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EXPERIMENTAL MEASUREMENTS IN HEAD SEAS OF THE SEAKEEPING CHARACTERISTICS OF A FAST DISPLACEMENT CATAMARAN OF SERIES 64 FORM

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CONTENTS

NOMENCLATURE

Symbols and some values used in the report:

Demihull	One of the hulls which make up the catamaran
LCG	Longitudinal centre of gravity
TF	Transfer function
RMS	Route mean square
FFT	Fast Fourier transform
Fn	Froude Number, $\left[u / \sqrt{gL}\right]$
Rn	Reynolds Number, $[uL / \nu]$
u	Velocity $[ms^{-1}]$
L, L_{BP}	Demihull length between perpendiculars [m]
A, WSA	Static wetted surface area $[m^2]$
B	Demihull maximum beam [m]
T	Demihull draught [m]
S	Separation between catamaran demihull centrelines [m]
∇	Volume of displacement (demihull) $[m^3]$
Δ	Mass displacement in freshwater (demihull) [kg]
C_B	Block coefficient (demihull)
C_P	Prismatic coefficient (demihull)
C_M	Midship section area coefficient (demihull)
$L / \nabla^{1/3}$	Length : Displacement ratio (demihull)
γ	Ship : Model scale factor
Added res. Coeff.	$\Delta R / (2\varsigma_{RMS}^2 \rho g B^2 / L)$ or $\Delta R / (\varsigma^2 \rho g B^2 / L)$
λ	Wavelength [m]
$h_{1/3}$	Significant wave height
T_o	Wave period, spectrum characteristic period [s]
ω, ω_0	Wave circular frequency $[rads^{-1}]$
ω_e	Wave encounter circular frequency $[rads^{-1}]$
μ	Ship heading [rad] (0=following seas, π=head seas)
TF (ω_e)	Transfer function spectrum
E_w (ω_e)	Wave energy spectrum
M (ω_e)	Motion spectrum
m_0	Zero moment of spectrum (area under spectrum)
g	Acceleration due to gravity $[9.80665\ ms^{-2}]$
ρ	Density of fresh water $[1000\ kg/m^3]$
ν	Kinematic viscosity of fresh water $[1.141 \times 10^{-6}\ m^2s^{-1}$ at $15^{\circ}C]$

1. INTRODUCTION

Experimental and theoretical work on the seakeeping characteristics of high speed displacement catamarans has been ongoing over a number of years at the University of Southampton in order to improve the understanding of their performance in waves and to provide design and validation data.

This report describes further model tests on a catamaran in long crested head seas. The experimental programme is a development of and complements the earlier work, reported in Ref. 1, in which an extensive series of seakeeping tests were carried out on catamarans derived from the NPL round bilge series, Ref. 2. The model in the current work is based on the SERIES 64 round bilge hull form, Ref. 3, and has been designated Model 5s. It corresponds to Model 5b in the earlier series, Ref. 1, having a length-displacement ratio ($L/\nabla^{1/3}$) of 8.5 and a Breadth-Draught ratio (B/T) of 2.0. The model was tested in monohull form and at two hull separations in catamaran configuration, in each case at four Froude numbers ranging from 0.20 to 0.80.

The work described formed part of a wider research programme, funded by EPSRC and Industry and managed by Marinetech South Ltd. The wider programme includes tests in oblique waves and model open sea tests which work is the subject of separate reports.

2. DETAILS OF MODELS

The model was of symmetrical round bilge form with transom stern, see Figure 1, and was based on the SERIES 64 hull form. The model was tested in both monohull and catamaran configurations, in all cases at Fn = 0.20, 0.53, 0.65 and 0.80. In the catamaran configuration, Separation : Length ratios (S/L) of 0.20 and 0.40 were tested.

The model was constructed using an epoxy-foam sandwich skin, which provided a good strength to weight ratio to facilitate the distribution of ballast weight. The model was fitted with turbulence stimulation comprising trip studs of 3.2mm diameter and 2.5mm height at a spacing of 25mm. The studs were situated 37.5m aft of the stem. The models were tested without underwater appendages.

The towing point was set coincident with the longitudinal (LCG) and vertical (VCG) centres of gravity where the VCG was 1.5 Draught above the base line. The longitudinal moment of inertia in pitch was set such that the longitudinal radius of gyration was 25% of the length of the model. It should be noted that the moving mass in pitch was less than that in heave. This was because the tow post and part of the tow fitting moved only in heave and were not free to pitch. The towpost represented 12.4% of the catamaran displacement.

No compensation was made for the vertical separation of the tow point and the propeller thrust line. The tow fitting allowed free movement in heave and pitch whilst movements in surge, sway, roll and yaw were restrained.

3. FACILITIES AND TESTS

3.1 Tank Facilities

The model experiments were, carried out in the Southampton Institute test tank. The principal particulars of the tank are given in Table 2.

The tank is fitted with a paddle-type wave maker at one end and a passive beach at the opposite end. The wave maker is computer controlled and is capable of generating both regular and irregular waves. Waves can be generated at various frequencies and wave heights dependent on the response of the wavemakers and the size and type of model being tested. The frequency range is from about 2.5Hz to 0.6Hz. The lowest frequency is determined by the longest wave possible in the tank without being affected by the tank bottom; this corresponds to a wave length of approximately 4.5m.

3.2 Instrumentation

Heave motions were measured with a linear potentiometer mounted at the longitudinal centre of gravity. Pitch was measured with an angular potentiometer in the tow fitting. Accelerations were measured using piezoresistive accelerometers at the longitudinal centre of gravity and 15% of the length of the model aft of the forward perpendicular. The wave system encountered during the run was measured with a stiff, sword type resistance wave probe mounted on the carriage ahead and to the side of the model. Comparisons of traces recorded from the carriage using this probe and from a shore based probe showed satisfactory correlation. All signals were acquired using a personal computer via an analogue to digital converter. This system enabled detailed analysis of the results from each run to be carried out during the experiments.

The wave maker was found to produce waves of the requested period but wave amplitudes showed some variation with frequency.

3.3 Test Conditions

Tests were carried out in head seas in three hull configurations: monohull and in catamaran mode with Separation:Length ratios (S/L) of 0.2 and 0.4. Measurements of each model configuration were taken at four Froude numbers (Fn= 0.20, 0.53, 0.65 and 0.80) and over an encounter frequency range of 4 rads^{-1} to 18 rads^{-1}. The steady speed run length for each test was 12.5m. The relationship between encounter frequency, and ship-length to wavelength ratio L/λ for the four speeds is given in Table 3.

4 DATA REDUCTION AND CORRECTIONS

During regular wave tests the models were allowed to encounter at least five to six waves before the responses were recorded, so as to allow transients in the response to die out. The models then encountered a minimum of six waves during which the measurements were taken. At the high wave frequencies many more waves were encountered.

Regular wave tests were analysed using two methods. Firstly, RMS values of the measured motions and the programmed wave frequency were used to calculate the transfer functions. Secondly, a least-squares sine wave fit was made to the measured motions, see Ref. 4 for details. This enabled the amplitude and period to be accurately determined. Good correlation between the two methods was found. The accuracy, of the accelerometer measurements was also confirmed by twice differentiating the vertical motions at the accelerometer positions. These derived accelerations were found to match the directly measured values reasonably well.

Transfer functions from the regular wave experiments were calculated as follows:

$$Heave\ TF = \frac{Heave\ Amplitude\ RMS}{Wave\ Amplitude\ RMS}$$

$$Pitch\ \ TF = \frac{Pitch\ Amplitude\ RMS\ [rad]}{Wave\ Amplitude\ RMS\ [m]} \times \frac{g\,[ms^{-2}]}{\omega_0^2\,[rads^{-1}]} \qquad (1)$$

$$Accel\ \ TF = \frac{Accel\ Amplitude\ RMS\ [ms^{-2}]}{Wave\ Amplitude\ RMS\ [m]} \times \frac{1}{\omega_e^2\,[rads^{-1}]}$$

where, the encounter frequency ω_e, is related to the wave frequency ω_0 by Equation 2; u is the ship speed and μ the ship heading with $\mu = 0$ for the following sea case and $\mu = \pi$ for the head sea case.

$$\omega_e = \omega_0 - \cos(\mu)\frac{\omega_0^2 u}{g} \qquad (2)$$

Added resistance was calculated from the regular wave data, noting the model was kept fixed in surge. The dynamometer was sufficiently stiff for the rise and fall in resistance during each wave cycle to be clearly visible on the resistance measurement trace. Added resistance was assumed to be proportional to wave height squared (this was confirmed at several test conditions by varying the wave amplitude) and has been presented in terms of the added resistance coefficient given in Equation 3. Note that the factor of 2 is included since, for a sine wave signal, the RMS is 1/√2 of the signal amplitude.

$$\text{Added Res. Coeff.} = \frac{R_{reg.waves} - R_{calmwater}}{2\zeta_{RMS}^{2}\rho g B^{2} / L} \qquad (3)$$

The tank temperature was monitored but not found to vary significantly. Tank blockage effects were investigated earlier and found to be small. For these reasons no corrections were applied to the data.

5. DISCUSSION OF RESULTS

5.1 Motions

The derived transfer functions for pitch, heave and vertical accelerations are given in Figures 2 to 25. Due to the failure of one of the accelerometers during the monohull tests, the accelerations at LCG for the monohull, shown in Figs. 6 to 9, were derived from the heave results. The graphs are plotted with circular wave encounter frequency as abscissa, and Table 4 shows how these may be converted to wavelength:ship-length ratios for the different speeds tested. Three dummy points at 0, 1 and 2 rads/sec have been added to the transfer function curves in order to force the curve fits.

The results for the monohull are shown in Figs. 2 to 9. These are generally as would be expected and follow classical transfer function shapes.

The results for the catamaran are shown in Figs. 10 to 25. In most cases these show similar trends to the monohull results. At the lowest speed (Fn = 0.2) a secondary peak in the heave response can be noted, which was also exhibited by the monohull.

The results in Figs. 2 to 25 indicate that there is an increase in the transfer functions with increase in forward speed. It is interesting to note that for pitch and forward acceleration this phenomenon is not so well defined and some overlap in the Fn = 0.65 and Fn = 0.80 results can be found.

The results for the catamarans in Figs. 10 to 25 indicate that hull spacing has a relatively small effect on the transfer functions at the different speeds tested.

5.2 Added Resistance

The added resistance for the model in the various test conditions is given in Figs. 26 to 28. The data are plotted to a base of encounter frequency. The added resistance has been non-dimensionalised according to Equation 3, noting that B^2/L was the same for the monohull and the catamaran.

The added resistance shows a distinct peak for all the conditions tested; this tends to be the usual form of the added resistance curve for these vessel types, as can be seen in Ref. 1 and other published data.

In general, the magnitude of the catamaran added resistance is approximately twice that of the demihull tested in isolation (monohull). This would be expected if there was little or no interaction between the demihulls in the catamaran configuration. The magnitude of the results for the catamaran with the closer spaced demihulls (S/L=0.2) is more than that with the larger separation.

The effect of Froude number on added resistance is clearly apparent. The added resistance increases steadily with increasing Froude number and the frequency at which the maximum added resistance occurs increases with speed.

5.3 Comparison with NPL Hull Form Results

Some comparisons between the results for the present tests (SERIES 64 form) and the NPL form tested earlier (Ref. 1) are shown in Figs. 29 to 35. The general form and magnitude of the results are broadly similar for both hull forms, although the maximum values tend to extend to higher encounter frequencies in the case of the NPL form.

6. CONCLUSIONS

The work described in this report covers the experimental determination of the seakeeping properties of a monohull and catamaran based on the SERIES 64 round bilge series. One hull form has been tested in monohull and two catamaran configurations at four Froude numbers in head seas. Measurements of heave, pitch and vertical accelerations as well as added resistance due to waves have been made.

The monohull heave and pitch transfer functions were as expected; at low frequency the motion followed that of the wave, whilst at high frequency little motion was present. A relatively narrow resonant peak was found between these two extremes. The effect of increasing forward speed was to increase the size of the resonant peaks, this effect being most pronounced when going from Fn = 0.2 to Fn = 0.5 with a much smaller change when going from Fn = 0.5 to Fn = 0.8. The forward speed also changed the relative frequencies at which the heave and pitch peaks occurred.

The catamaran transfer functions were found to be similar to the monohull. Some broadening of the resonant peak was found, the effect being most pronounced at reduced forward speed. For the slowest speed (Fn = 0.2), secondary resonant peaks became apparent, especially in heave.

The added resistance was generally found to increase with Froude number. The change was greater between Fn = 0.2 to 0.5 and much less between Fn = 0.5 to 0.8. The added resistance of the catamarans was found to be more than twice the monohull value, especially at the higher Froude numbers. It was also discovered that the closer spaced catamaran (S/L = 0.2) had less added resistance than the wider catamaran.

ACKNOWLEDGEMENTS

The work described in this report covers part of the Fast Craft Research Programme funded by EPSRC and Industry and managed by Marinetech South Ltd.

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2. Bailey, D. The NPL High Speed Round Bilge Displacement Hull Series. Maritime Technology Monograph No. 4, Royal Institution of Naval Architects, 1976.

3. Yeh, H.Y.H. Series 64 Resistance Experiments on High Speed Displacement Forms. Marine Technology, July 1965.

Model	5s
Length	1.6m
$L/\nabla^{1/3}$	8.5
L/B	12.8
B/T	2.0
C_B	0.537
C_p	0.633
C_M	0.848
WSA	0.261 m^2
LCB	-6.4%

Table 1: Hull form principal particulars (monohull). Model 5s (based on SERIES 64 form)

Length	60m
Breadth	3.7m
Water depth	1.8m
Max carriage speed	4.2ms^{-1}

Table 2: Southampton Institute Tank Details

	Froude Number			
ω_e	**0.20**	**0.50**	**0.65**	**0.80**
6	0.52	0.32	0.27	0.24
11	1.33	0.73	0.61	0.52
16	2.19	1.23	0.98	0.84

Table 3: Relationship between encounter frequency ω_e and ship length to wavelength ratio L/λ at four Froude numbers

	Encounter Frequency [$rads^{-1}$]						
Fn	**4.0**	**6.0**	**8.0**	**10.0**	**12.0**	**14.0**	**16.0**
0.2	3.08	1.97	1.26	0.90	0.69	0.55	0.46
0.5	5.63	3.13	2.09	1.55	1.22	1.00	0.84
0.65	6.47	3.66	2.49	1.86	1.47	1.21	1.02
0.8	7.31	4.19	2.87	2.16	1.71	1.42	1.21

Table 4: Wavelength:Model length ratio for the test conditions

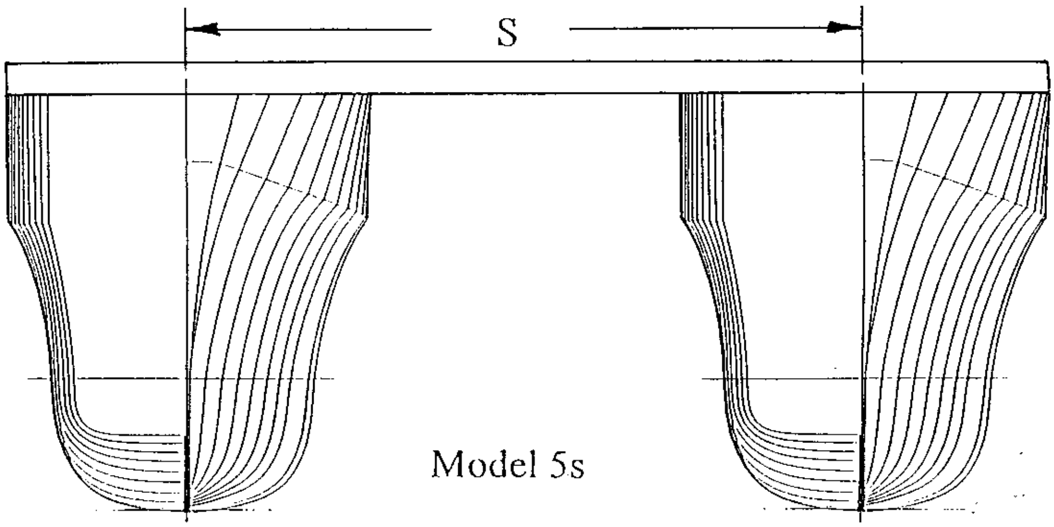

Fig 1: Body plan of model.

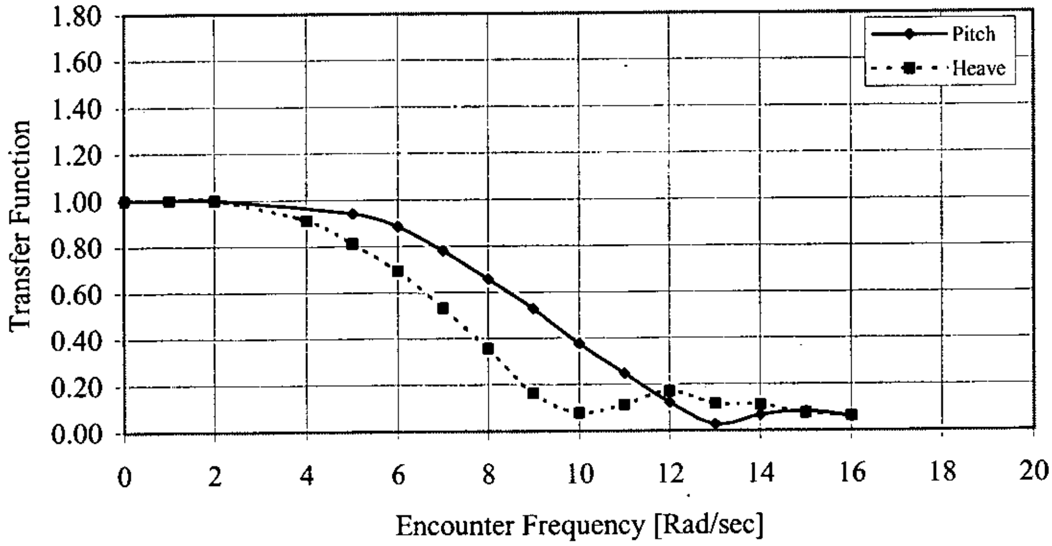

Fig 2: SERIES 64 Monohull, Fn=0.2 - Heave and Pitch

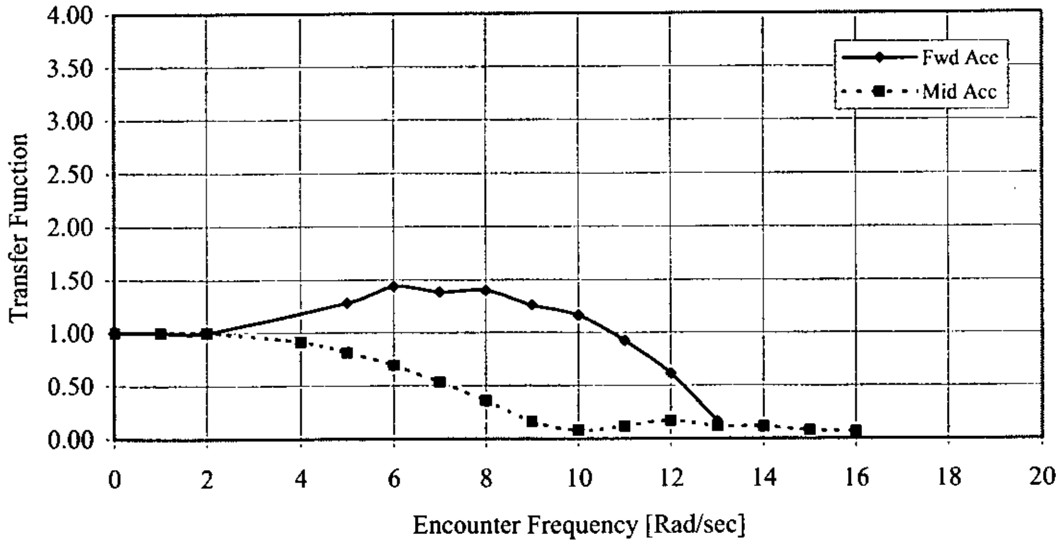

Fig 3: SERIES 64 Monohull, Fn=0.2 - Accelerations

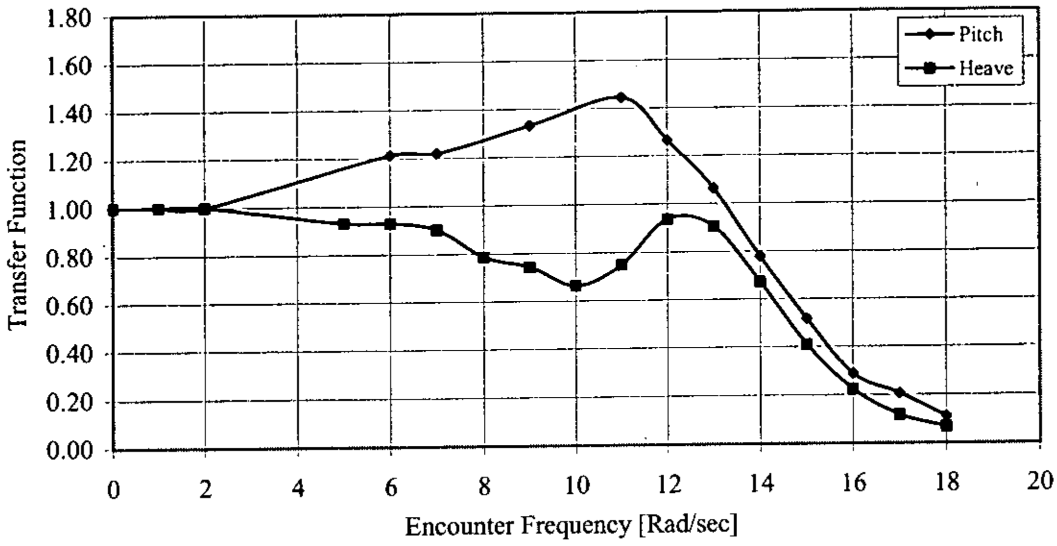

Fig 4: SERIES 64 Monohull, Fn=0.53 - Heave and Pitch

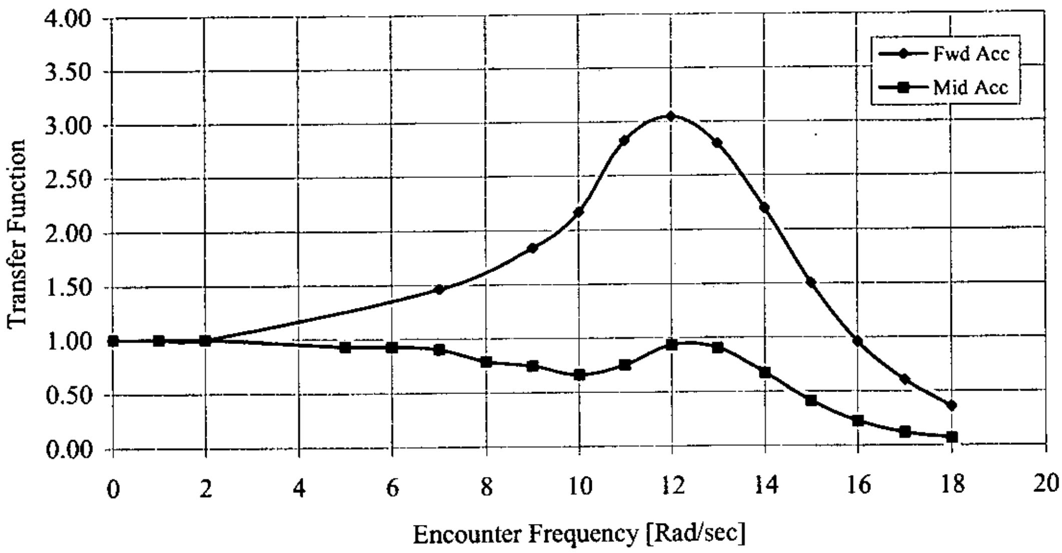

Fig 5: SERIES 64 Monohull, Fn=0.53 - Accelerations

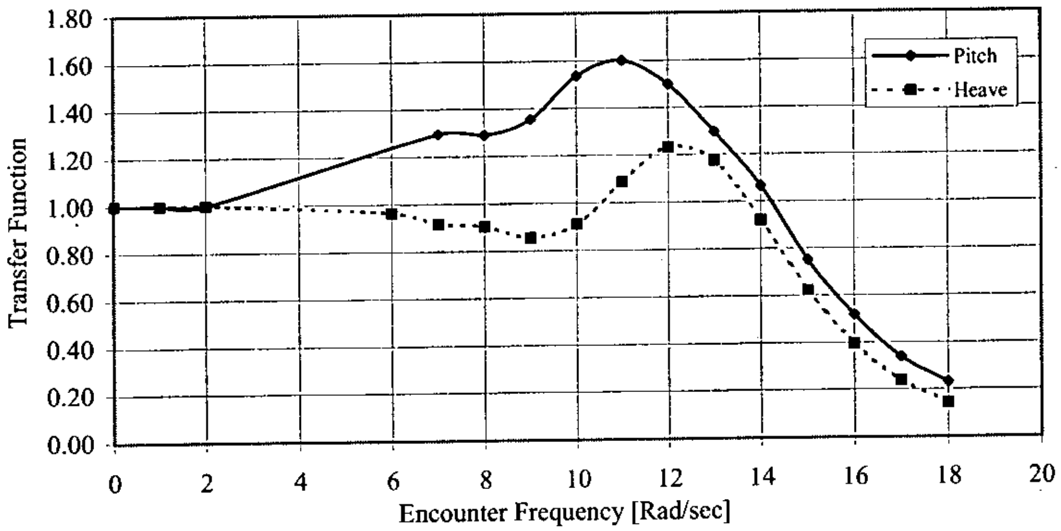

Fig 6: SERIES 64 Monohull, Fn=0.65 - Heave and Pitch

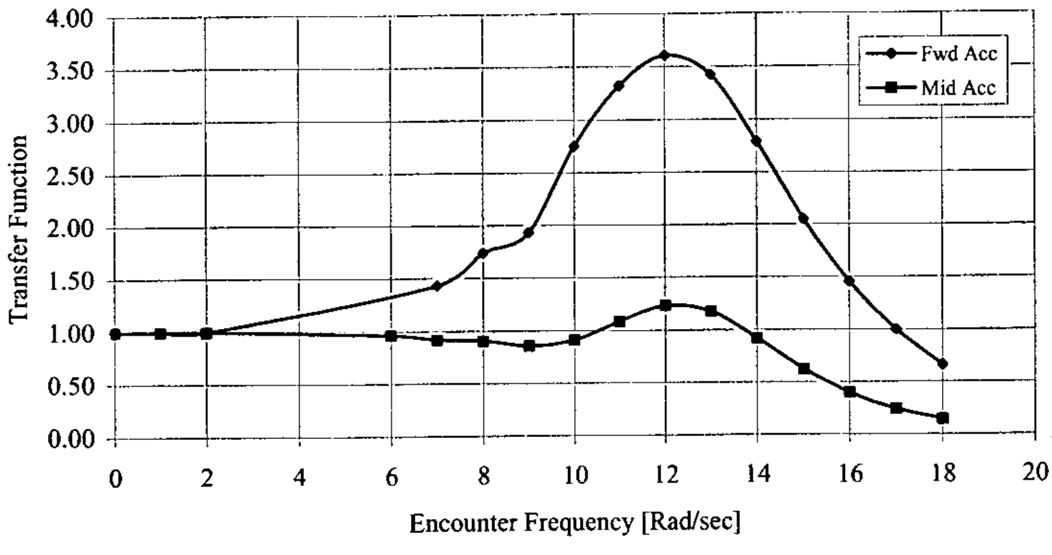

Fig 7: SERIES 64 Monohull, Fn=0.65 - Accelerations

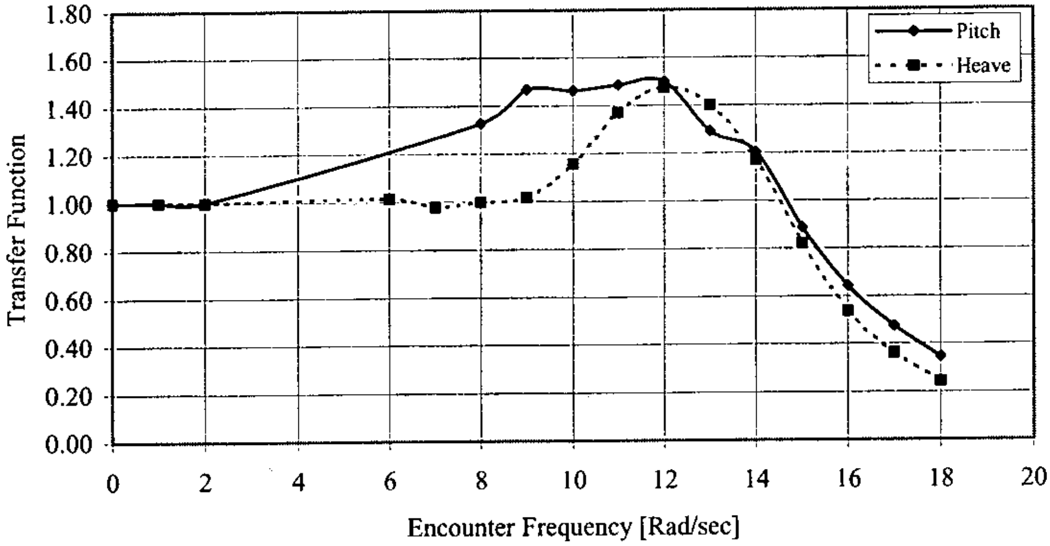

Fig 8: SERIES 64 Monohull, Fn=0.8 - Heave and Pitch

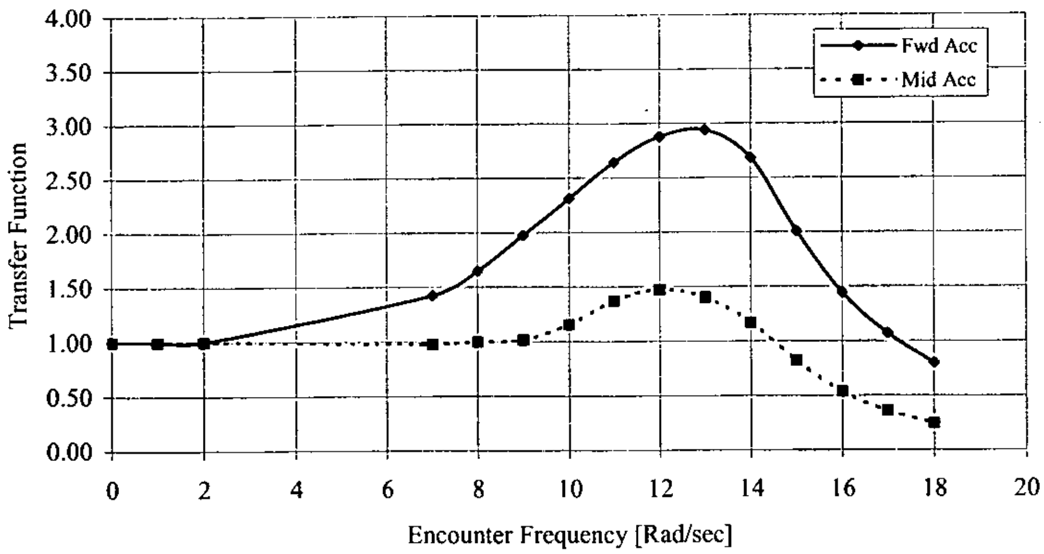

Fig 9: SERIES 64 Monohull, Fn=0.8 - Accelerations

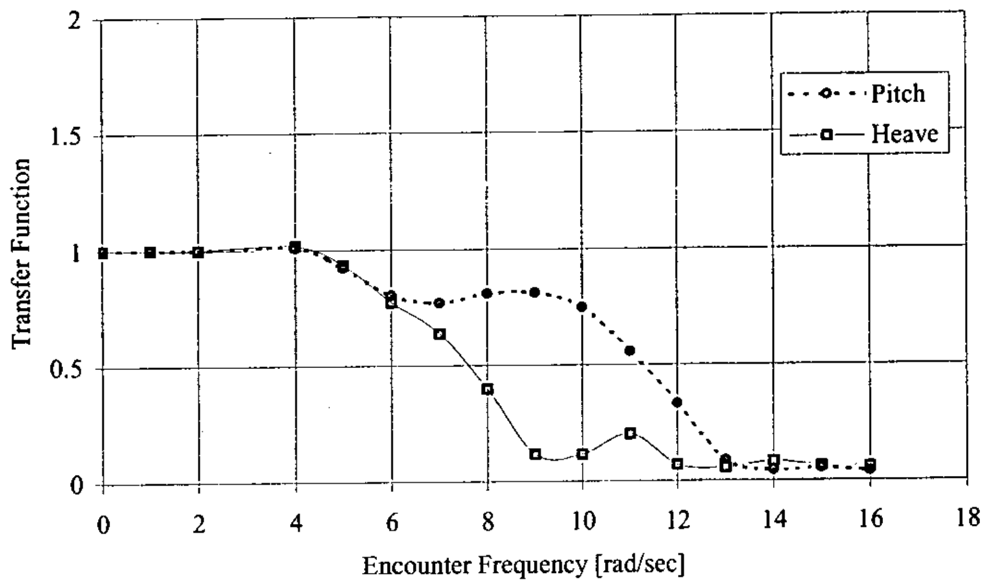

Fig 10: S/L=0.2 Fn=0.2 - Heave and Pitch

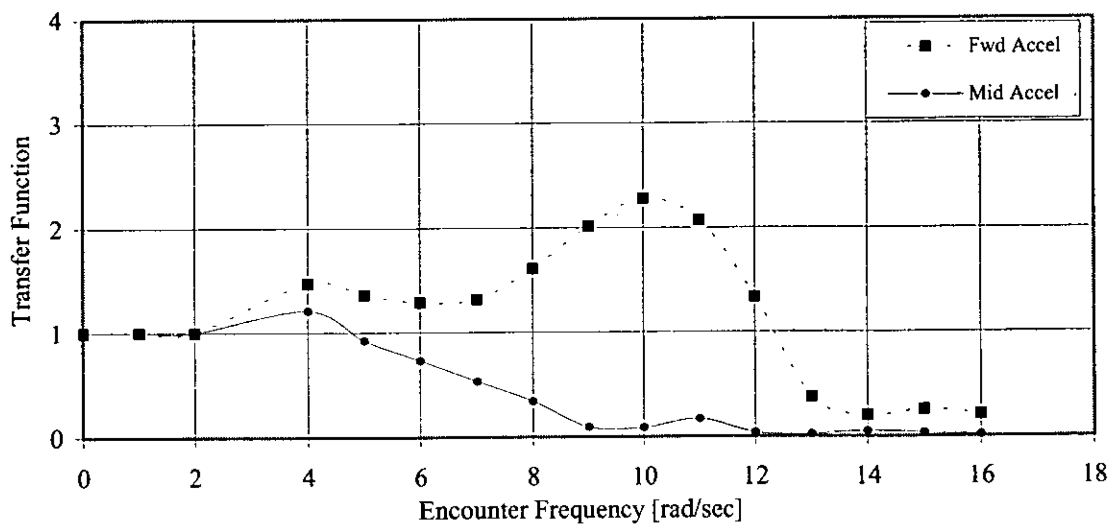

Fig 11: S/L=0.2 Fn=0.2 - Accelerations

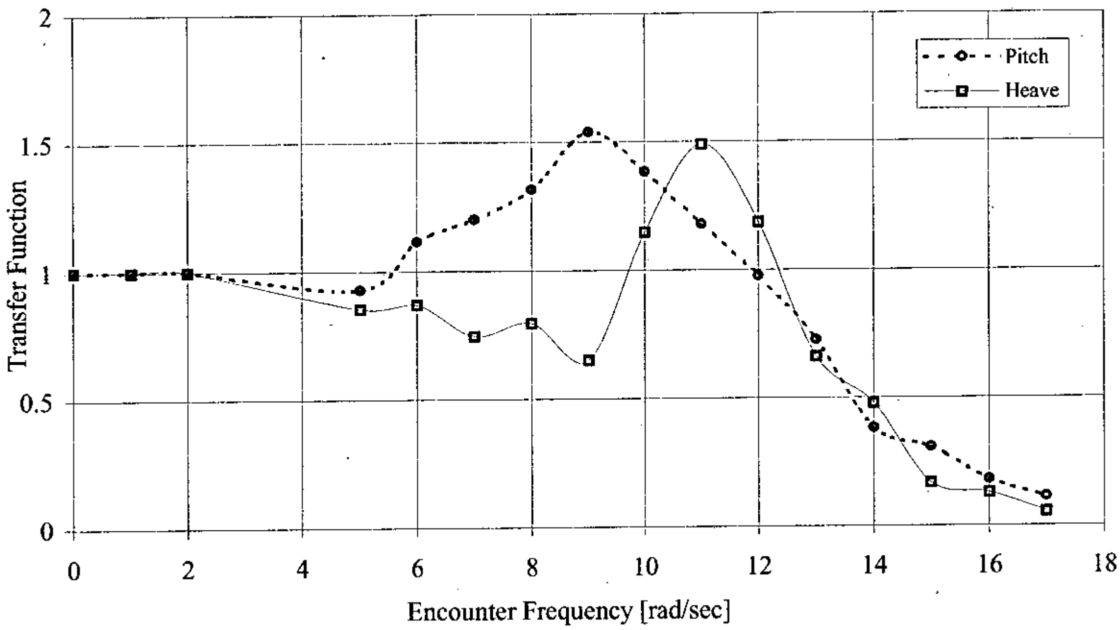

Fig 12: S/L=0.2, Fn=0.53 - Heave and Pitch

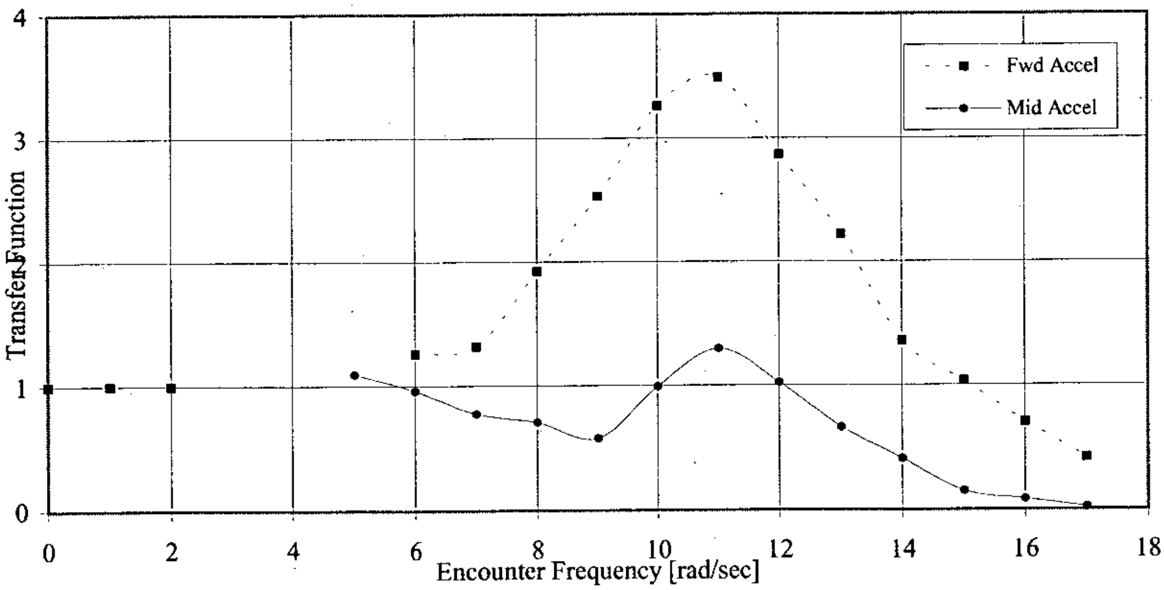

Fig 13: S/L=0.2, Fn=0.53 - Accelerations

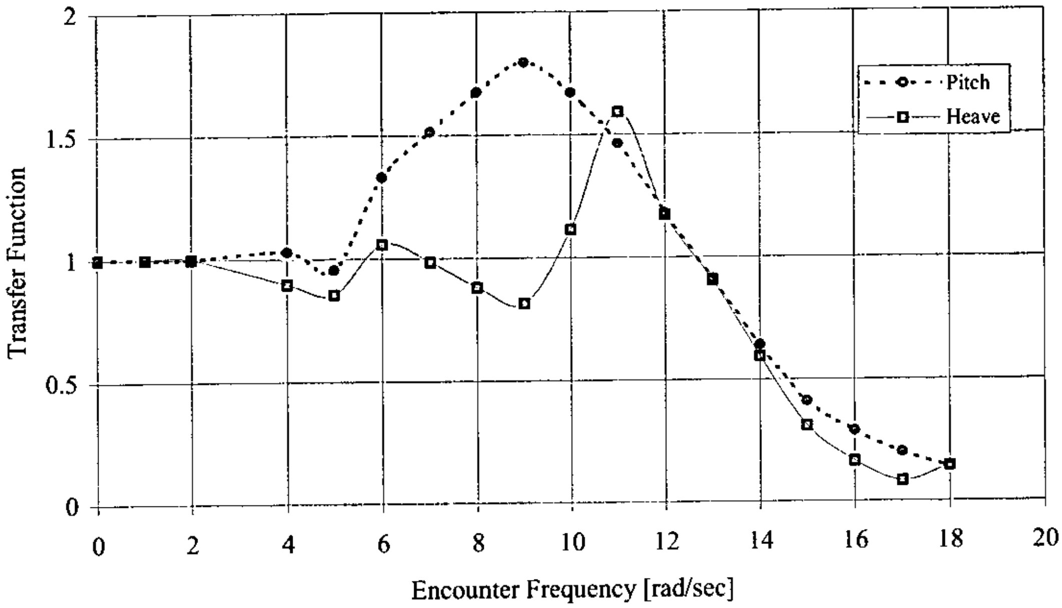

Fig 14: S/L=0.2 Fn=0.65 - Heave and Pitch

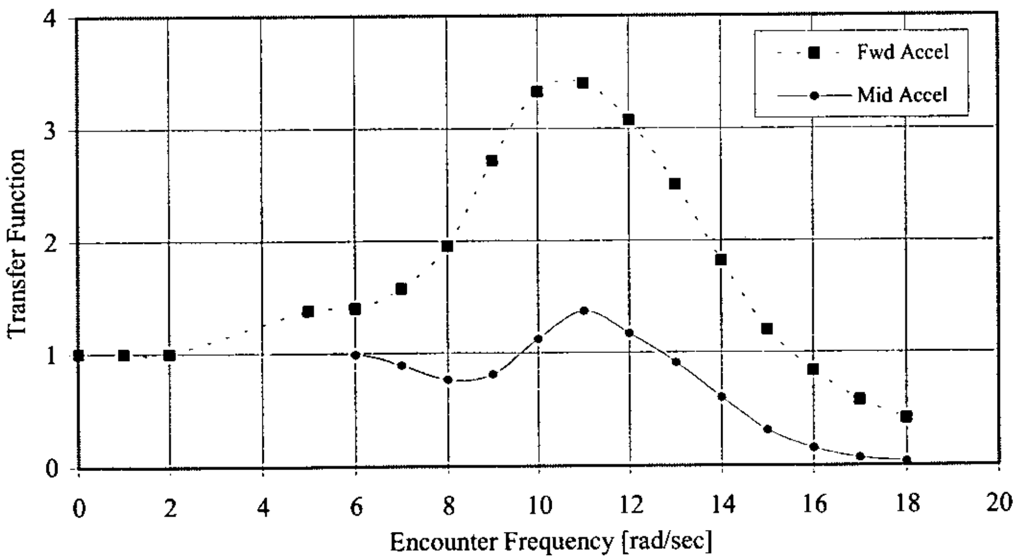

Fig 15: S/L=0.2, Fn=0.65 - Accelerations

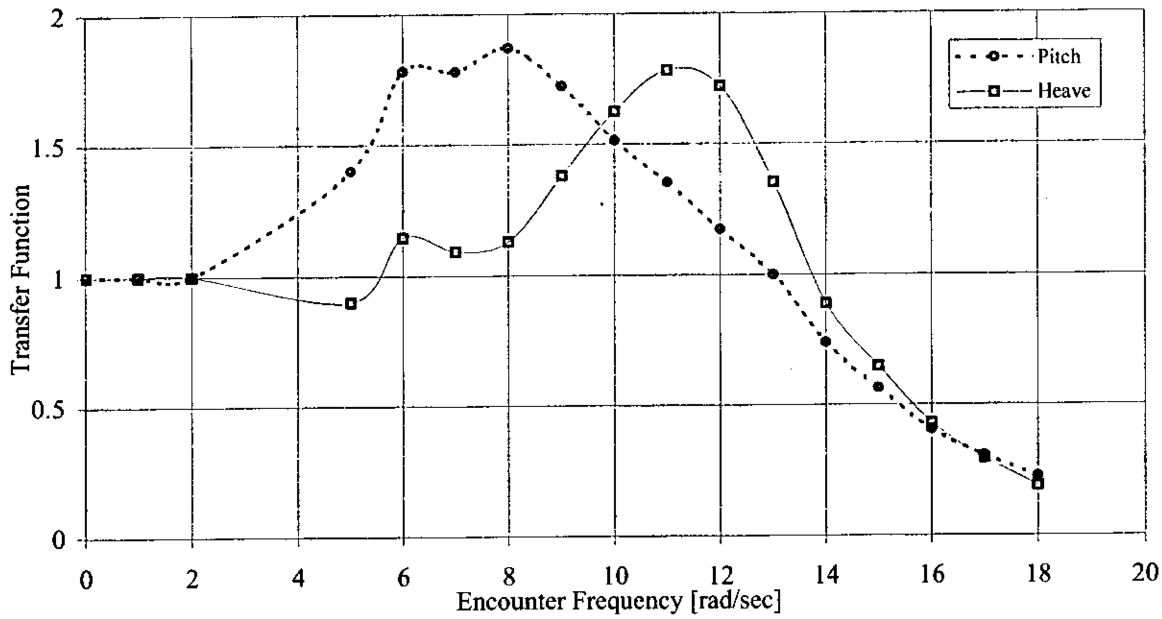

Fig 16: S/L=0.2, Fn=0.8 - Heave and Pitch

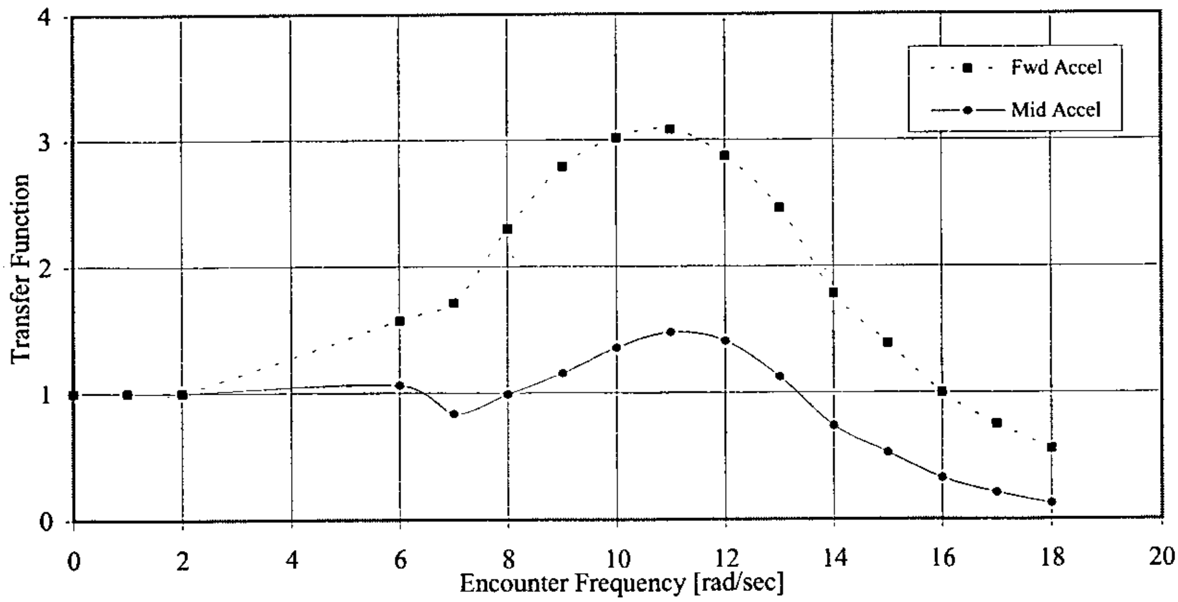

Fig 17: S/L=0.2, Fn=0.8 - Accelerations

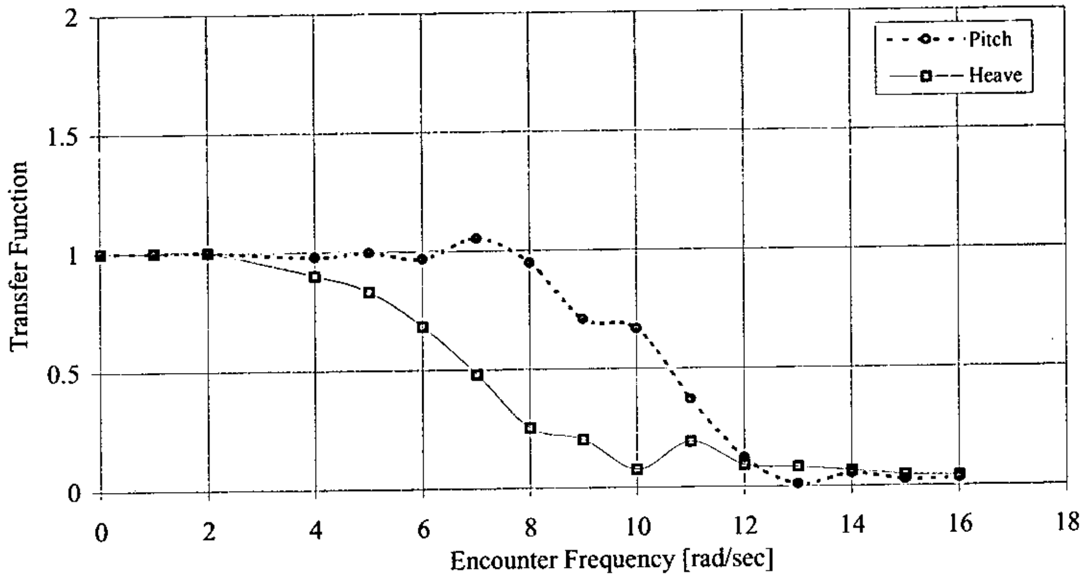

Fig 18: S/L=0.4, Fn=0.2 - Heave and Pitch

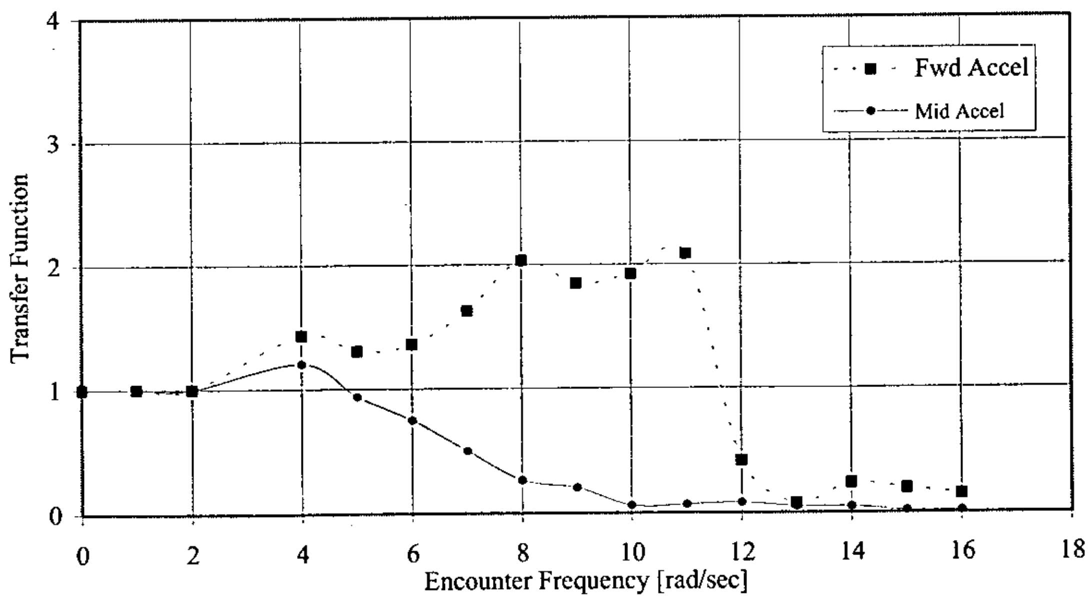

Fig 19: S/L=0.4, Fn=0.2 - Accelerations

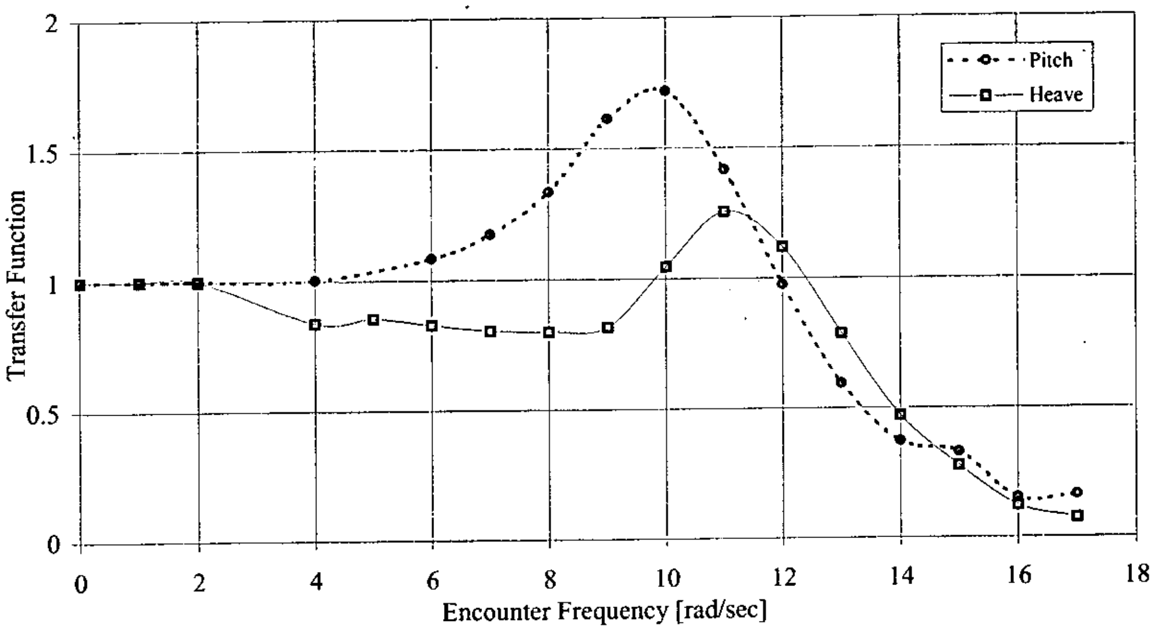

Fig 20: S/L=0.4, Fn=0.53 - Heave and Pitch

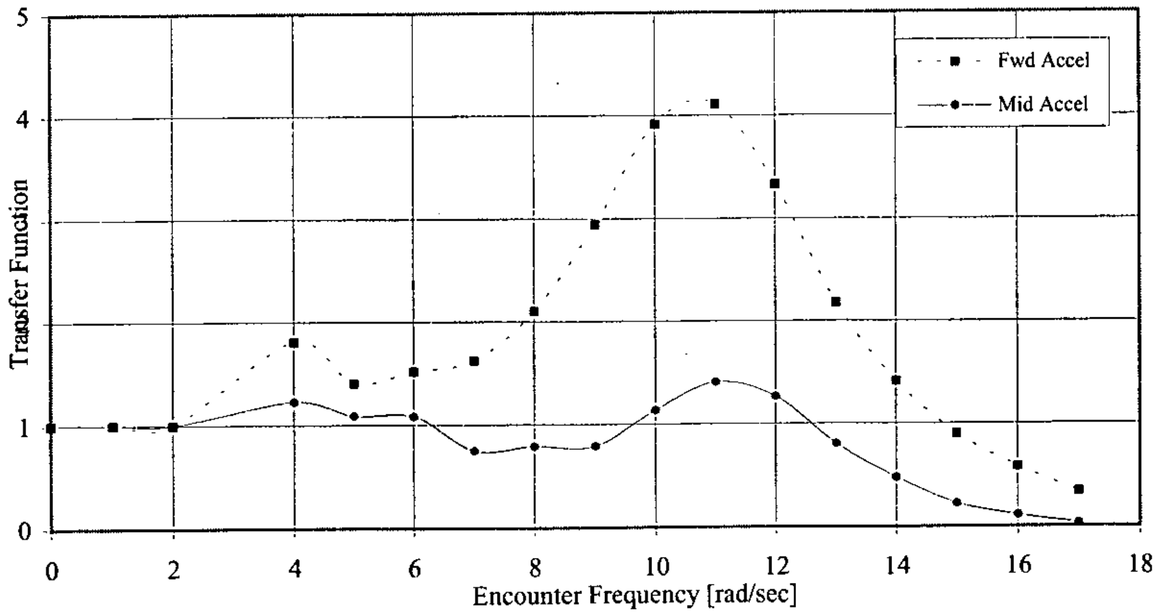

Fig 21: S/L=0.4, Fn=0.53 - Accelerations

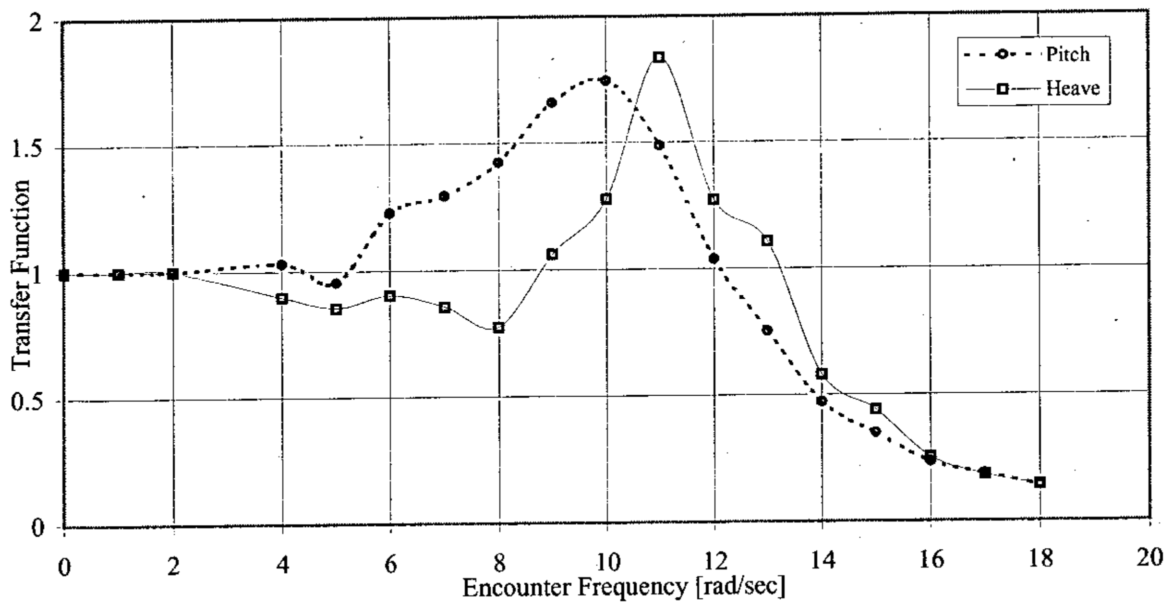

Fig 22: S/L=0.4, Fn=0.65 - Heave and Pitch

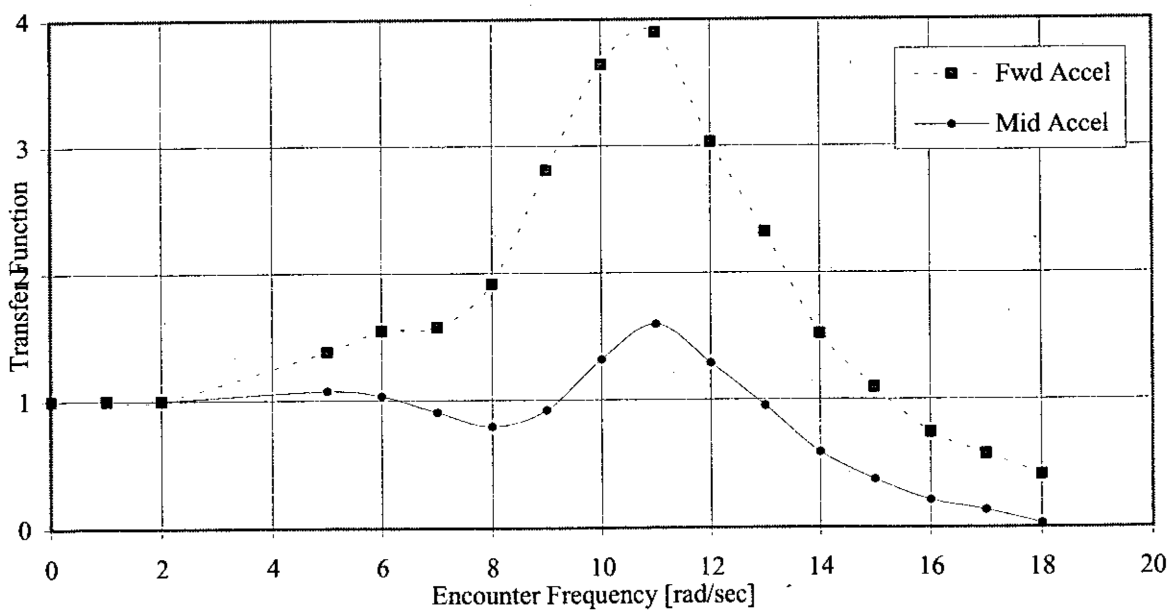

Fig 23: S/L=0.4, Fn=0.65 - Accelerations

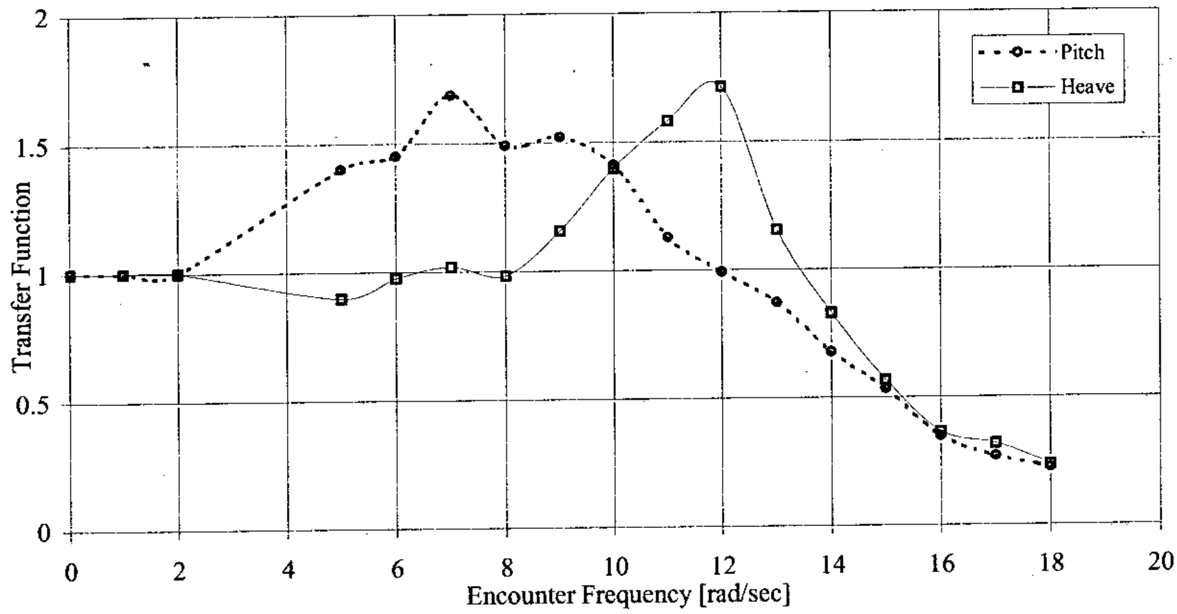

Fig 24: S/L=0.4, Fn=0.8 - Heave and Pitch

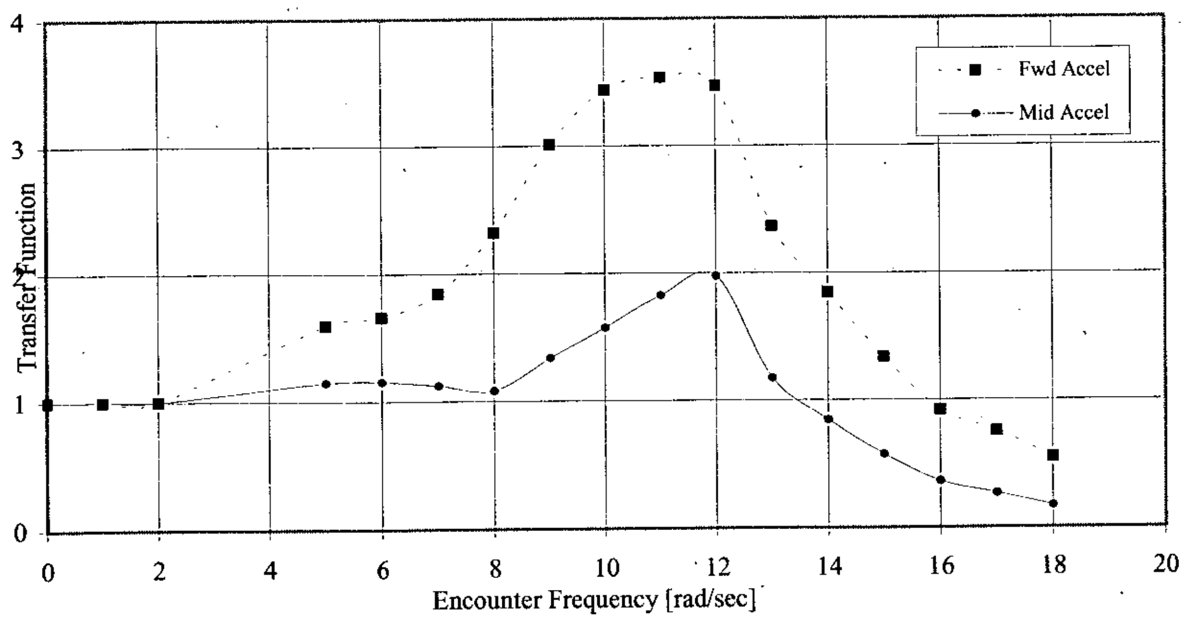

Fig 25: S/L=0.4, Fn=0.8 - Accelerations

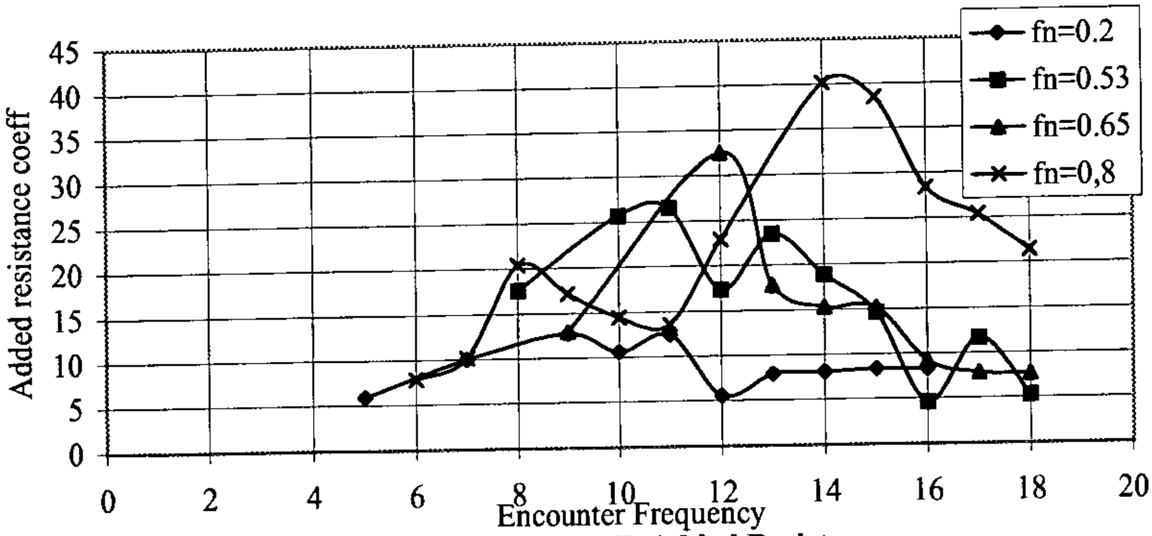

Fig 26: SERIES 64 Monohull, Added Resistance

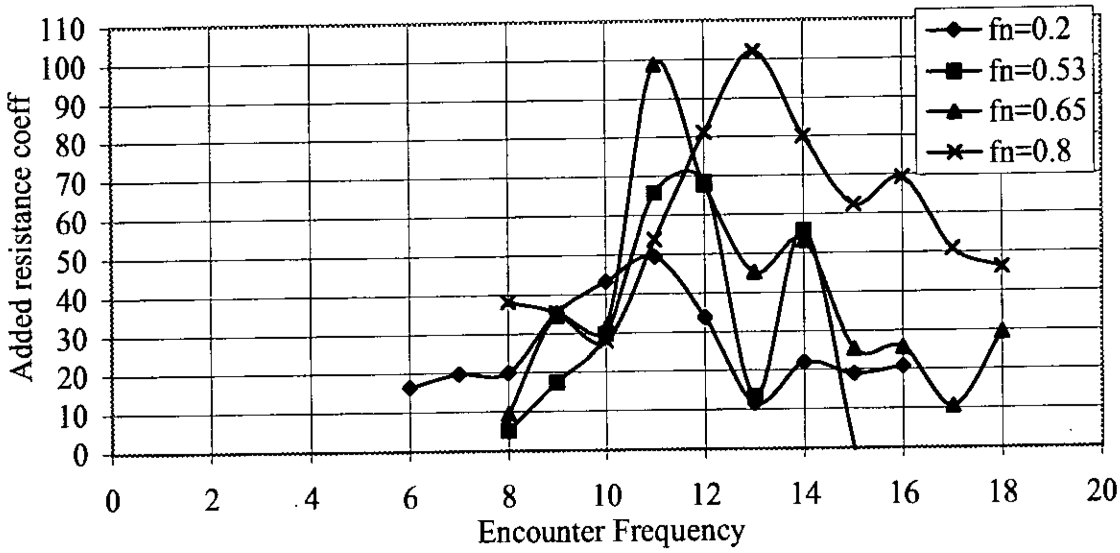

Fig 27: SERIES 64 S/L=0.2, Added Resistance

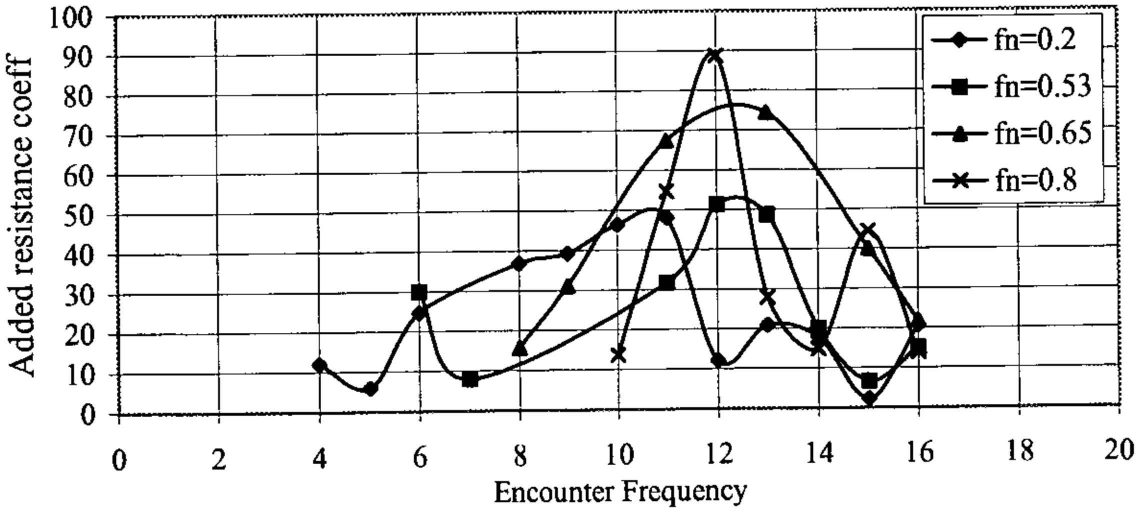

Fig 28: SERIES 64 S/L=0.4, Added Resistance

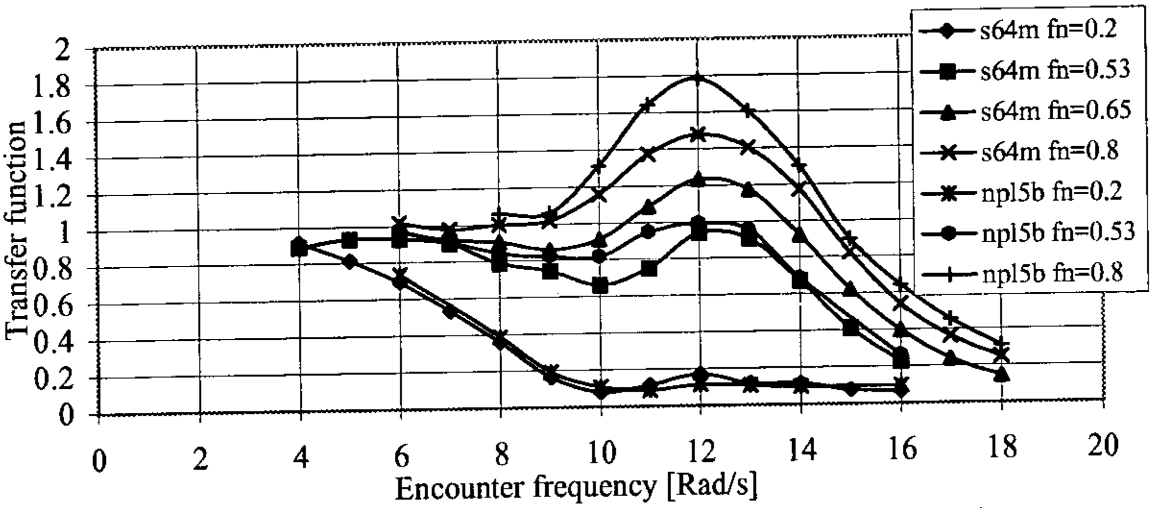

Fig 29: Comparison of heave transfer functions for 5b and 5s monohull

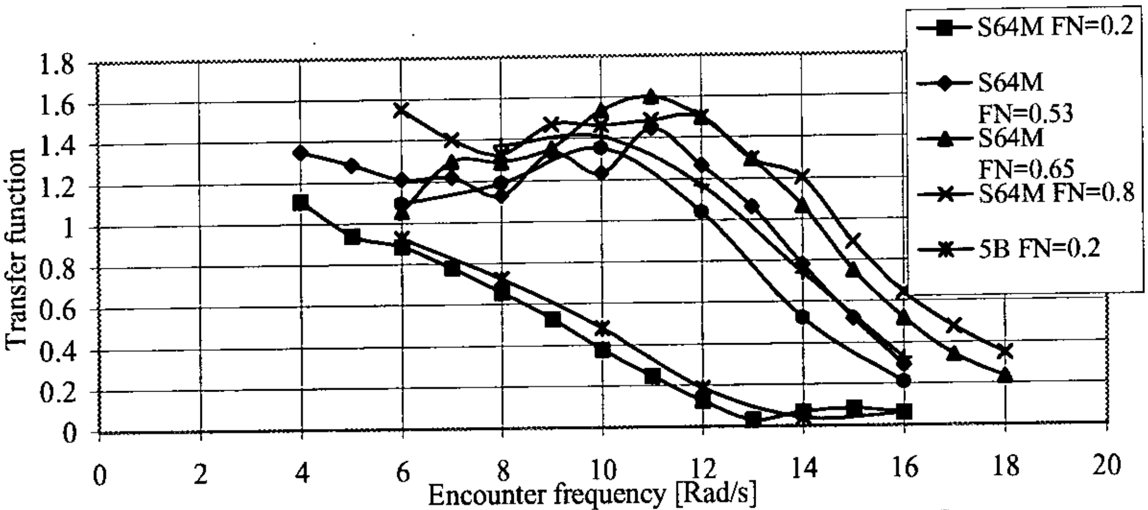

Fig 30: Comparison of pitch transfer functions for 5b and 5s monohull

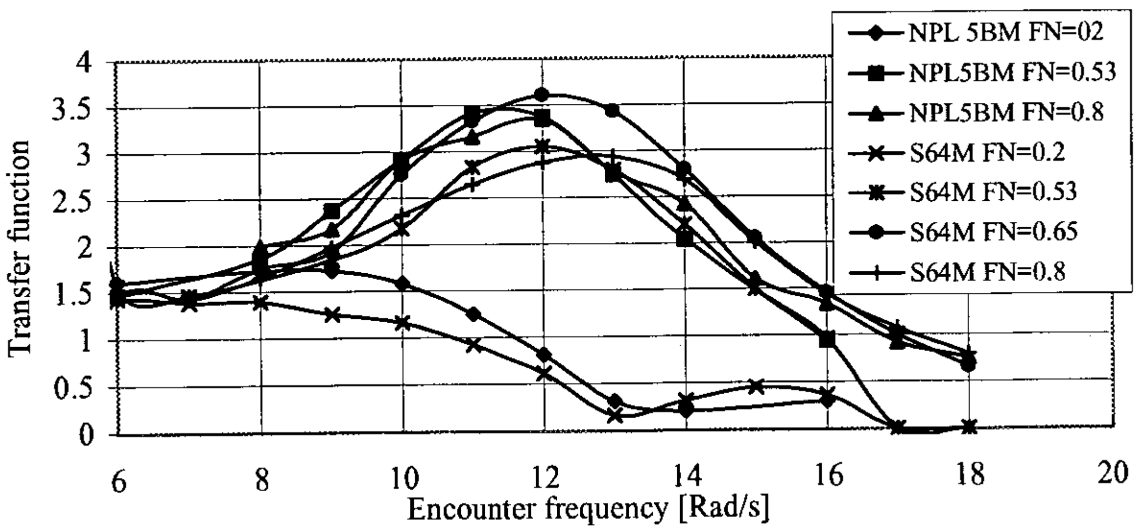

Fig 31: Comparison of accleration transfer functions for 5b and 5s monohull

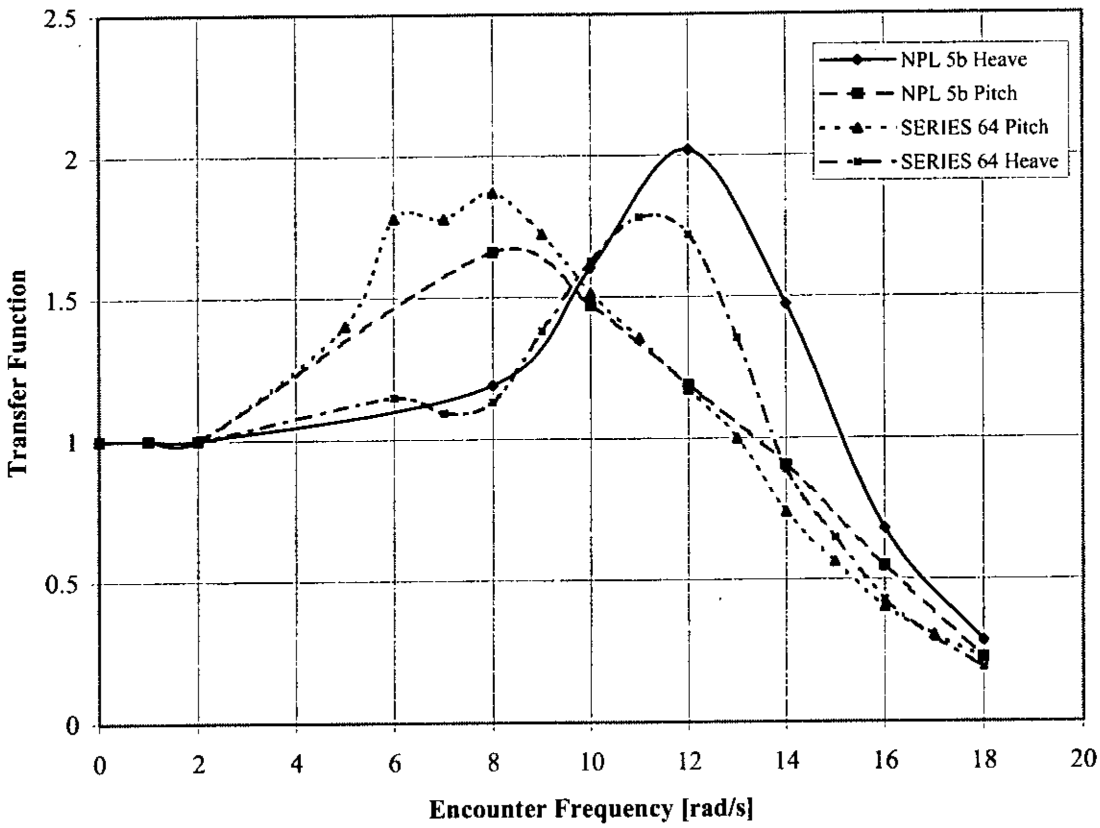

Fig 32: Comparison of NPL 5b and SERIES 64 Catamarans S/L=0.2 at Fn=0.8

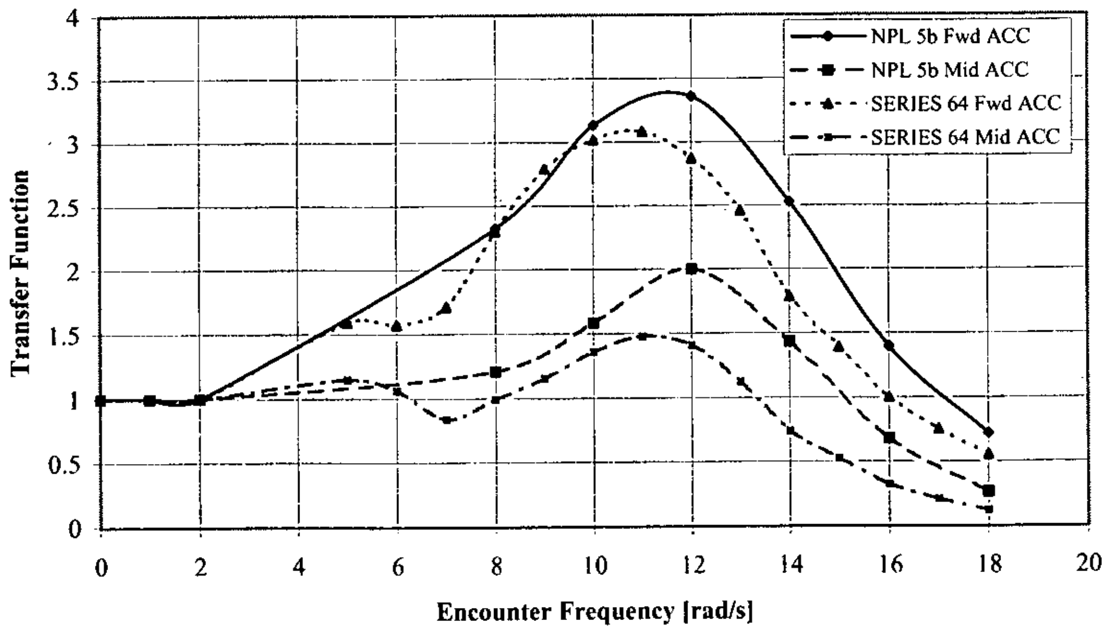

Fig 33: Comparison of NPL 5b and SERIES 64 Catamarans S/L=0.2 at Fn=0.8

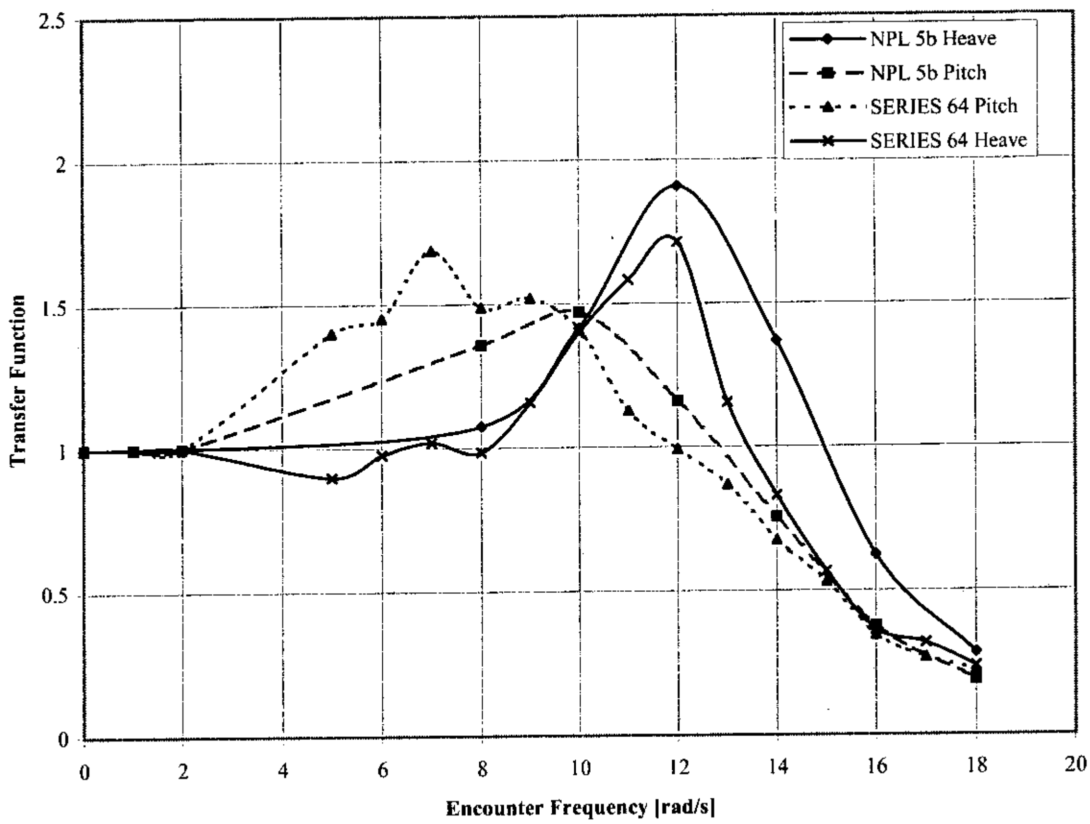

Fig 34: Comparison of NPL 5b and SERIES 64 Catamarans S/L=0.4 at Fn=0.8

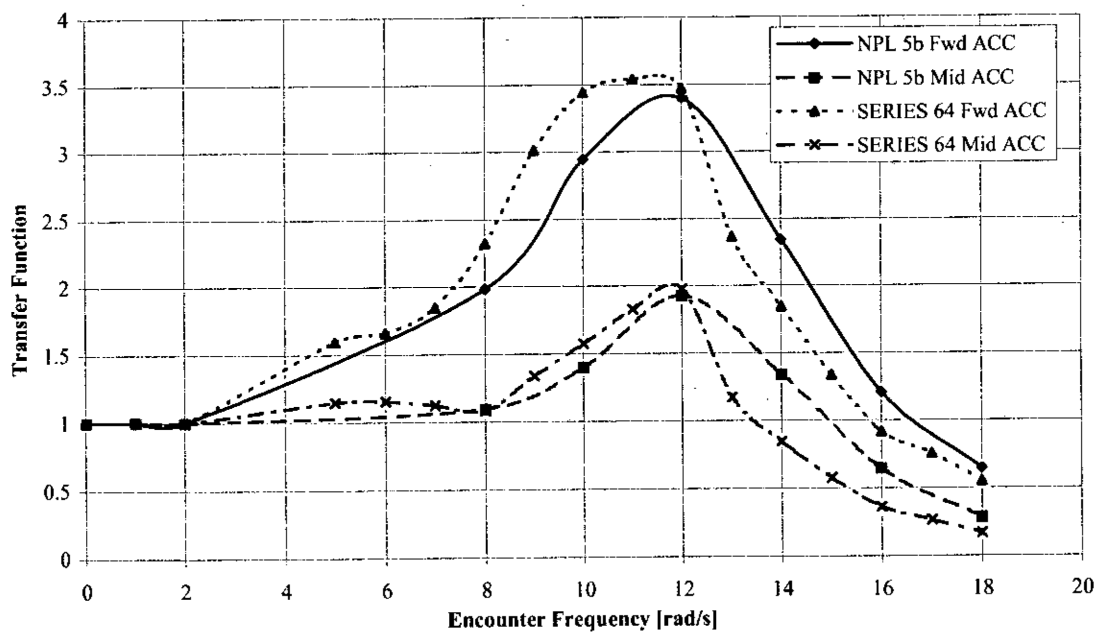

Fig 35: Comparison of NPL 5b and SERIES 64 Catamarans S/L=0.4 at Fn=0.8