 90°$ and $F_r = 0$ (Fig. 7c) can also be compared with the corresponding curve of Fig. 14 of Ref. 3. Again, the two curves have different trends. This is mainly due to the difference in the basic assumptions as stated previously. The fluctuating trend of the present results for $\mu = 120°$ and $F_r = 0.253$ is similar to that in Fig. 17 of Ref. 1.

It should be mentioned that the theoretical values overestimate the bending moments in the range of long waves in all cases, whereas in shorter waves the agreement between theory and experiment is better. The reason for this is not clear at this time. A comparison of predicted and measured yaw moments is shown in Figs. 7d and 8d. It is seen that there is satisfactory agreement in all cases except for $\mu = 90°$ and $F_r = 0.253$. More detailed experiments are required in the range of λ/L from 0.5 to 1.5 in order to establish the presence of peak values.

It must be mentioned that the correlation of the theoretical and experimental values of the torsional moment is relatively poor. The results are not presented in the figures. In addition, it is to be noted that the viscous damping has not been accounted for in the present study. On the whole, it is concluded from this study that the theoretical evaluation gives a better prediction for zero speed than for the high speed, and that the prediction for heading $\mu = 90°$ is superior to that for $\mu = 120°$.

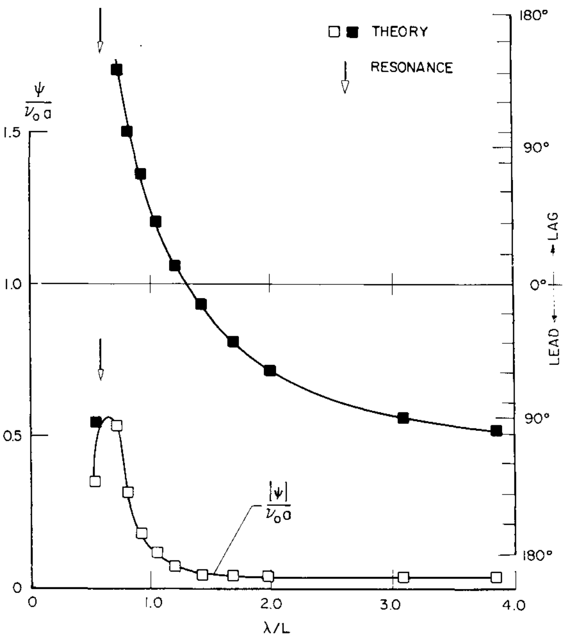

Fig. 5a Pitch response of ASR catamaran: Fr. No. $=0.1$; $\mu=90°$.

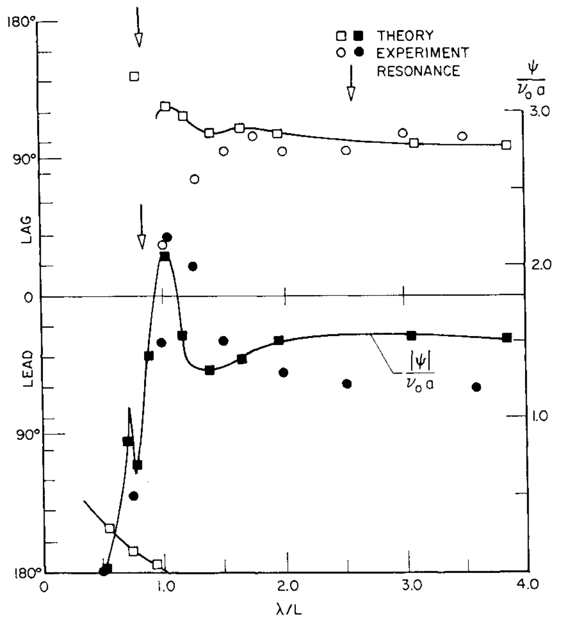

Fig. 5b Pitch response of ASR catamaran: Fr. No. $=0.1$; $\mu=135°$.

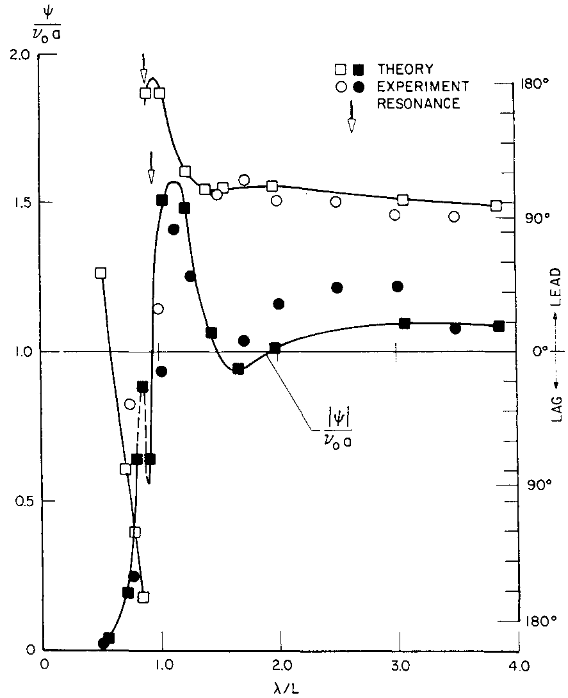

Fig. 5c Pitch response of ASR catamaran: Fr. No. $=0.1$; $\mu=180°$.

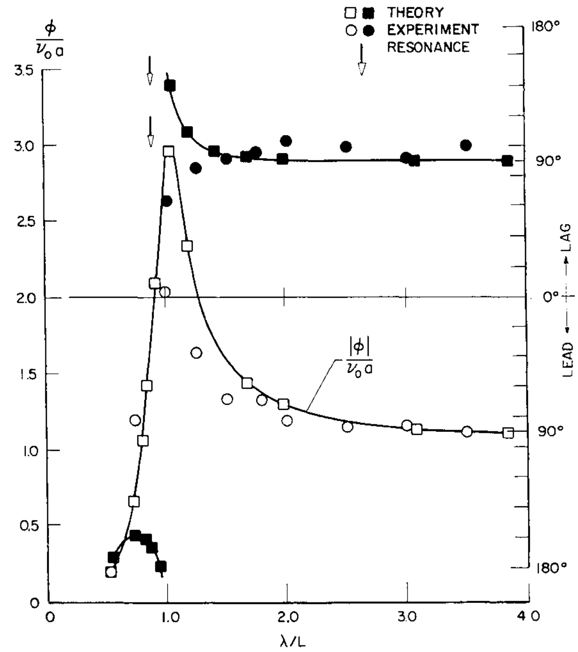

Fig. 6a Roll response of ASR catamaran: Fr. No. $=0.1$; $\mu=90°$.

IV. Application to Seakeeping Characteristics of a Semi-Submersible

In Sec. III, the present analysis and computer program adaptable to CDC-6600 has been utilized for the evaluation of motions and wave loads of a catamaran platform of arbitrary shape moving in oblique waves. A further application of the present method is given in this section by investigating the seakeeping characteristics of a semi-submersible type platform.

Such information is necessary in the preliminary design stage. Indeed the architectural design of one such platform meeting the required conditions has been carried out at Davidson Laboratory of Stevens Institute of Technology by means of seakeeping tests and the theoretical calculations. Table 3 presents the particulars of the semi-submersible designed for Harbor Branch Foundation, Inc. and Fig. 9a exhibits the lines.

From both theoretical and experimental investigations, it was found that there is a strong coupling between heaving and pitching motions which induces a large vertical displacement at the stern. This coupling was found to be due to the asymmetrical distribution of cross-sectional areas which results in a nonsymmetric distribution of hydromechanical forces (Figs. 9b and 9c).

It was imperative, in meeting the original requirements, to reduce the vertical motion at the stern by redistributing the sectional area and buoyancy forces along the hull length. By a simple rearrangement of the sections, a relatively symmetrical distribution has been achieved as shown by dotted lines on Figs. 9b and 9c.

Calculations for heave, pitch and roll have been carried out for this modified configuration and for the original con-

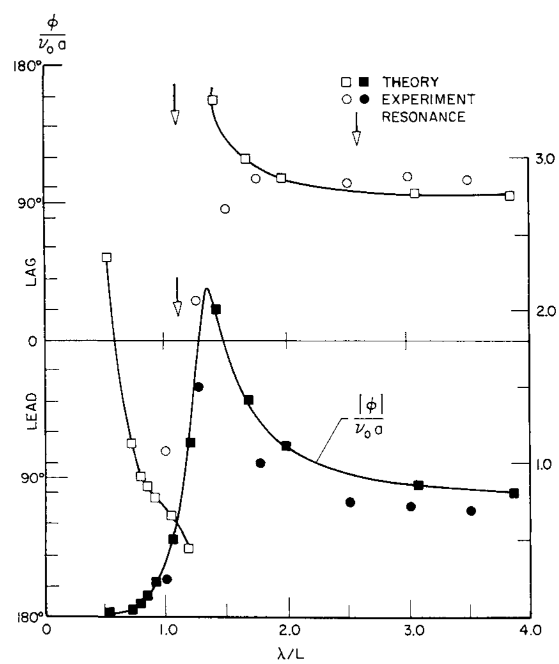

Fig. 6b Roll response of ASR catamaran: Fr. No. $=0.1$; $\mu=135°$.

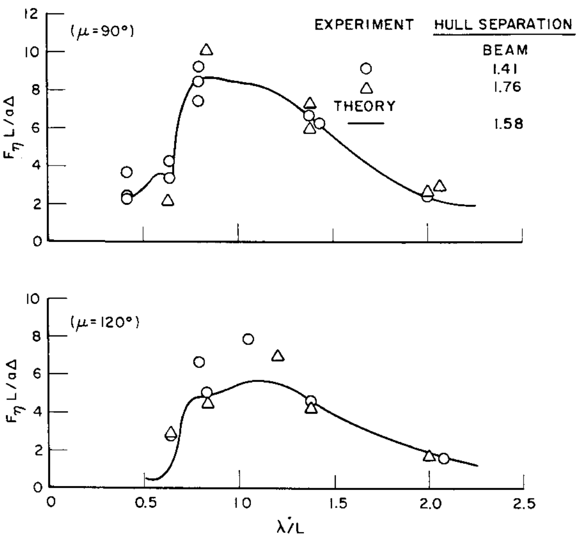

Fig. 7a Nondimensional amplitude of transverse force, Model 5061, zero speed.

figuration as well. Figures 10a-10e present the results of these calculations for heave, pitch, and roll motions at zero speed and two headings, beam and head seas, together with the experimental values. It is seen that there is good agreement between experimental and theoretical values except at long wave lengths and at resonant points. The discrepancy between theory and experiment at resonant points is ascribed to the fact that the viscous damping was neglected. The question may be raised why the heave response of the semi-submersible to the long wavelength does not approach unity (Figs. 10a, 10b) whereas the heave response of the ASR catamaran, a surface-type ship, does (Figs. 3a-3c). The reason may lie in the following behavior of the heave-exciting force and the transfer function of the semi-submersible for the long wavelength. The heave-exciting force coefficient of the semi-submersible, nondimensionalized on the basis of the heave-restoring force, is about one fifth that of the ASR catamaran for the $\lambda=L=2.5$, while the heave-restoring forces for both models are dominant among the terms in each transfer function.

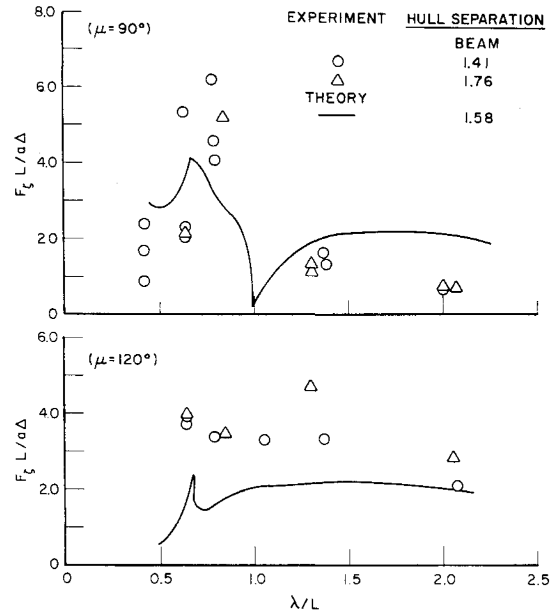

Fig. 7b Nondimensional amplitude of shear force, Model 5061, zero speed.

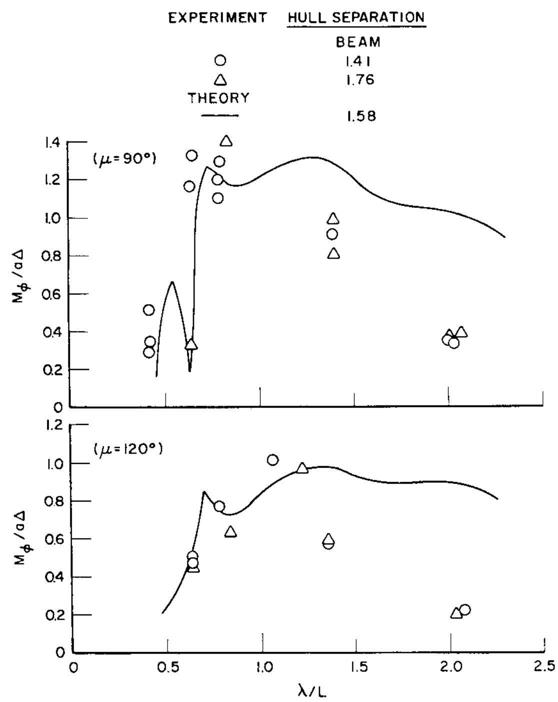

Fig. 7c Nondimensional bending moment amplitude, Model 5061, zero speed.

Table 3 Particulars of the harbor branch foundation, semi-submersible

Length (between perpendiculars) L, ft	160
Beam (overall) B_m, ft	56
Beam (each hull) B, ft	8
Draft T, ft	20
Hull separation S, ft	24
Displacement of both hulls SW, long tons	1,567
Longitudinal c.g. aft of ⊗, ft	13
Vertical c.g. above keel, ft	14.1
Vertical center of buoyancy above keel, ft	9.23
Pitch gyradius, ft	34.5
Roll gyradius, ft	21.9
Transverse metacentric height, $\overline{GM}_\varphi$, ft	7.66

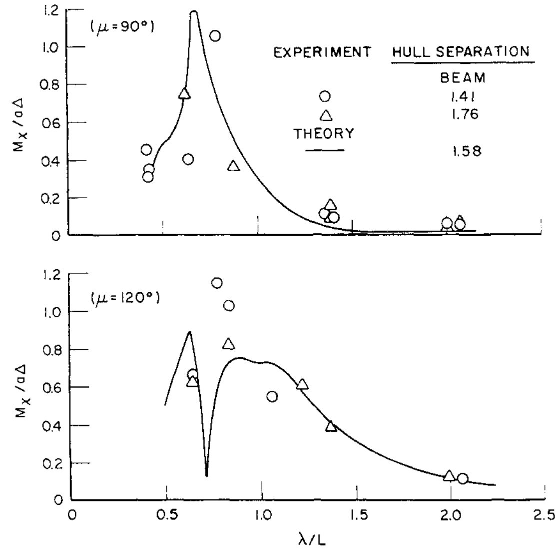

Fig. 7d Nondimensional amplitude of yaw moment, Model 5061, zero speed.

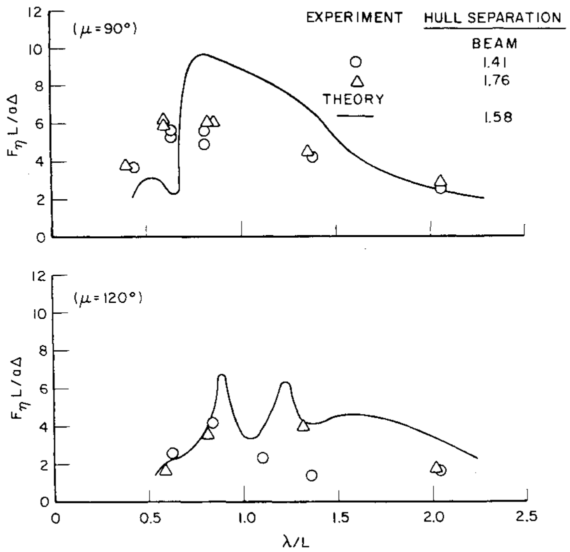

Fig. 8a Nondimensional amplitude of transverse force, Model 5061, Fr. No. =0.253.

V. Conclusions

A theoretical method has been developed for predicting the response motions and loads of a catamaran of arbitrary shape (or semi-submersible platform) moving in oblique regular wave trains. The hydrodynamic interaction was taken into account in a two-dimensional fashion, and, by a stripwise method which had been devised and successfully applied in a monohull ship case, the motions and loads of the catamaran have been formulated.[8] A corresponding computer program written in FORTRAN IV has been developed adaptable to the CDC-6600 high-speed digital computer. Extensive numerical calculations were carried out for the ASR catamaran and for the Harbor Branch Foundation semi-submersible platform which has been designed and tested at Davidson Laboratory. Comparison of theoretical results with those of experiments, whenever available, has generally shown satisfactory agreement except in some cases at resonant frequencies. It must be remembered that the present procedure does not account for viscous damping. In fact, the results at zero speed show better agreement than those at high speed and those at shorter wave lengths are better than those in the range of

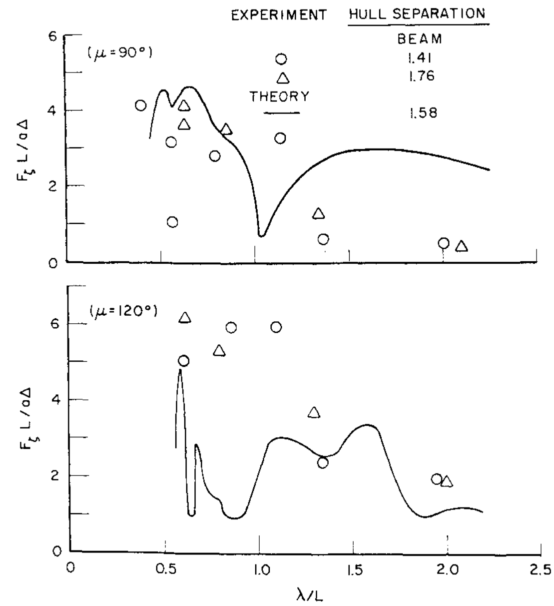

Fig. 8b Nondimensional amplitude of shear force. Model 5061, Fr. No. =0.253.

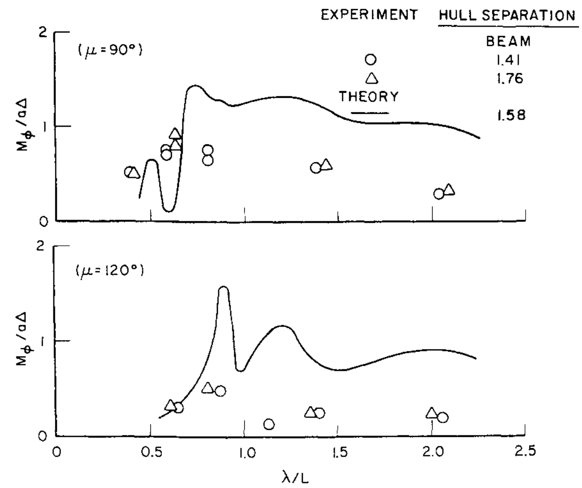

Fig. 8c Nondimensional bending moment amplitude, Model 5061, Fr. No. =0.253.

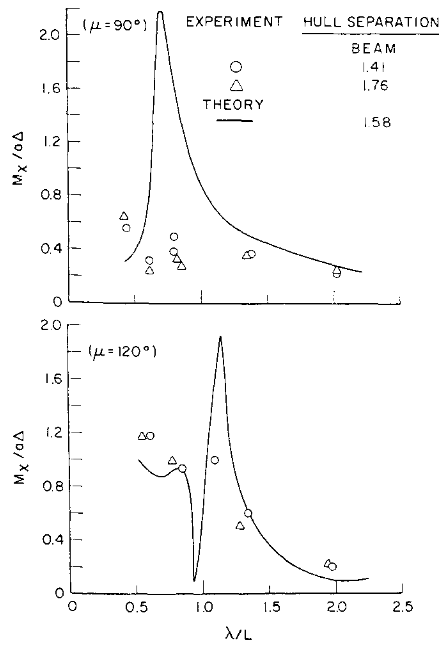

Fig. 8d Nondimensional amplitude of yaw moment, Model 5061, Fr. No. =0.253.

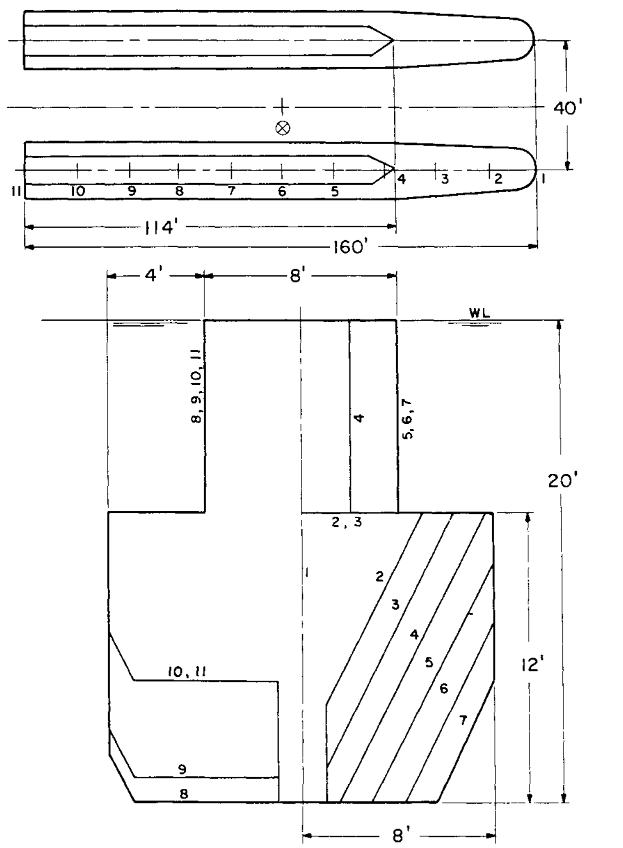

Fig. 9a Lines of the Harbor Branch Foundation. (HBF) semi-submersible.

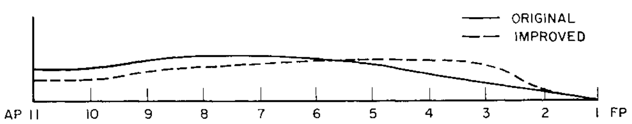

Fig. 9b Sketch of distribution of sectional area $S(x)$, HBF semi-submersible.

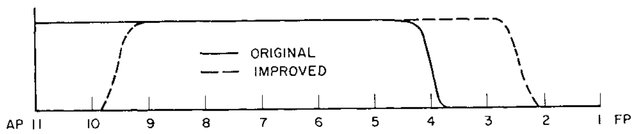

Fig. 9c Sketch of distribution of buoyancy $\rho g B$ (x), HBF semi-submersible.

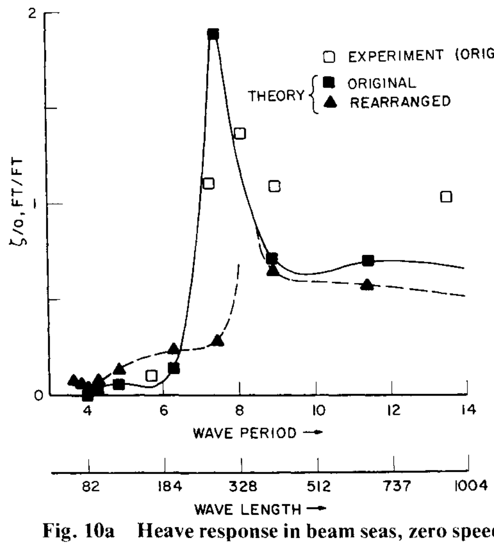

Fig. 10a Heave response in beam seas, zero speed.

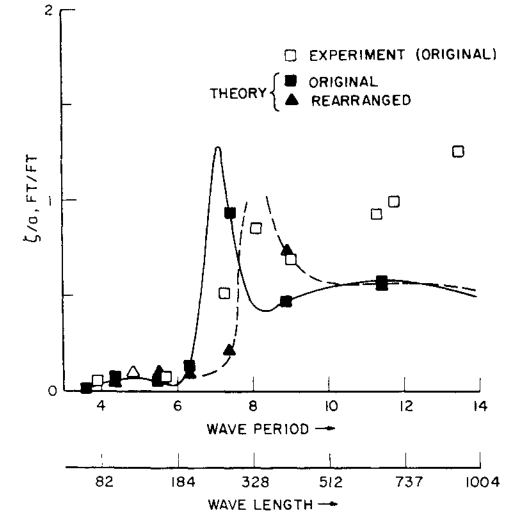

Fig. 10b Heave response in head seas, zero speed.

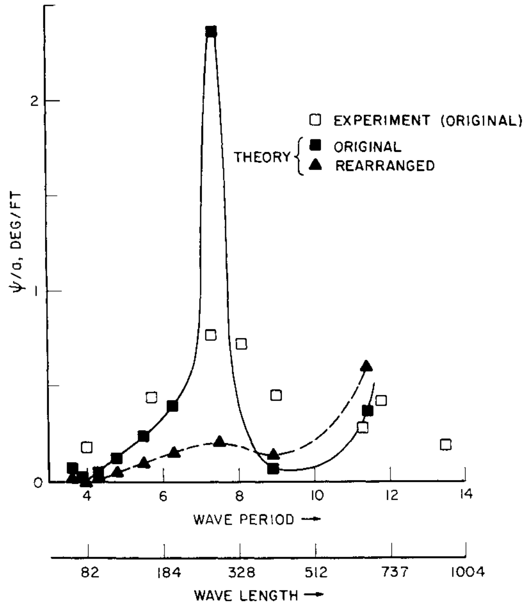

Fig. 10c Pitch response in beam seas, zero speed.

longer waves. Furthermore, it is found that for nonsmooth sectional contours with sharp corners, a large number of singularities are required for the accurate representation of the cross section in order, in turn, to evaluate accurately the hydrodynamic forces and moments. It is advisable, therefore, when the cross sections are not smooth to undertake a quick investigation to determine the minimum number of singularities required.

It appears that the computational method presented here can be a valuable design tool for predicting motions and loads of a catamaran of arbitrary shape or a semi-submersible type platform moving or stationary in a seaway. Similar computational schemes[3,9] for predicting motions and loads in head seas and beam seas at zero speed have already proven of great value to the U.S. Navy.[9] The potential of the present method is quite evident. In order to utilize it more fully, further research is necessary: 1) to investigate the cause of discrepancies in long waves; 2) to carry out a more extensive evaluation of motions and loads for higher Froude numbers; 3) to investigate the effect of viscous damping in the resonant frequency range where the present potential theory overestimates the responses; and 4) to investigate the effect of relative bow motion on deck wetness.

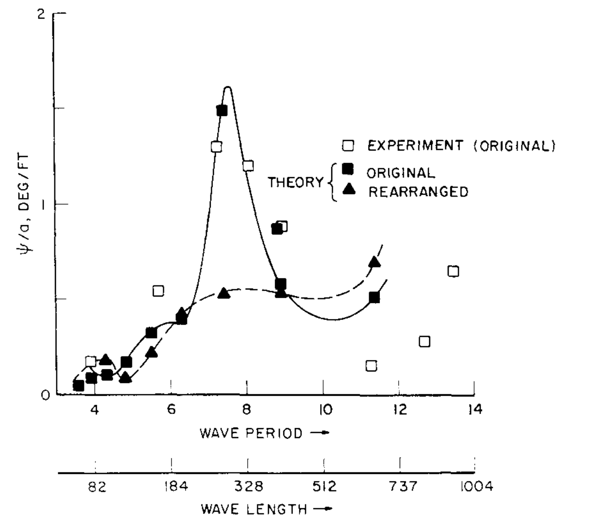

Fig. 10d **Pitch response in head seas, zero speed.**

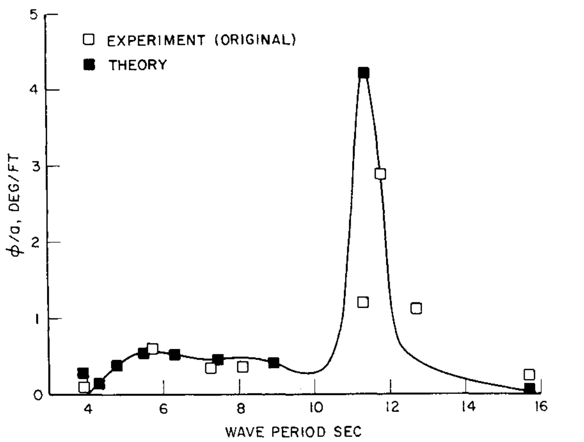

Fig. 10e **Roll response in beam seas, zero speed.**

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