NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20034

CATAMARAN MOTION PREDICTIONS IN REGULAR WAVES

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IN REGULAR WAVES

by

Harry D. Jones

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Report 3700

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Naval Ship Research and Development Center
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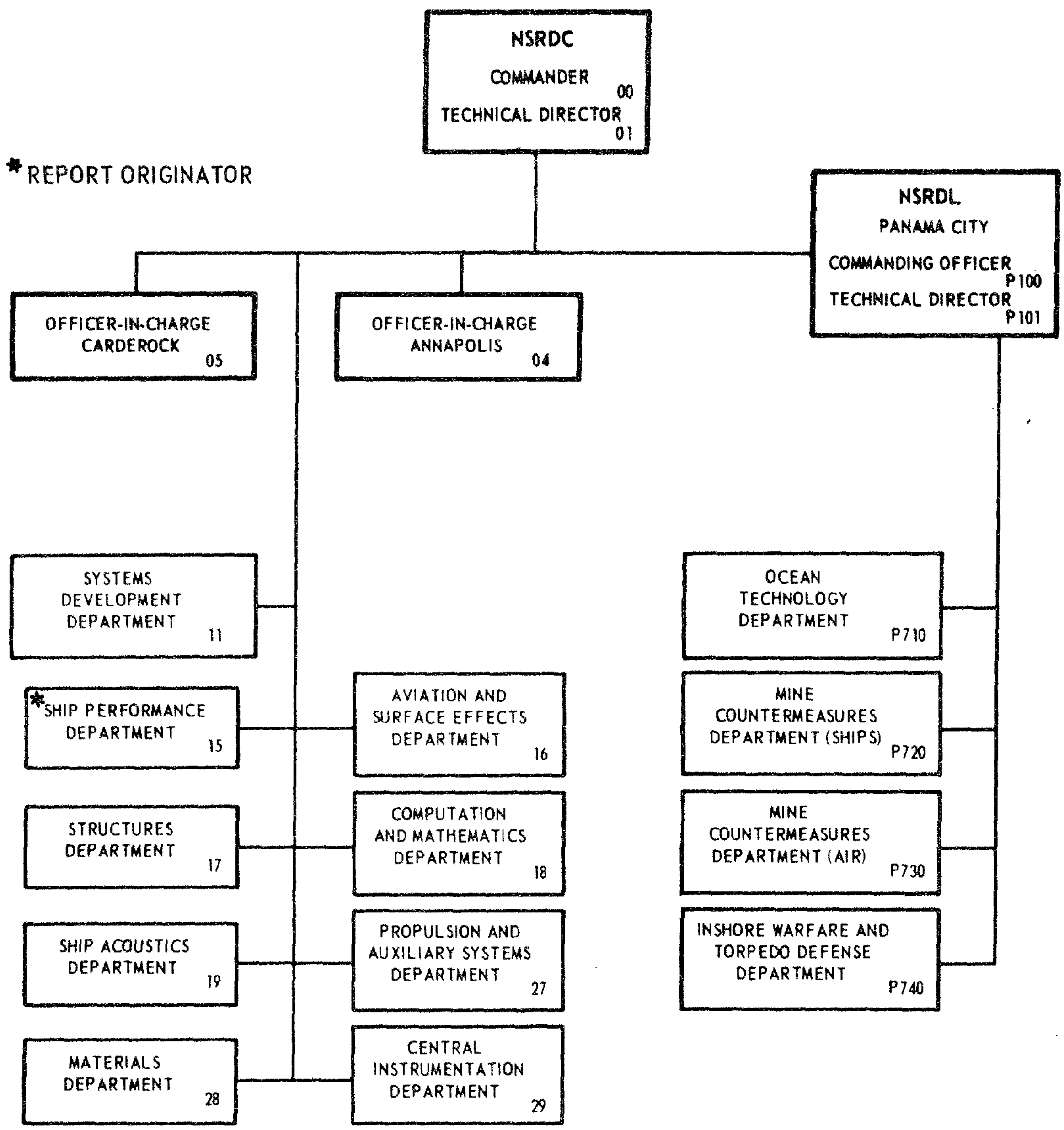

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DEPARTMENT OF THE NAVY
NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER
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NOTATION

a, b, c, d, e, h	Coefficients in the heave equation
A, B, C, D, E, H	Coefficients in the pitch equation
A_{ij}	Nondimensional mass coefficients (i,j = 3 and 5)
B_{ij}	Nondimensional damping coefficients (i,j = 3 and 5)
B	Single hull beam
C_{ij}	Nondimensional restoring coefficients (i,j = 3 and 5)
C_p	Longitudinal prismatic coefficient
C_x	Maximum transverse section coefficient
$F(t)$	Heave forcing function
$\overline{F}$	Heave force amplitude
F_i, F_j	Nondimensional forcing functions (i,j = 3 and 5)
F_n	Froude number, $\frac{V}{\sqrt{gL}}$
g	Gravitational acceleration
HS	Hull separation distance (distance between closest points of the two hulls)
I_p	Mass moment of inertia
L	Length between perpendiculars
$M(t)$	Pitch forcing function
$\overline{M}$	Pitch moment amplitude
m	Displaced mass
R_p	Nondimensional pitch radius of gyration
T	Draft
t	Time
V	Ship speed
x_i, x_j	Nondimensional response motions (i,j = 3 and 5)

z	Heave response motion
$\overline{z}$	Heave amplitude
α	Heave phase
β	Pitch phase
Δ	Displacement weight
δ	Pitch moment phase
ϵ	Heave force phase
ζ_A	Wave amplitude
λ	Wave length
μ_e	Nondimensional frequency of wave encounter ($\mu_e = \omega_e\sqrt{L/g}$)
χ	Heading angle
θ	Pitch response motion
$\overline{\theta}$	Pitch amplitude
$\overline{\psi}$	Roll amplitude
ω_e	Frequency of wave encounter

ABSTRACT

As part of an effort to advance the development of catamaran technology, ship motion prediction theory for monohulls has been adapted, and programmed for a digital computer, to predict the heave and pitch motion characteristics of a catamaran in regular head waves. This report provides verification of the computer program utilizing existing experimental model data. Predictions are also made for the effects of changes in certain hull parameters on catamaran motions. An existing computer program, based on simplified theory, is also utilized to predict catamaran roll motion in the parametric variation study.

ADMINISTRATIVE INFORMATION

This work was performed under the in-house Independent Research Program of the Naval Ship Research and Development Center (NSRDC) and funded under Subproject ZR 0011 01 01, local work unit number 568-120 (formerly 588-092). The experimental results utilized herein were funded through other sources and performed at the Center.

INTRODUCTION

As a first step towards the development of analytical methods for the prediction of the motions of catamarans in waves, the Naval Ship Research and Development Center developed a linear theory for the determination of the added mass and damping of two heaving circular cylinders, and verified these predictions using experimental results.[1] The next step was to develop an analytical method for determining the added mass and damping of two dimensional twin bodies with arbitrary cross sections. This method resulted in a computer program, CAT1, which was experimentally validated for cross sections used in conventional catamarans in Reference 2. The good agreement between theory and experiment led to the development of a computer program utilizing a strip theory to predict the regular head wave heave and pitch characteristics of a catamaran. This was done by modifying computer program YF17, the Frank Close Fit Ship Motion Computer Program.[3] This modification was accomplished by utilizing the two dimensional twin body theory of CAT1 to compute the section added mass and damping, but retaining the monohull strip theory of YF17. This approach assumes that the effects of forward speed on the motion coefficients of a catamaran are identical to those predicted for a monohull ship. The prediction procedure was then correlated with experimentally obtained motion coefficients, exciting forces and moments, and heave and pitch motion data.

The next step was to use this catamaran computer program, designated as HJCT, to show the effects on the motions of making changes to some of the hull parameters. This was done taking an early ASR hull form as a parent design and covering a practical range of hull geometry variations.

This report presents the results of the computer program correlation as well as the parametric variation effects.

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[1] References are listed on page 22.

HEAVE AND PITCH COMPUTER PROGRAM

The computer program, HJCT, to predict the regular head wave catamaran heave and pitch motion characteristics was developed by incorporating the prediction of two dimensional twin body heave added mass and damping coefficients, described in Reference 2, into the monohull ship motion program YF17. This involved modification of the program to allow input of hull sectional shapes common to catamarans, i.e., asymmetrical shapes with reduced waterplanes and enlarged submerged portions such as the MODCAT, and shapes totally submerged such as floating platforms. Modification of the portion of YF17 which computed the two dimensional coefficients was accomplished by replacing the single body techniques of YF17 with twin body techniques of CAT1.[2]

A problem which is encountered using the close fit method described in Reference 3, is the occurrence of mathematical discontinuities in the sectional added mass and damping at certain "critical" frequencies, as pointed out by John.[4] The program prints out the frequency at which these discontinuities occur station by station, and a determination must be made as to whether or not these frequencies are within the range of interest. It has been found that this problem can be eliminated for single bodies by completely enclosing the station at the waterline, when inputing the offsets describing it. The possibility of using this technique with twin bodies is presently under investigation at NSRDC by Lee,[2] but at this time is not completely verified. However, initial indications point to the validity of this approach. Caution must be exercised whenever one is inputing station offsets with horizontally level surfaces such as is required to eliminate the John's phenomenon by including the waterline, or the case of a flat bottomed hull. The computational methods utilized cannot handle these surfaces, so that this problem must be overcome by putting a very slight incline on the surface.

In developing a computer program to predict catamaran motions in regular head waves, it was assumed that the monohull strip theory of YF17 is valid for catamarans. The major assumptions are that the monohull forward speed effects and the slender body restrictions are also applicable to catamarans.

The catamaran computer program, HJCT, has retained the additional capabilities of YF17 to predict heave and pitch motions for regular following waves and the irregular head sea computations using the linear superposition technique. The plotting capabilities of YF17 are also retained to give plots of the input offset data describing the hull form as well as the regular wave ship motions and phase predictions. The plotted motion data of HJCT uses wavelength to shiplength ratio, λ/L, as an abscissa, rather than L/λ used in YF17.

This program is available in two versions, one which is acceptable to the IBM 7090 computer, and the other to the CDC 6700.

ROLL COMPUTER PROGRAM

The computer program, RLAC, utilized for the roll predictions in this study was developed at the Center by Hubble.[5] It is used to predict the rolling motions and accelerations of a catamaran in beam seas at zero speed, and is based on the work of Wahab.[6]

EXPERIMENTAL PROGRAM

The experimental results used to validate the prediction method, i.e., program HJCT, were obtained from tests carried out at the Center. These data were obtained from tests carried out with models representing four catamaran designs, i.e., ASR, CVA, LST, and MODCAT. The main characteristics of these four designs are given in Table 1 and the body plans are given in Figure 1.

The most extensive correlation of the computer program was carried out using data from tests on the ASR model. These data were obtained from (1) forced oscillation tests (2) restrained model tests and (3) model motion tests in waves, presented in Center test reports by Jones and Reference 7.

The hydrodynamic coefficients for the coupled equations of motion for the ASR were determined by forced oscillation tests. These tests were conducted using an existing 12.43 ft model (designated 5061) of an early design of a catamaran mother ship intended to service the Deep Sea Rescue Vehicle. The model consisted of two rigid wooden hulls with asymmetric forebodies and symmetric afterbodies. The two hulls were rigidly coupled by four wooden cross beams at their design hull spacing of 27 inches.

The model was first forced to heave sinusoidally at the free surface of the water using the "X" frame set up described in Reference 1 to attach the model to the oscillator. The heaving frequency was controlled by the voltage input to the oscillator's motor allowing essentially any frequency within the desired range of 0.5 to 2.0 cps. For linearity checks, tests were carried out at three different heave amplitudes over a portion of the frequency range. The model was next forced to pitch sinusoidally at the free surface of the water. This was accomplished by restraining the model at the LCG, so that it was free to pivot about a point coincident with the LCG and the design waterline, and forcing it sinusoidally at the stern. The frequency range for tests in the pitch mode was identical to that for tests in the heave mode, with linearity checks performed in the same manner.

The regular wave exciting forces and moments were determined by restraining the model at the free surface of the water and measuring the forces imposed as the waves passed. These tests were conducted in regular head waves ranging in wavelength to shiplength ratio λ/L from 0.9 to 2.0 for a range of wave steepness ratios $2\zeta_a/\lambda$ = 1/30 to 1/130. However, the predominant wave steepness ratio was in the neighborhood of 1/50.

To measure the forces required in the determination of the hydrodynamic coefficients and the regular wave exciting forces and moments, four ±25 lb block gages were used. The tests were conducted on Carriage 2 of the Deep Water Basin at the Center for Froude Numbers, F_n, of 0, 0.126, 0.253 and 0.316, except in the pitch mode where the highest speed had to be eliminated as the required forces exceeded the limits of the block gages.

The motion data for the ASR[7] were obtained by attaching the self propelled model, floating at its waterline, to the carriage by means of the Center's motion measuring apparatus. This apparatus allows the model to respond in all six modes and measures these responses by means of linear potentiometers. The inertial effects of this apparatus on the model's motions were considered negligible. These self propelled model tests were carried out at Froude Numbers of 0, 0.104, 0.311, and 0.414, in wavelength to shiplength ratios of 0.5 to 3.5 in the Center's Maneuvering and Seakeeping Basin.

TABLE 1

Ship Particulars of Catamarans Used in Making Comparisons

Particular	ASR	CVA	LST	MODCAT
NSRDC Model Number	5061	5,228	5,182	5,226
Beam (Each Hull) in Feet at the Waterline	24.0	95.8	38.0	17.1
Draft in Feet (Station 10)	18.0	36.5	17.0	40.0
Length in Feet at the Waterline	210.0	820.0	550.0	440.0
Displacement of Each Hull in Long Tons	1386 (S.W.)*	47,400 (S.W.)	14,000 (S.W.)	11,300 (S.W.)
Hull Spacing in Feet	38.0	141.2	30.0	157.9
Longitudinal Center of Gravity Aft of F. P. in Feet	105.6	419.0	285.3	211.8
Longitudinal Radius of Gyration in Feet	0.233L	0.23L	0.24L	0.25L
Block Coefficient	0.55	0.59	0.72	1.36
Scale Ratio	16.89	54.67	24.78	40.96
Diameter in Feet	–	–	–	30.72

*Salt Water

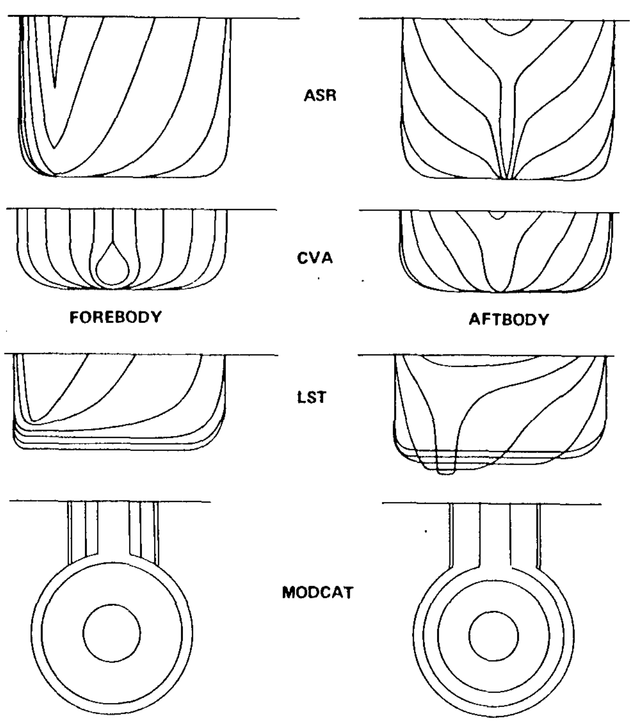

Figure 1 – Body Plans Representing the ASR, CVA, LST and MODCAT Catamarans

The motion data for the CVA were taken from Reference 8. These tests were carried out using a 15.0 ft model (designated 5228) designed to represent a large CVA catamaran of conventional form. The hulls were constructed of polyurethane and coupled at their design spacing of 2.56 ft by a strain gaged beam designed to measure the bridging structure loads. These tests were carried out with the model self-propelled and free to move in all six modes. The only connections between the model and the carriage were the cables to the electronic measurement devices and those needed for model powering and control, together with the flexible tethering ropes required to accelerate and decelerate the model. During the time data were taken all the connections were slack and did not affect the model motions. These tests were carried out at Froude Numbers of 0, 0.156, and 0.312 in wavelength to shiplength ratios of 0.83 to 2.17 in the Center's Maneuvering and Seakeeping Basin.

The motion data for the LST were taken from a Center test report by Pritchett. These tests were carried out using an existent 22.47 ft model (5182) designed to represent an LST catamaran. The wooden hulls were coupled at their design hull spacing of 1.23 ft and the test program carried out in the same manner as described for the CVA. The tests were carried out at Froude Numbers of 0, 0.128, and 0.256, for wavelength to shiplength ratios of 0.4 to 2.7 in the Center's Maneuvering and Seakeeping Basin.

The final correlation of the computer program, HJCT, was made using data from tests conducted with a model (5226) designed to represent a modified catamaran (MODCAT). This is basically a design to reduce the waterplane area thereby causing the major buoyancy contribution to be from an enlarged subsurface form. In this case the subsurface hull form was cylindrical which permitted it to be constructed of aluminum tubing with streamlined wooden ends. A relatively narrow wall-sided strut section with fine ends was attached to the body of revolution and extended up through the water's surface. The results of the tests carried out with this model are presented in a Center test report by Yeh. These tests were carried out at Froude Numbers of 0, 0.312, and 0.384 (based on the waterline length) for wavelength to shiplength ratios of 0.5 to 2.5 using the same type of test program and facility as for the CVA and LST.

COMPUTER PROGRAM CORRELATION AND EQUATIONS OF MOTION

The correlation of the heave and pitch motions of a catamaran predicted by the computer program HJCT was carried out utilizing data from model tests conducted with ASR, CVA, LST and MODCAT models. Comparisons were made of the hydrodynamic coefficients in the equations of motion as well as the resulting pitch and heave motions. The equations of motion in dimensional form are:

$$a\ddot{z} + b\dot{z} + cz + d\ddot{\theta} + e\dot{\theta} + h\theta = F(t),$$

$$D\ddot{z} + E\dot{z} + Hz + A\ddot{\theta} + B\dot{\theta} + C\theta = M(t),$$

where $F(t) = \overline{F} \cos (\omega_e t + \epsilon)$ is the heave exciting force,

$M(t) = \overline{M} \cos (\omega_e t + \delta)$ is the pitch exciting moment,

$z = \overline{z} \cos (\omega_e t + a)$ is the prescribed heave motion,

$\theta = \overline{\theta} \cos (\omega_e t + \beta)$ is the prescribed pitch motion,

a = the mass of the model plus the added mass,

b = the heave damping,

c = the heave restoring constant,

A = the moment of inertia of the model in air plus the added moment of inertia,

B = the pitch damping,

C = the pitch restoring constant,

with the remaining coefficients being the cross-coupling terms between heave and pitch. All the terms of these coupled equations of motions were then determined experimentally using the procedures outlined previously.

The coupled equations of motion as utilized in the computer program in nondimensional form may be expressed as follows:

$$(A_{33} + 1)\ddot{x}_3 + B_{33}\dot{x}_3 + C_{33}x_3 + A_{35}\ddot{x}_5 + B_{35}\dot{x}_5 + C_{35}x_5 = F_3,$$

$$A_{53}\ddot{x}_3 + B_{53}\dot{x}_3 + C_{53}x_3 + (A_{55} + R_p^2)\ddot{x}_5 + B_{55}\dot{x}_5 + C_{55}x_5 = F_5,$$

with time nondimensionalized by $\sqrt{L/g}$, $F(t)$ by Δ, and $M(t)$ by $L\Delta$.

The coefficients in these nondimensional equations may be expressed in terms of the previously indicated dimensional equations as follows:

$$\begin{aligned}
A_{33} &= (a/m) - 1,\\
B_{33} &= b/(m\sqrt{g/L}),\\
C_{33} &= cL/\Delta,\\
A_{35} &= d/mL,\\
B_{35} &= e/(mL\sqrt{g/L}),\\
C_{35} &= h/\Delta,\\
A_{53} &= D/mL,\\
B_{53} &= E/(mL\sqrt{g/L}),\\
C_{53} &= H/\Delta,\\
A_{55} &= (A - I_p)/mL^2,\\
B_{55} &= B/(mL^2\sqrt{g/L}),\\
C_{55} &= C/\Delta L.
\end{aligned}$$

The experimental results presented are in the forms indicated, so that the comparisons may be made directly with output from the computer program. The motion and wave excitation parameters are presented as follows, which is the form of the computer output:

Heave	$= (\bar{z}/\zeta_A) \cos (\omega_e t + a)$,
Pitch	$= (\bar{\psi}\lambda/2\pi\zeta_A) \cos (\omega_e t + \beta)$,
Heave exciting force	$= (\bar{F}/\zeta_A c) \cos (\omega_e t + \epsilon)$,
Pitch exciting moment	$= (\overline{ML}/\zeta_A C) \cos (\omega_e t + \delta)$.

The phase angles presented are given in degrees which relate to the wave at the CG with positive indicating a lead.

PARAMETRIC VARIATIONS

The study into the effects of parametric variations on heave, pitch and roll motions, was carried out using the ASR as a parent design. This study was conducted at three Froude numbers, $F_n = 0, 0.15$, and 0.30 for the heave and pitch results. The roll investigation was limited to the zero speed case only.

The effects of parametric variations for the ASR parent design were studied by varying the beam to draft, hull separation to beam, and length to beam ration; i.e., B/T, HS/B and L/B, respectively. With regard to:

(1) HS/B variation, this was accomplished by changing HS while holding Δ, L, B and T constant;

(2) B/T variation, this was accomplished by simultaneously varying B and T by equal but opposite amounts while holding Δ, L, C_p, C_x, and the distance between hull centerlines constant;

(3) L/B variation, this was accomplished by varying L and B by equal but opposite amounts, for constant Δ and distance between the hull centerlines, keeping first T, then B/T constant.

In the use of the heave and pitch motions program, HJCT, variations made in beam and/or draft were accomplished by proportionally varying the offsets used to define each station for the parent design. In using the roll program, RLAC, these parameters were varied directly.

RESULTS AND DISCUSSION

Figures 2 to 15 and Table 2 present comparisons between experimental measurements and predicted values.

For the ASR, the comparisons of nondimensional added mass and damping coefficients A_{33}, B_{33}, A_{35}, B_{35}, A_{53}, B_{53}, A_{55}, and B_{55} are shown as a function of nondimensional frequency μ_e in Figures 2 to 5. There is generally fair to good agreement with some exceptions. For instance, at the higher Froude numbers the experimentally obtained damping does not always exhibit the sharp inflections predicted analytically.

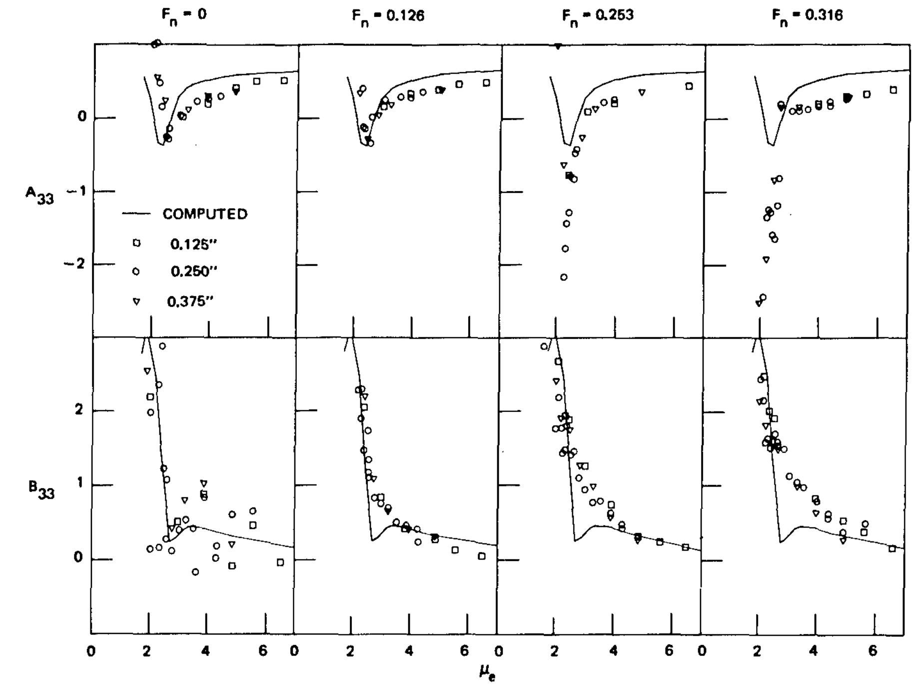

Figure 2 – The Coefficients A_{33} and B_{33} versus Nondimensional Frequency of Encounter for ASR

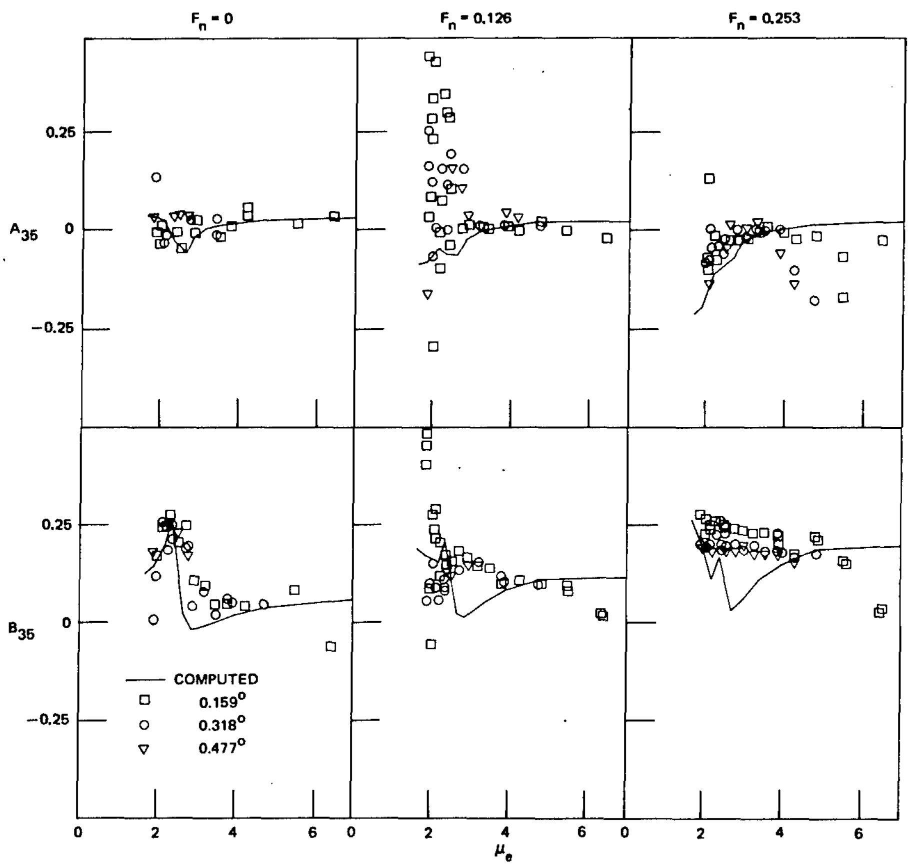

Figure 3 – The Coefficients A_{35} and B_{35} versus Nondimensional Frequency of Encounter for the ASR

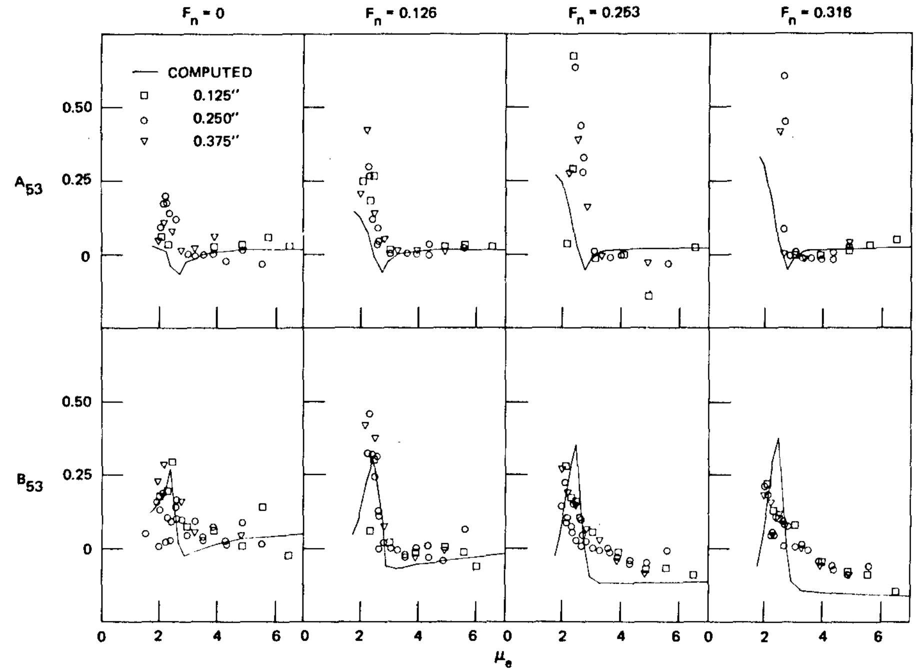

Figure 4 – The Coefficients A_{53} and B_{53} versus Nondimensional Frequency of Encounter for the ASR

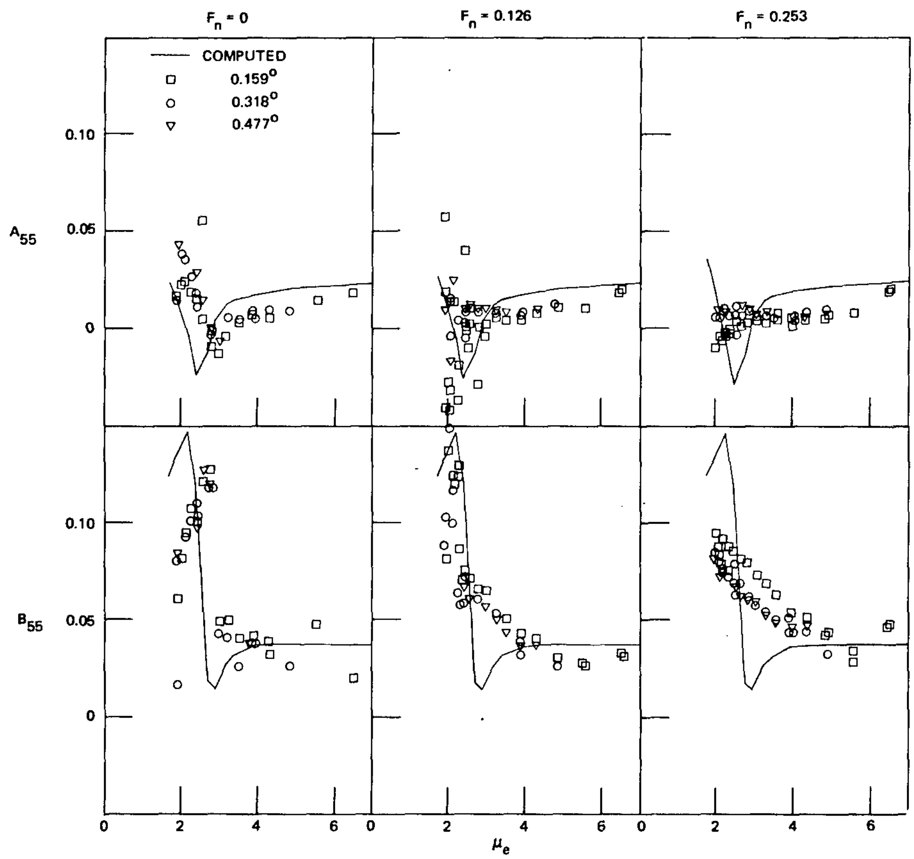

Figure 5 – The Coefficients A_{55} and B_{55} versus Nondimensional Frequency of Encounter for the ASR

It should be pointed out that the technique and equipment used to measure added mass and damping are identical to those used for measuring the two-dimensional twin cylinder data, at zero Froude number, reported in References 1 and 2. Table 2 gives a comparison of the nondimensional restoring coefficients C_{33}, C_{35}, C_{53}, and C_{55} which are derived from the dimensional model scale data of Figure 6. This shows that there is a 9 and 15 percent overprediction for the values of C_{33} and C_{55} respectively with excellent agreement for the cross-coupling terms. It can be seen in Figure 6 that there is a shift in the force and moment plots as forward speed increases. This indicates the forces and moments are different due to changing hull wave patterns which result in model sinkage and trim.

The regular wave heave and pitch exciting forces and moments are presented for the ASR in nondimensional form in Figure 7 with phases given in Figure 8. The agreement between prediction and measurement is good for the heave excitation force and poor for the pitch exciting moment. In the latter case, although trends compare, the prediction grossly overestimates the measured data. Predicted and measured phases are in good agreement.

The results of the motion comparisons are given in Figures 9 to 15 for the four catamaran hull forms, i.e., ASR, CVA, LST and MODCAT, respectively. These regular wave results are presented as nondimensional head wave heave and pitch transfer functions, $\frac{\bar{z}}{\zeta_a}$ and $\frac{\bar{\theta}\lambda}{2\pi\zeta_a}$, together with phase angles in degrees related to the wave at the center of gravity, with positive indicating a lead. No phase results are given for the MODCAT since no data were available.

The agreement, shown by these comparisons between prediction and measurement for heave and pitch motion of the ASR, CVA and LST, is quite good for low speeds. In fact for the LST the agreement is excellent for all the tested speeds. The main discrepancies occur for the higher tested speeds, where predicted peak motion magnitudes are overestimated. The higher speed discrepancies shown for the ASR and CVA, as compared to the results for the LST, tend to indicate that the monohull strip theory approach is not completely adequate for predicting the motions of catamarans with average hull separation to beam ratios.

Here it should be pointed out that the hull separation to length ratio for the LST is 0.05, i.e., three times smaller than for the ASR and CVA. It is probable that for this extremely small hull separation to length ratio the LST may be tending to monohull behavior as regards forward speed hydrodynamic interaction effects.

The better agreement between the results for the LST and CVA (away from the peaks) as compared to the ASR (away from the peaks), tend to indicate the advantage of performing free running model tests as opposed to using a motion measuring device which couples the model and carriage.

In the case of the MODCAT, which possesses a radically different hull shape, the amount of measured data is too limited to examine any possible discrepancies for peak motion magnitudes at higher speeds. The measured results available are in good agreement with predicted values.

The question of what constitutes an adequate description of a catamaran hull for the purposes of prediction was investigated. For the case of the ASR a comparison was made between the computed prediction results presented herein, which utilized a twenty one station description of the hull, and the prediction results computed using a thirty station description of the hull. No significant differences in the prediction results materialized as a result of this refinement.

TABLE 2

Comparison of Restoring Coefficients for ASR

Coefficient	Experimental	Computed
C_{33}	14.3	15.6
C_{53}	0.499	0.508
C_{35}	0.511	0.508
C_{55}	0.739	0.853

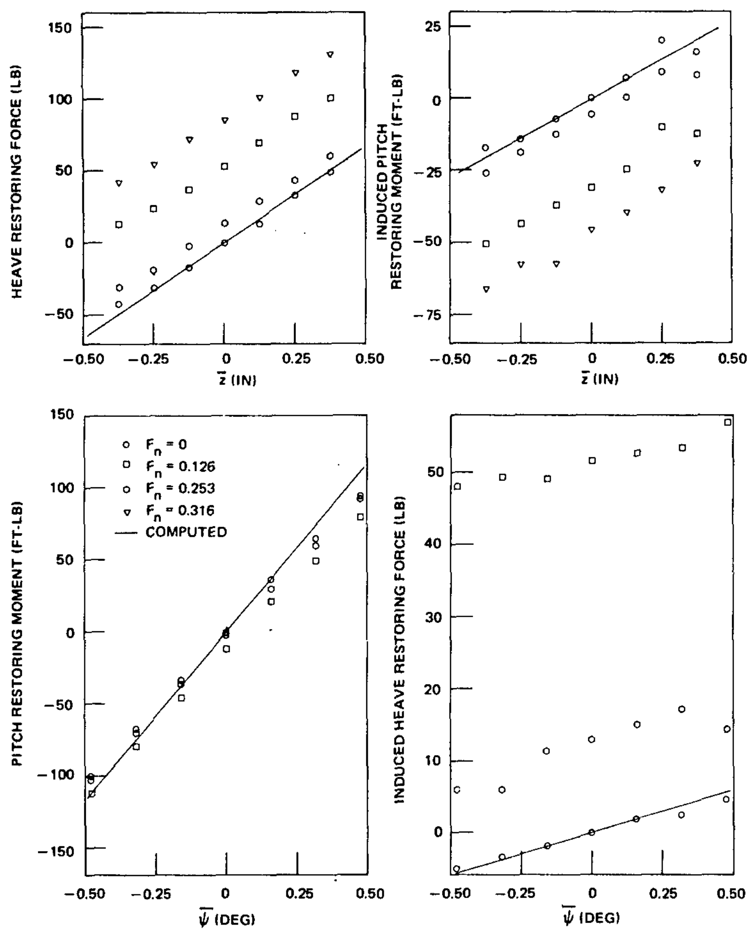

Figure 6 – Force and Moment Plots for Determination of Heave and Pitch Restoring Constants for the ASR (Model Scale)

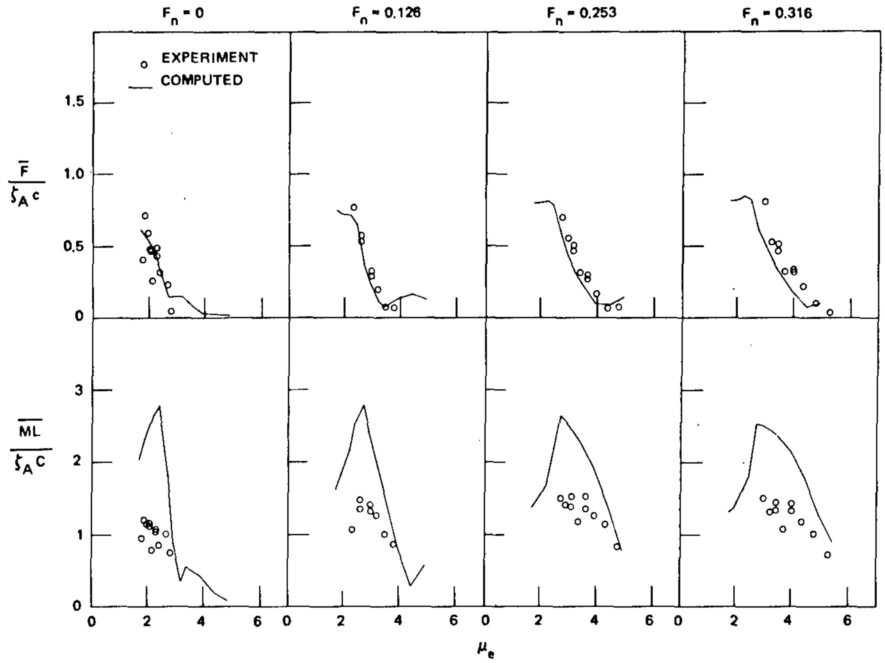

Figure 7 – Heave Exciting Force and Pitch Exciting Moment Parameters versus Nondimensional Frequency of Encounter for the ASR

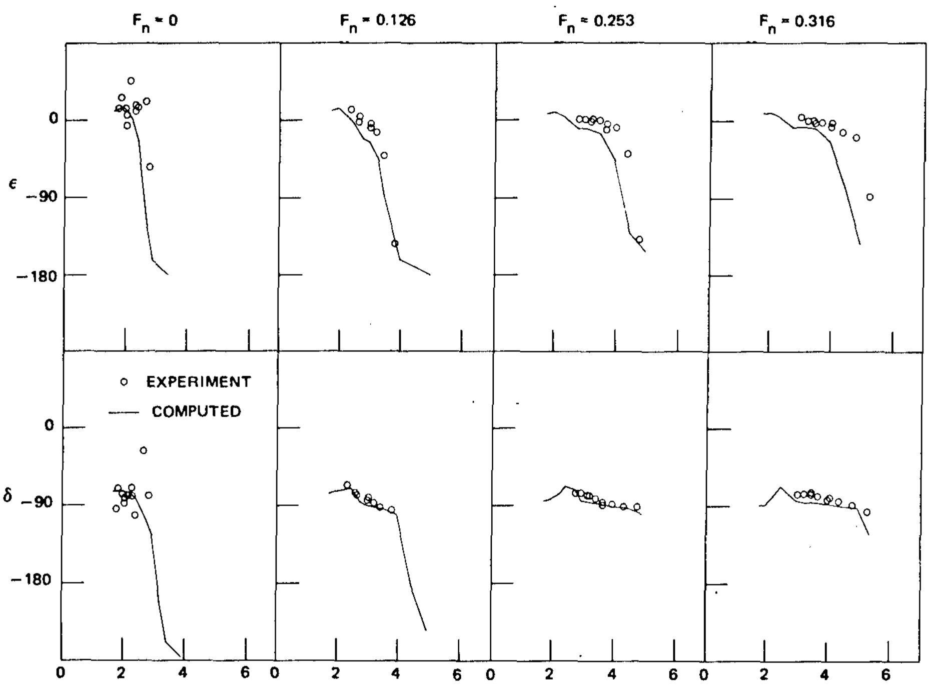

Figure 8 – Heave Exciting Force and Pitch Exciting Moment Phases versus Nondimensional Frequency of Encounter for the ASR (Degrees)

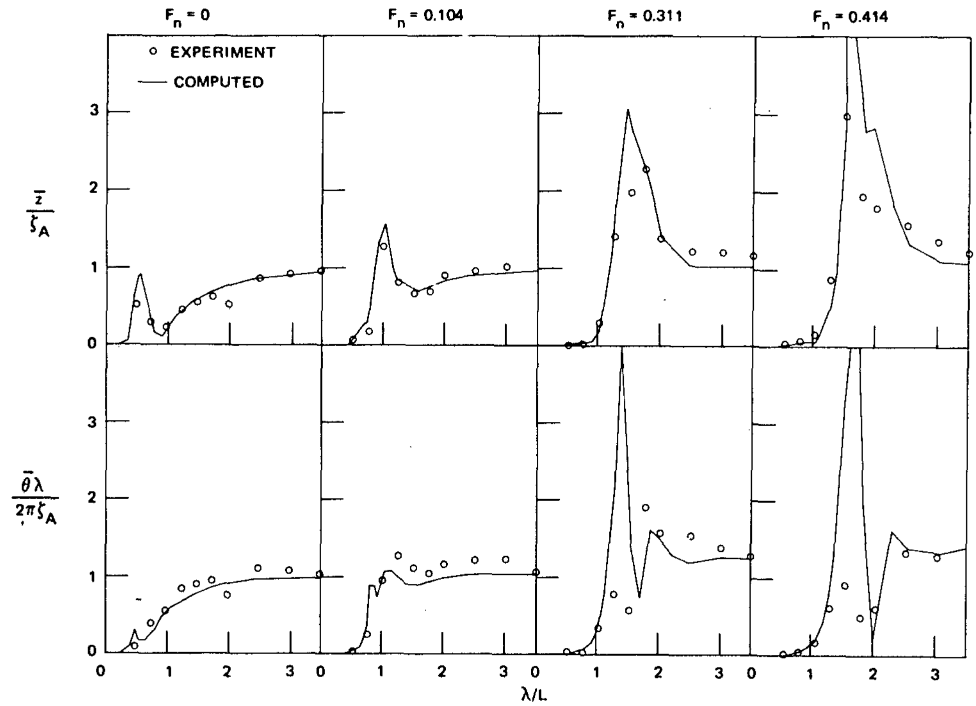

Figure 9 – Nondimensional Heave and Pitch Parameters versus Wavelength to Shiplength Ratio for the ASR

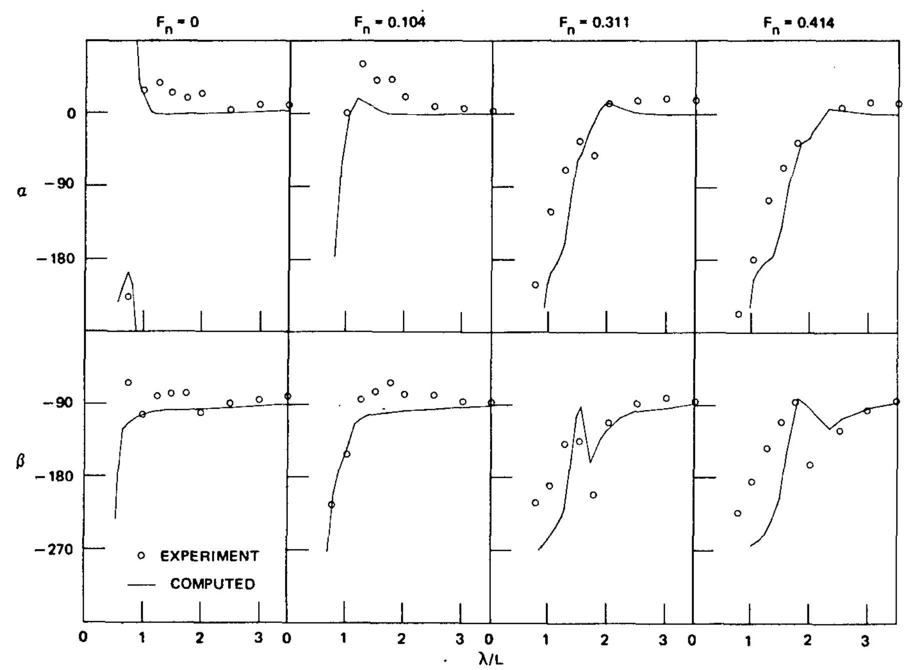

Figure 10 – Heave and Pitch Motion Phases versus Wavelength to Shiplength Ratio for the ASR (Degrees)

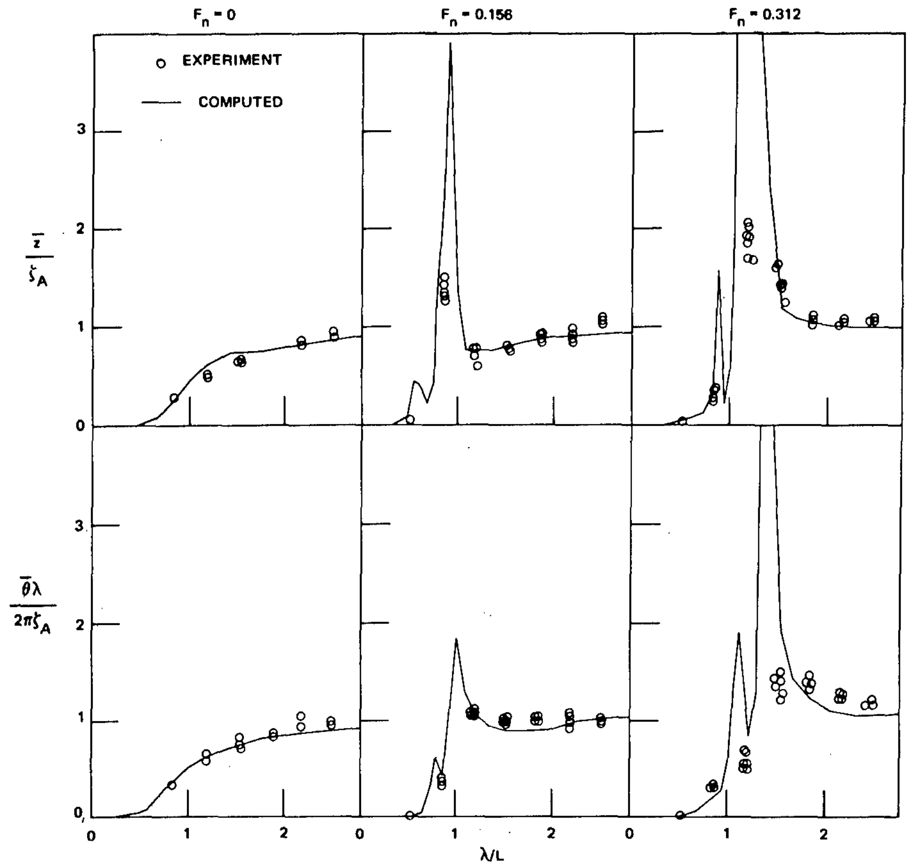

Figure 11 – Nondimensional Heave and Pitch Parameters versus Wavelength to Shiplength Ratio for the CVA

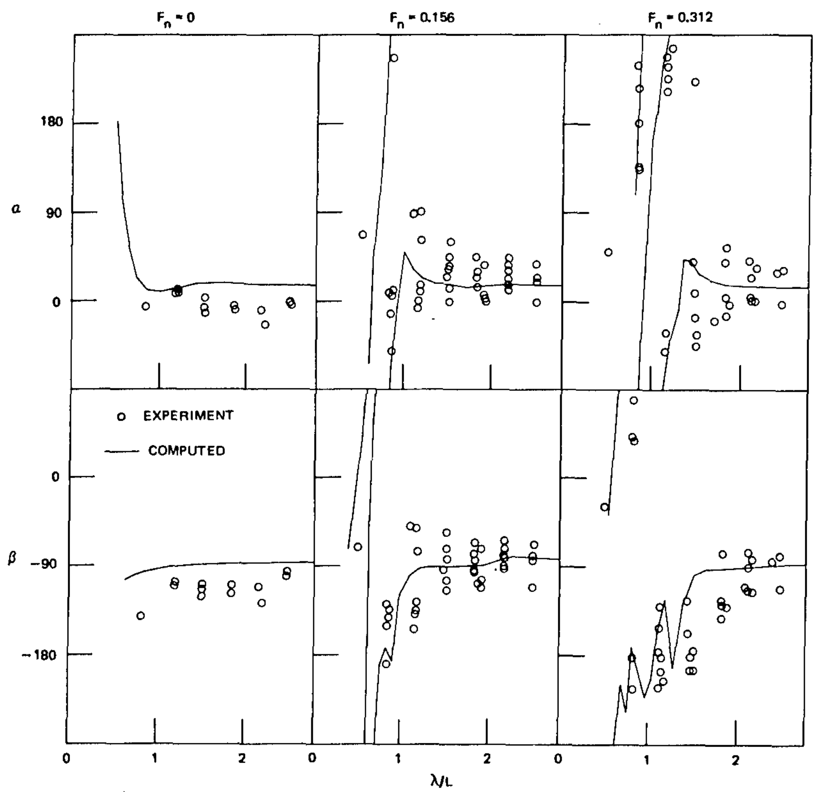

Figure 12 – Heave and Pitch Motion Phases versus Wavelength to Shiplength Ratio for the CVA (Degrees)

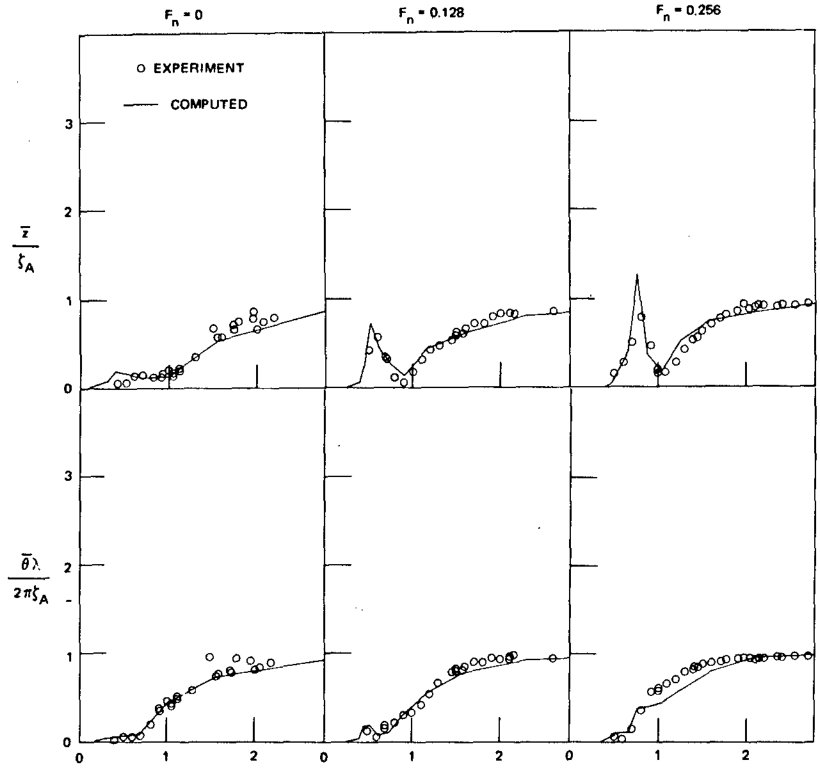

Figure 13 – Nondimensional Heave and Pitch Parameters versus Wavelength to Shiplength Ratio for the LST

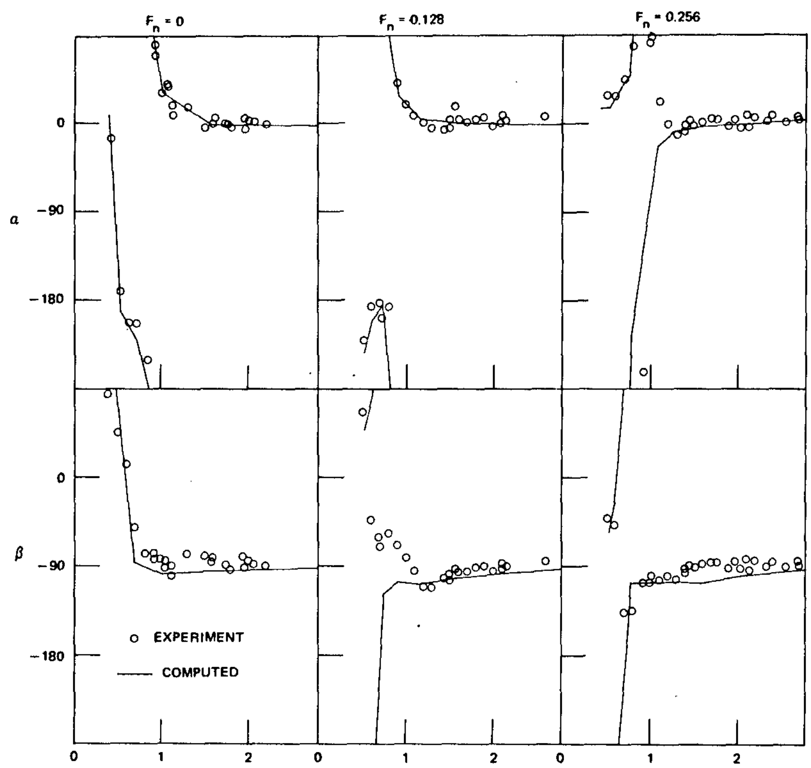

Figure 14 – Heave and Pitch Motion Phases versus Wavelength to Shiplength Ratio for the LST (Degrees)

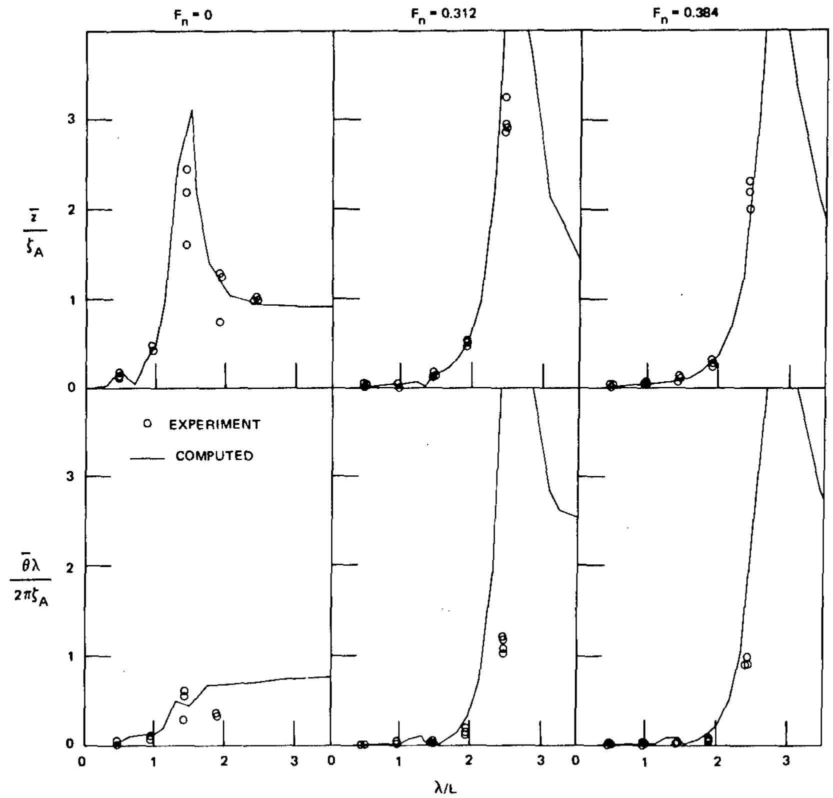

Figure 15 – Nondimensional Heave and Pitch Parameters versus Wavelength to Shiplength Ratio for the MODCAT

The results for the investigation of the effects of parametric hull form variations on the motions, are presented in Figures 16 to 19 for the ASR. They are presented as nondimensional head wave heave and pitch transfer functions, $\frac{\bar{z}}{\zeta_a}$ and $\frac{\bar{\theta}\lambda}{2\pi\zeta_a}$, for Froude numbers of F_n = 0, 0.15 and 0.30. In addition, for the ASR, results are presented for the nondimensional roll transfer function, $\frac{\bar{\psi}\lambda}{2\pi\zeta_a}$, for zero speed in beam waves.

The results of varying the hull separation to beam ratio, *HS/B*, for the ASR parent design, while holding displacement, length, beam and draft constant, are shown in Figure 16. This shows that increasing this ratio from the parent design value *HS/B* = 0.75 to 1.50, results in significant increases in the heave and pitch motions for speeds greater than zero. However, experimental results given in Reference 7 do not support these significant increases, other than for the heave motion at the intermediate speed. Further increases in hull separation to beam ratio do not result in any further significant effects on the heave and pitch motions. As is to be expected increases in hull separation to beam ratio result in consequent reductions in roll motions for zero speed.

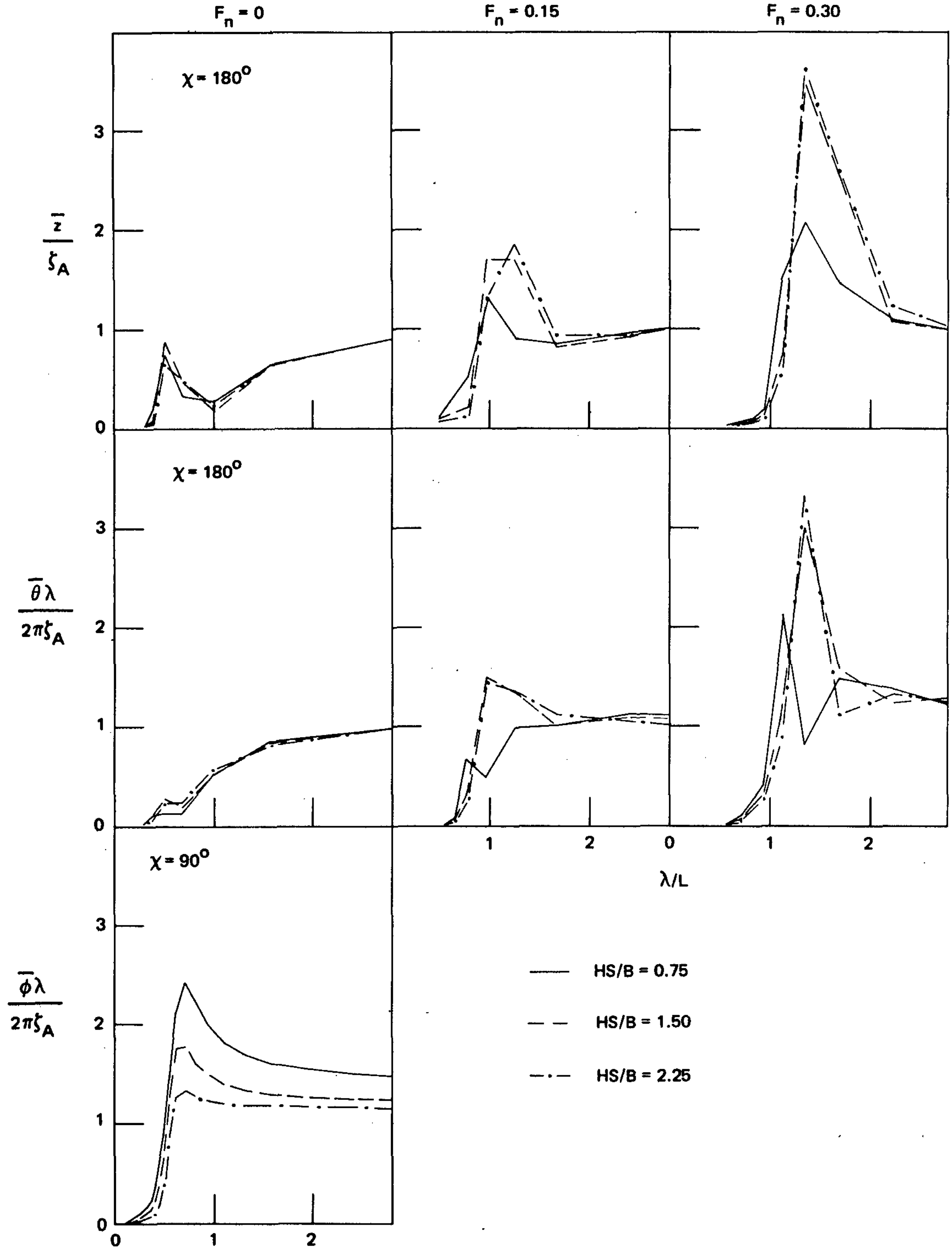

Figure 16 – The Effect of Variation of the Hull Separation to Beam Ratio on Heave, Pitch and Roll Motions versus Wavelength to Shiplength Ratio for the ASR

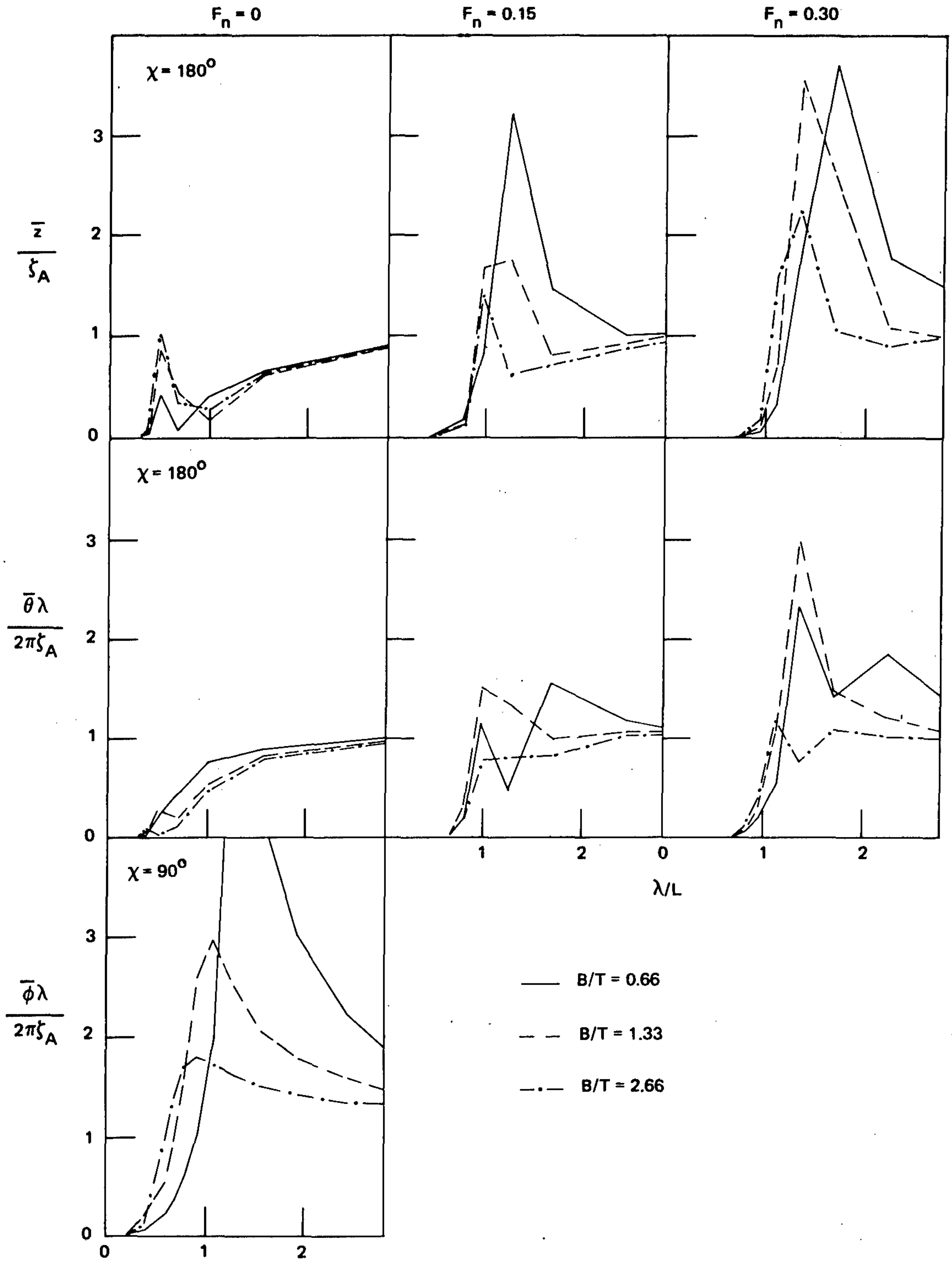

Figure 17 – The Effect of Variation of the Beam to Draft Ratio on Heave, Pitch and Roll Motions versus Wavelength to Shiplength Ratio for the ASR

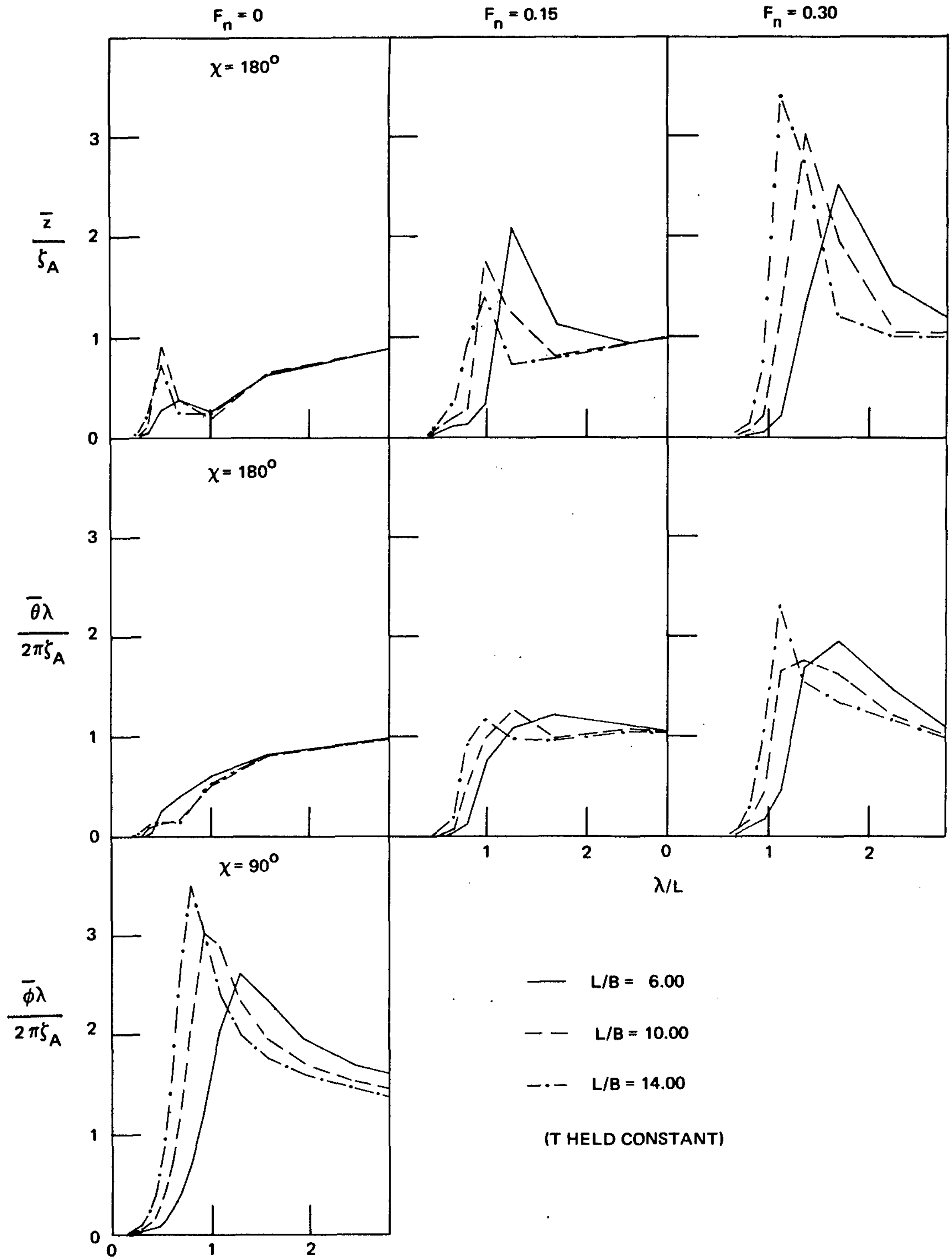

Figure 18 – The Effect of Variation of the Length to Beam Ratio on Heave, Pitch and Roll Motions versus Wavelength to Shiplength Ratio for the ASR

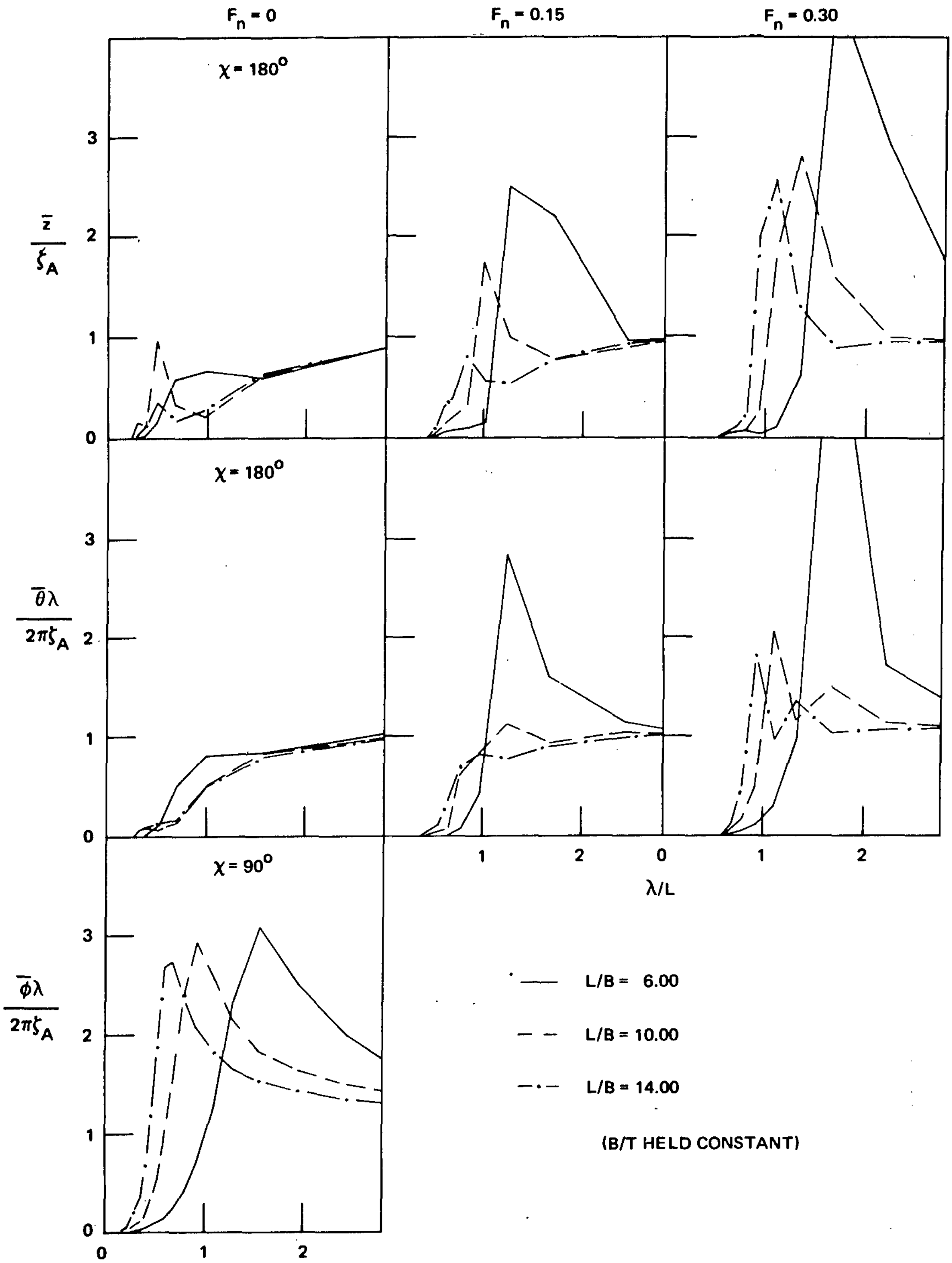

Figure 19 – The Effect of Variation of the Length to Beam Ratio Holding the Beam to Draft Ratio Constant on Heave, Pitch and Roll Motions versus Wavelength to Shiplength Ratio for the ASR

The results of varying the beam to draft ratio, B/T, for the ASR parent design, while holding displacement, length, and the distance between the hull centerlines constant, are shown in Figure 17. Here again, for heave and pitch motions, the minimum effect is shown for zero speed. At the higher speeds, the general trend is that motions are reduced as beam to draft ratio is increased. For roll motion at zero speed, the effect of increasing beam to draft ratio has a much greater effect in reducing roll motion for wavelength to shiplength ratios greater than unity.

Figures 18 and 19 show the results of varying length to beam ratio, L/B, for the ASR parent design for constant displacement and distance between the hull centerlines keeping first draft, then beam to draft ratio, constant. The only major effect of note is for the heave and pitch motion keeping beam to draft ratio constant where, for higher speeds, increasing the length to beam ratio from 6.0 to 10.0 drastically reduces the magnitude of the peak motions.

CONCLUDING REMARKS

The results of comparisons between measured and predicted values show that the heave and pitch motions of a catamaran, in regular head waves, can be accurately predicted for low speeds. The accuracy decreases as speed increases but is still reasonable away from resonance values. For regions of resonance, although the wavelength to shiplength ratio at which the resonance occurs is satisfactorily predicted, there can be considerable overestimation for the magnitude of the motion.

The cause of the decrease in accuracy with increasing speed is probably associated with the assumption that the speed effects on the motions are the same as for monohulls. The hydrodynamic interaction between the twin hulls due to forward speed is ignored.

The excellent agreement between measured and predicted motion values for the LST is probably associated with the fact that the hull spacing to length ratio is much smaller than for any of the other catamarans studied, i.e., HS/L = 0.18 for ASR, 0.17 for CVA, 0.05 for LST, and 0.36 for MODCAT. For this extremely small hull separation to length ratio the LST may be tending to monohull behavior as regards forward speed hydrodynamic interaction effects.

The discrepancies discussed above are not considered to vitiate the usefulness of the prediction program as a tool for studying the effects of parametric hull geometry variations. The wavelength to shiplength ratio at which resonance occur, together with resonance trends, are valuable in determining optimum hull geometry.

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REFERENCES

1. Wang, S. and Wahab, R., "Heaving Oscillation of Twin Cylinders in a Free Surface," Journal of Ship Research (Mar 1971).

2. Lee, C. M., Bedel, J. W., and Jones, H., "Added Mass and Damping Coefficients of Heaving Twin Cylinders in a Free Surface," Naval Ship Research and Development Center Report 3695 (Aug 1971).

3. Frank, W. and Salvesen, N., "The Frank Close-Fit Ship-Motion Computer Program," Naval Ship Research and Development Center Report 3289 (Jun 1970).

4. John, F., "On the Motion of Floating Bodies, Part II," Comm. Pure Appl. Math., Vol. 3 (1950).

5. Wahab, R. and Hubble, E. N., "Simplified Theoretical Methods of Predicting the Motions of a Catamaran in Waves," Naval Ship Research and Development Center Report 3736 (Sep 1971).

6. Wahab, R., "Het Slingeren van een Catamaran op Zee," Publikatie No. 230 van het Nederlansch Scheepsbouwhandig Proefstation (1964).

7. Wahab, R., Pritchett, C., and Ruth, L. C., "On the Behavior of the ASR Catamaran in Waves," Marine Technology, Vol. 8, No. 3 (Jul 1971).

8. Jones, H. D., "Motion and Bridging Structure Load Characteristics for a Large CVA Catamaran in Waves," Naval Ship Research and Development Center Report 3604 (Apr 1971).

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13. ABSTRACT

As part of an effort to advance the development of catamaran technology, ship motion prediction theory for monohulls has been adapted, and programmed for a digital computer, to predict the heave and pitch motion characteristics of a catamaran in regular head waves. This report provides verification of the computer program utilizing existing experimental model data. Predictions are also made for the effects of changes in certain hull parameters on catamaran motions. An existing computer program, based on simplified theory, is also utilized to predict catamaran roll motion in the parametric variation study.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Motions						
Computer Programs						
Variations						