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DAVID W. TAYLOR NAVAL SHIP
RESEARCH AND DEVELOPMENT CENTER
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REGULAR WAVE RESPONSES AND STABILITY CHARACTERISTICS OF

A SYSTEMATIC SERIES OF UNAPPENDED SWATH DESIGNS

by

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and

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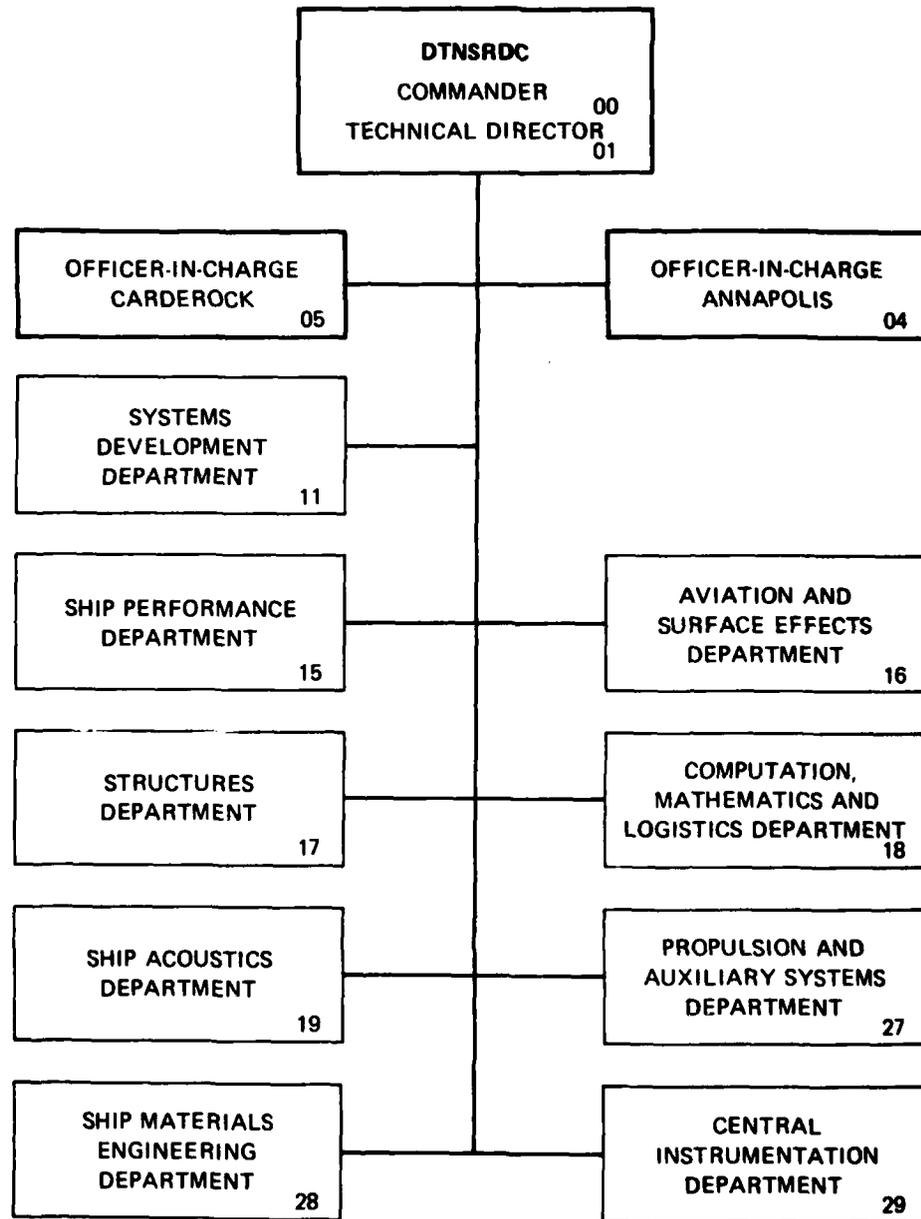
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The effect of several hydrostatic parameters on the stability characteristics and regular wave responses of Small Waterplane Area Twin Hull (SWATH) ships is investigated. Only one parameter is varied to produce each configuration. For head and following waves the effects of longitudinal center of buoyancy, separation between the longitudinal centers of buoyancy and flotation, longitudinal metacentric height, waterplane area and variation in lower hull diameter are investigated. For beam waves the

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effect of transverse metacentric height is studied. For the values studied all hydrostatic quantities expect longitudinal center of buoyancy are shown to have a significant effect on the motions.

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ABSTRACT

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teristics and regular wave responses of Small Waterplane Area Twin Hull
(SWATH) ships is investigated. Only one parameter is varied to produce
each configuration. For head and following waves the effects of longitudi-
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buoyancy and flotation, longitudinal metacentric height, waterplane area
and variation in lower hull diameter are investigated. For beam waves the
effect of transverse metacentric height is studied. For the values studied
all hydrostatic quantities except longitudinal center of buoyancy are shown
to have a significant effect on the motions.

ADMINISTRATIVE INFORMATION

INTRODUCTION

The effect of hydrostatic parameters on motions and on stability
characteristics is an important consideration in the design of ships. For
SWATH ships the available data for analysis is limited. Although motion
predictions have been made for several SWATH designs, these designs had
few common characteristics. Therefore, analysis of the effect of any par-
ticular hydrostatic characteristics is impossible.

During an early stage in the development of SWATH motion prediction,
a brief investigation was undertaken in which longitudinal center of buoy-
ancy (LCB) and longitudinal center of flotation (LCF) were varied. Heave
and pitch motions in regular waves were analyzed. This investigation
revealed significant changes in the dynamic response characteristics of

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the configurations without stabilizing fins. When stabilizing fins were added, the effect of the LCB and LCF variations was diminished.

A second parametric investigation was carried out by the Davidson Laboratory of Stevens Institute of Technology[1*]. That study focused on minimizing absolute motion at a towpoint at zero speed in regular head waves. It demonstrated that SWATH heave and pitch responses are sensitive to longitudinal metacentric height (GM_L), pitch gyradius, waterplane area (WPA), LCB and LCF. There were variations in more than one of these parameters in most configurations.

The data available for analysis of the effects of hydrostatic parameters on heave and pitch motions is thus inadequate. The purpose of this study is to expand the SWATH motion data base so that for several speeds the effect of individual hydrostatic characteristics can be assessed.

In this study several hydrostatic and geometric characteristics were specified for a base configuration. Hydrostatic characteristics were systematically varied so that for each of fifteen additional configurations the body and strut shapes were modified so that only one of the base configuration parameters was changed. The design parameters varied were LCB, separation of LCB and LCF (LCB-LCF), GM_L, WPA, overall length to mid-ship lower hull diameter ratio (L/D), and transverse metacentric height (GM_T).

APPROACH

In order to minimize the effect of factors other than the varied hydrostatic parameters on the motion responses, all ships in the study

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*References are listed on Page 21..

shared the characteristics given in Table 1. In addition, stabilizing fins were not included. Properly designed fins are important since with forward speed they will reduce heave and pitch motion and alleviate pitch instability. However, their influence could make evaluation of the effect of a given parameter difficult. In a later study stabilizing fins will be added to the configurations investigated here.

Nominal values of the parameters that were varied are given in Table 2 with the baseline configuration values marked by an asterisk. When (LCB-LCF)/L is positive LCF is forward of LCB. Only one characteristic is varied in each configuration. Thus, for example, in the case where LCB/L = .44, (LCB-LCF)/L, GM_L, WPA, L/D and GM_T were all specified to be those of the base configuration.

The geometry of the ships used in the study was determined analytically. The general shape of each hull of the various SWATH configurations is a combination of an elongated, circular sectioned, totally submerged main body and one or two vertical cylindrical struts passing through the water free surface. The geometry of each can be represented analytically by a Chebyshev series whose coefficients are functions of specific body parameters as reported by Lin and Day[2]. In conjunction with this analysis a computer program was devised whose output was two polynomials evaluated at a set of longitudinal points, one representing the cross-sectional area curve of the lower hull and the other representing the half-thickness curve of the strut. For the present study extensive modifications were required to the initial program in an effort to unite the lower hull and strut(s) into a single rigid body with prescribed hydrostatic quantities

as the input. The program was then used to generate the geometries of the SWATH ships in accordance with the specified parametric values in Tables 1 and 2. For each set of values several strut locations were examined resulting in a variety of lower hull and strut shapes. Also calculated for each hull geometry was the appropriate centerplane to centerplane hull separation as a function of the generated hull characteristics and the specified GM_T. For each set of parametric values the final design chosen was the form with the smoothest, non-negative curves although in the single strut cases an attempt was made to fix the longitudinal location of the strut. This approach resulted in a direct process for finding a shape which met all the design requirements.

In accordance with the desired values for the SWATH parameters given in Tables 1 and 2, sixteen forms were generated analytically. The single strut SWATH configuration was the preferred type and was realizable for all parametric variations except for GM_L greater than 12 meters where tandem struts became mandatory. The hydrostatic and geometric restrictions on a design, rather than the number of struts, were assumed to dominate the motion characteristics. This assumption was checked with a comparative study of a single strut and a twin strut SWATH configuration at GM_L = 11.5 meters.

Sketches of one hull for 14 of the various SWATH configurations are shown in Figure 1 with the base configuration as the first form and the subsequent forms indicated by the final values of the varied parameter. Note that for GM_L = 11.5 meters there is both a single strut and twin strut form. The two SWATH forms for the GM_T variation of 1.22 and 3.66 meters are not shown since their geometries are identical to the base

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configuration. The body diameter of the lower hull and the strut thickness in Figure 1 are faired curves through points at each of the 2 stations where the Chebyshev polynomials were evaluated. Table 3 lists the parametric values calculated by the motion program in addition to the centerplane to centerplane hull separation designated S_D for the corresponding SWATH forms in Figure 1. The first column in the table indicates the parameter varied. The minor deficiencies between the desired SWATH parametric values in Tables 1 and 2 and the values determined by the SWATH motions program in Table 3 were considered acceptable. These variations are attributed to the difference between defining these values by integrating continuous Chebyshev polynomials and by summing a discrete set of values.

Calm water stability characteristics of fourteen of the base hull SWATH forms (all but the GM_T variations) were determined from a computer program based on theory developed by Lee and Martin[3]. As compared to a conventional monohull of equal displacement, a SWATH ship has a larger natural period in heave and pitch due to the smaller waterplane area. Larger natural periods in these modes, together with small waterplane area and low vertical center of buoyancy, provide SWATH ship forms with superior seakeeping characteristics in moderate seas. However, in more severe seas where modal periods of the sea spectra are larger, the modal periods will tend to coincide with the natural periods of the motions. Large responses can result.

Heave and pitch responses in regular head and following waves were then predicted using the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) SWATH motion prediction program[4] for the base

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configuration and the forms generated by varying LCB, (LCB-LCF), GM_L, WPA and L/D. Similarly, in beam seas sway, roll and yaw responses were determined for the base configuration and forms generated by varying GM_T. These configurations differed from the base only in their centerplane to centerplane hull separations. Ship speeds investigated for the three headings of head, beam and following waves corresponded to Froude Number, Fn = 0, 0.1, 0.3 and 0.4. The results obtained in following waves at Fn = 0.3 and 0.4 were very large. This is probably due to the absence of stabilizing fins. These results are not presented in this report. In addition to the computation of transfer functions for the five modes of motion, absolute and relative motion transfer functions were obtained in head and following waves in each ship's plane of symmetry at the longitudinal location of the bow and stern of the lower hull and at the leading and trailing edges of the single strut or tandem strut system. The relative and absolute motion results are not presented in this report.

In a report presenting the theory[5] utilized in the DTNSRDC SWATH motions program, experimental and theoretical results are presented for the

SWATH 6A. The correlation is generally good although the magnitudes of the theoretical peaks are generally higher than those of the experimental results. In addition, the theoretical pitch and relative motion amplitudes are larger than the experimental results for zero speed in head waves for wave lengths greater than three times the ship length.

PRESENTATION AND DISCUSSION OF RESULTS

CALM WATER, BARE HULL STABILITY CHARACTERISTICS

Calm water stability characteristics of all the SWATH configurations are presented in Table 4 where they are denoted by subscripts 3 and 5 for

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pitch and heave respectively. The approximate maximum speed where pitch motion remains stable is given in the record column. For the speeds which are less than the critical speed for pitch instability the following are given: the computed natural periods of oscillation, T; the damping ratios, ζ; the half-decay times, $T^{(1/2)}$; and the motion reduction factors at resonant frequencies in waves, D, obtained from the solution of the coupled heave-pitch equations of motion. The solution to the simultaneous homogeneous differential equations provides four roots. They can be real or complex with the complex values appearing in conjugate pairs. D is then equal to the absolute value of the product of real and imaginary parts for both heave and pitch.

The vertical plane stability of SWATH ships must be considered carefully. As speed increases, unappended SWATH ships tend to experience pitch instability. The investigation by Lee and Martin demonstrated the effectiveness of inboard fixed fins in alleviating this instability. Although fins have not been included in the present study, fins would be present on any proposed design. For the present study the same stability characteristics discussed in Reference 5 were investigated for all the parametric variations except for GM_T variations. The stability characteristics presented in Table 4 give the approximate speeds for each SWATH configuration beyond which pitch is unstable. The configuration with the lowest pitch instability inception speed was 14.6 knots for L/D = 13.1. The base configuration becomes unstable in pitch at 17.7 knots, the approximate speed where most of the other configurations become unstable. A notable exception is in the GM_L variations where pitch becomes progressively more stable with increasing GM_L. The maximum GM_L of 33.93 meters has the

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correspondingly maximum pitch instability inception speed of 40.6 knots. Natural heave periods generally tend to be relatively constant with speed for each SWATH configuration in Table 4. If heave and pitch modes both have low damping ratios, on the order of 0.05 or less, then the frequency response in heave and pitch will generally show two resonant peaks corresponding to the resonant encounter frequencies of both modes of motion. This occurrence is quite evident when comparing the damping ratios in Table 4 to the transfer functions, especially in the pitch mode at zero speed. When the heave and pitch natural periods are close together, there will be a tendency for a steeper peak unless this is offset by the presence of small wave exciting force and moment at this frequency. This condition has occurred to some degree for the high valued GM_L SWATH configurations of 29.33 and 33.93 meters. Large damping in heave nullifies this phenomenon somewhat. The half-decay times in heave and pitch, $T_3^{(1/2)}$ and $T_5^{(1/2)}$, are the times that would be required for a disturbance of a given mode to halve its amplitudes of oscillation. Clearly, as a mode becomes less stable, $T^{(1/2)}$ becomes larger. Another factor deterimimg the values of $T^{(1/2)}$ is damping. This accounts for the somewhat inconsistent trends in $T_3^{(1/2)}$ and $T_5^{(1/2)}$ in Table 4 where occasional long half-decay times are noted at zero speed. For a given configuration maximum values of the motion reduction factors D_3 and D_5 will become more meaningful in the evaluation of various inboard fin configurations mounted on a given SWATH hull.

MOTION TRANSFER FUNCTIONS

Heave and pitch transfer functions for all SWATH parametric variations except GM_T are presented for the various SWATH forms in head waves at

Froude Number (Fn) equal to 0.0, 0.1, 0.3 and 0.4, and in following waves at 0.0 and 0.1 in Figures 2 through 19. The Froude Numbers 0.0, 0.1, 0.3 and 0.4 correspond approximately to 0, 5, 15 and 20 knots for the full scale craft. Transverse metacentric height, GM_T, was the only parameter expected to significantly affect roll responses in beam waves. Presented in Figures 20 and 21 are the resulting roll transfer functions at the same speeds of Fn = 0, 0.1, 0.3 and 0.4.

The circular wave frequency range chosen for the evaluation of the transfer functions in the SWATH motions programs was 0.2 to 2.0 radians/ sec. It is within this frequency range that most of the energy lies in sea wave spectra. The assumption is therefore that responses of a craft outside this frequency range would not significantly alter its behavior in a seaway.

Heave amplitude is nondimensionalized by wave amplitude. Pitch is scaled by wave amplitude divided by half the ship length which gives the unit vertical bow (or stern) displacement amplitude due to pitch. Similarly, roll is scaled by wave amplitude divided by half the centerplane to centerplane hull separation which gives the unit vertical displacement of a hull due to roll. Thus the results for pitch and roll reflect linear displacements and are quite different from the usual results where pitch and roll are nondimensionalized by wave slope. However, for head seas for the configurations investigated, the peaks occur at essentially the same frequencies for both methods of presentation. The transfer functions are given as a function of circular wave frequency. A second scale indicates the wave encounter frequency, a third the wave length divided by ship length.

Wave encounter periods corresponding to the maximum value of each of the motion transfer functions for the SWATH configurations are given in

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Tables 5a, b, and c. Since the transfer functions were evaluated at discrete encounter frequencies, the wave encounter periods corresponding to the maximum heave and pitch responses in Table 5a and 5b and to roll responses in Table 5c were obtained from Newton's divided difference interpolation formula for three points about the maximum response amplitudes.

LCB/L VARIATIONS

The three LCB/L variations of 0.445, 0.489 and 0.532 had little effect on pitch and even less on heave response particularly in head waves, as shown in Figures 2 to 4. The only notable effect of varying LCB was in the heave mode in following waves ($\beta = 0$), Fn = 0.1. In that case the magnitude of the transfer function increases with increasing LCB/L. The same is true for pitch at $\beta = 0$, although to a lesser extent.

Tables 4 and 5 and Figures 2 to 4 show that the dominant peaks of the heave transfer functions occur near the natural heave periods. A smaller peak particularly evident at $\beta = 0$, Fn = 0.0 occurs at the natural pitch period and stems from the coupling effect between the two modes and the high pitch response at pitch resonance.

In the pitch mode the coupling effect is significant as noted by the two pitch transfer function peaks at Fn = 0 and 0.1 in both headings. The first peak near the wave frequency of $\omega = 0.25$ at Fn = 0.0 and 0.1 in both headings occurs near the natural pitch period. In head waves at the higher speed of Fn = 0.3 and 0.4 the pitch natural period shifts to a wave frequency less than $\omega = 0.2$ radians per second (RPS), the lowest frequency for which the transfer functions were evaluated. Pitch resonance at Fn = 0.3 and 0.4 is therefore not included in Figure 3, but the frequency at

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which it occurs ω_n can be determined from Table 5 to be near $\omega = 0.15$ RPS. The second peak of the pitch transfer function at the higher wave frequency occurs near the natural heave period and has a magnitude that increases somewhat with speed in both headings. (This is actually the first peak in the figure for Fn = 0.3 and 0.4)

As with the motion characteristics little effect is also noted in the calm water stability characteristics (Table 4) for the LCB variations examined and can be considered inconsequential. For all three configurations the maximum speed for pitch stability is about 17 knots.

From the three SWATH configurations investigated, LCB/L has little effect on the heave and pitch motion characteristics.

(LCB-LCF)/L VARIATIONS

The four (LCB-LCF)/L variations of -0.196, 0.001, 0.045, and 0.065 indicated a significant effect on SWATH heave and pitch motion characteristics. (When LCB-LCF is positive the LCF is forward of the LCB.) Due to the other constraints on the design of the configurations, 0.065 was the largest positive value that was possible. Referring to Table 4 both the natural heave and pitch periods vary with (LCB-LCF)/L. The maximum natural heave period occurs close to the parametric value of zero and the maximum natural pitch period occurs with (LCB-LCF)/L = -0.196. This latter case resulted in the most dramatic changes in the motion characteristics.

The heave transfer functions presented in Figures 5 to 7 peak near the natural heave periods as is shown in Tables 4 and 5. The natural period for (LCB-LCF)/L = -0.196 is 5.87 seconds which contrasts sharply with the other configurations where the natural periods are between 8.00 and 8.60 seconds. In head waves this is the only important difference

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among the responses of the configurations. Pitch coupling effects are evident only in following waves where low amplitude peaks occur at the heave natural periods. In following waves, the magnitude of heave is reduced as the distance between LCB and LCF increases. This is most dramatic at Fn = 0.1. For the largest separation where (LCB-LCF)/L = -0.196 the heave transfer function is notably small.

The dramatic effect of the LCB-LCF separation on pitch can be seen in Figures 6 to 7. For the positive values of LCB-LCF for both head and following seas two peaks occur in the pitch transfer functions. The peaks at the low frequencies occur at the pitch natural periods. At the higher speed for the positive values of LCB-LCF, the natural pitch frequency is less than ω = 0.2 RPS, the lowest frequency for which computations were made, and the peaks shown occur at the heave natural period. For all speeds in head waves for the value of (LCB-LCF)/L = -0.196 the pitch natural frequency is less than 0.2 RPS and the resonant peaks shown occur at the heave natural period. For this configuration in following waves, peaks occur at both the heave and pitch natural periods.

For all conditions except Fn = 0.1 in following waves, the peaks for (LCB-LCF)/L = -0.196 occur at a natural encounter period of about 6 seconds. These transfer functions are much broader and are larger in magnitude than the transfer functions for the other LCB-LCF variations. For head seas for (LCB-LCF)/L = 0.001 the zero speed transfer function is broad and large in magnitude. For Fn = 0.0 and 0.1 for both headings the magnitude and breadth of the resonant peak decreases as the LCF moves farther forward. In following waves the peaks occurring at the heave natural period are broad and are significant in value for all cases but

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the (LCB-LCF)/L = 0.001. The magnitude in this region increases as the separation between LCB and LCF increases. In head waves for Fn = 0.3 and 0.4 the differences in pitch among the three configuration where the LCF is forward of the LCB are minor.

The configuration where the LCF is aft of the LCB has transfer functions which peak at smaller encounter periods than the other configurations. In following waves for both speeds the magnitude of the separation between LCB and LCF alters the transfer functions.

GM_L VARIATIONS

The four GM_L variations of 5.58, 11.25, 29.38 and 33.93 meters (18.3 36.9, 96.4 and 111.4 feet) had a notable effect on SWATH motion characteristics in both the heave and pitch modes. The range of the parametric change necessitated the use of two different SWATH strut designs; that is, the single strut design and the tandem strut design. As shown in Figure 1, the single strut configuration was used for the GM_L of 5.58 and 11.25 meters whereas the tandem strut design was required for GM_L of 29.38 and 33.93 meters.

A study was undertaken to compare the motion characteristics of a single strut and a tandem strut design at approximately the same GM_L; namely, 11.25 and 11.64 meters, respectively. Craft characteristics and the geometry are given in Table 3 and Figure 1 respectively and the resulting motion characteristics are given in Tables 4 and 5 and Figures 8 through 10. The differences in the heave and pitch motion characteristics between the two designs are minimal except for following seas for Fn = 0.1. Table 4 indicates that the calm water stability characteristics

are essentially the same. These results support the assumption that char-
acteristics other than the number of struts determine the ship response.
Although strip theory does not include the interference effects between
the forward and aft struts, agreement between experimental and predicted
responses for the twin strut SWATH 6C design are as good as those for the
single strut SWATH 6A design. Thus it is reasonable to include single
and twin strut designs in the current study.

The heave transfer functions peak near the natural heave period for
GM_L = 5.58 and 11.25 meters in both head and following waves, as shown in
Figures 11 to 13. The same is not true for the GM_L = 29.38 and 33.93
meter SWATH configurations. In these cases heave is damped to the extent
that there is not a peak at the heave natural period although definite peaks
occur in heave at the pitch natural periods. The heave natural period
is about 8.5 seconds for the smaller values of GM_L and about 9.5 seconds
for the larger ones. Clearly, the heave motion responses decrease as GM_L
increases. However, heave stability as reflected by $T_3^{1/2}$ decreases with
increasing GM_L. The base configuration with a GM_L of 5.58 meters has the
highest heave response at all speeds and both headings.

In the pitch mode in head waves (Figure 12) the natural pitch
frequency for the GM_L of 11.25 configuration like the base configuration
shifts to a frequency less than ω = 0.2 RPS at the two highest speeds. The
pitch peaks which occur at the heave natural period diminish in magnitude
with increasing speed in both headings (Figures 12 and 13). For the two
largest GM_L configurations the natural pitch periods are within the range
of frequencies calculated. The peaks of the pitch transfer functions
occur at the natural pitch periods at all speeds and headings. Pitch

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natural period decreases significantly as GM_L increases. Due to the
closeness of the heave and pitch natural periods for the two larger GM_L
variations heave cross coupling does not result in two predominant peaks
but may account for the rather broad frequency response in pitch and
the large magnitude of the peak. Pitch stability from Table 5 increases
dramatically with increasing GM_L. The critical speed for pitch stability
reaches 43.5 knots for the unappended configuration with GM_L of 33.93
meters.

GM_L clearly affects the heave and pitch characteristics. Heave is
reduced significantly as GM_L increases and the character of the pitch

response changes radically. Pitch response is larger, occurs over a
broader frequency band, and at low speeds is radically different in shape,
resonating at higher wave frequencies for larger values of GM_L. These same
traits were evident in experimental work by Kallio[6] where the 2900 LTSW
SWATH 6 designs had GM_L values of 6.10, 11.6 and 13.7 meters (20, 38 and
45 feet). Scaled to 1800 LTSW these GM_L values are 5.3, 10.0 and 11.8
meters.

WPA VARIATIONS

Waterplane Areas (WPA) of 12.48, 152.8 and 161.7 meters^2 (1343, 1645
and 1747 feet^2) were studied. Table 5 indicates that the heave and pitch
natural periods decrease as WPA increases. The damping ratios, ζ_3 and ζ_5,
and the times to half amplitude, $T_3^{(1/2)}$ and $T_5^{(1/2)}$ indicate that the
stability of the unappended configurations increases as WPA increases. This
is consistent with the fact that the heave restoring coefficient is pro-
portional to the WPA.

The heave transfer functions (Figures 14 to 16) are single peaked,

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with the peaks occurring near the natural periods. In addition, the transfer functions become broader as WPA increases. This characteristic is less pronounced at the higher speed.

The pitch transfer functions (Figures 14 to 16) reflect pitch-heave coupling. At the lower speeds peaks occur near both the pitch and heave natural periods. At the two higher speeds the largest peak occurs near the heave natural period. The pitch natural period in these cases occurs at a frequency lower than 0.2 RPS. As with heave, for speeds and headings investigated, there is a broadening of the pitch transfer function as WPA increases.

The narrow band of response in heave and pitch for the smaller waterplane area would lead to reduced responses in a seaway; however, consideration also must be given to the loss in restoring force and stability which results from reduced waterplane area.

L/D VARIATIONS

Three SWATH configurations with lower hull length to midship diameter ratios of 13.1, 18.0 and 21.0 were studied. The effect of this parametric variation was of some significance in peak amplitude variations. Natural heave and pitch frequencies remained generally independent of L/D.

Heave transfer functions, shown in Figures 17 to 19, in head and following waves peaked near the natural heave frequency. In head waves their magnitudes did not vary significantly among the three L/D values nor with speed. The peak at heave resonance in following waves varied appreciably with L/D especially at Fn = 0.1. For this heading the peak amplitude increased with increasing L/D. Double peaks due to pitch-heave coupling effects were quite evident at low wave frequencies in the heave transfer

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functions at Fn = 0, 0.1 in head waves and especially in following waves.
At these speeds in head waves the heave motion is reduced near pitch reso-
nance especially at zero speed. In following waves the opposite holds true
and a significant peak in heave at pitch resonance is present especially
for L/D = 13.1.

The pitch transfer fucntions peak (Figures 18 and 19) at the natural
frequency. This peak is dominant at Fn = 0 and 0.1 in both headings and
passes to a frequency less than ω = 0.2 for the higher speeds of Fn = 0.3
and 0.4 in head waves. At zero speed the peak magnitude is high especially
for L/D = 13.1 and decreases with speed. The peaks' magnitude increases
dramatically with decreasing L/D, especially for L/D = 13.1. In following
waves the heave and pitch peaks at the heave natural periods decrease with
decreasing L/D. This behavior is noteworthy for L/D = 13.1 for Fn = 0.1

Of the three L/D values investigated L/D = 13.1 may be considered as
comparatively inferior in pitch due to the large magnitude of response in
most conditions. The motion characteristics of the L/D = 18.0 and 21.0
valued configurations are similar. Within the restrictions of this study
a larger value of L/D was not possible.

GM_T VARIATIONS

For the study of GM_T variations in SWATH motion characteristics, the
base configuration was utilized with two additional hull separations result-
ing in GM_T values of 1.22, 2.44 and 3.66 meters (4.0, 8.0 and 12.0 feet).
In beam waves, variations in heave and pitch motion with GM_T are negligible.
Likewise, the motions in the sway and yaw modes were found to be indepen-
dent of variations in GM_T and speed. The only mode significantly affected
by GM_T variations was roll as shown in Figures 20 and 21 for Fn = 0, 0.1,

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0.3 and 0.4. The sharp peaks at low wave frequencies occur near the natural roll frequencies which vary directly with the square root of GM_T and inversely with the transverse gyradius. For the roll gyradius ($K_{yy}/L = .24$) investigated, natural roll frequencies increase with increasing GM_T. The magnitudes of the transfer functions at these roll resonance frequencies were highest at zero speed and diminished with speed. An optimum speed is reached for each value of GM_T where roll at resonance reaches a minimum. The configuration with $GM_T = 1.22$ meters had the highest roll amplitude at zero speed. Furthermore, this amplitude decreases most rapidly with speed reaching a minimum at approximately $Fn = 0.2$. This effect is attributed to hydrodynamic interference forces between the two hulls with their relatively small separation. The variation of peak amplitude with speed for the two higher GM_T's was much less pronounced. Although the $GM_T = 1.22$ meters configuration at roll resonance is the worst at zero speed, it tends to be better with forward speed than the other two configurations.

The two other peaks at higher frequencies are amplitude-wise not as dominant as the amplitudes at roll resonance but their frequency span is much greater. Roll responses within the frequencies spanned by the two peaks tend to be independent of GM_T and forward speed. The second of the two peaks near the wave frequency of 1.8 RPS tends to coincide with a peak in both the sway and yaw transfer functions which reflect cross-coupling of these two modes in roll.

These results are not inconsistent with Kallio's experimental results. The roll transfer functions had two peaks for the SWATH 6A and 6B. His results did not extend to the smaller wave length to ship length (λ/L)

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region where the third peak occurs in these results. For the SWATH 6A a peak occurred in the λ/L region from about 0.75 to 2.5 which is similar to these results. A sharper peak occurred in the SWATH 6B results.

CONCLUDING REMARKS

In this study hydrostatic and geometric factors have been controlled so that the effects on ship response of varying a specified parameter have been carefully isolated. The variations were made over ranges that were within the bounds that might be used for a design. In some cases a wider variation of a parameter was desired but could not be obtained due to the requirements of keeping the other hydrostatic quantities fixed. Within these limitations the following observations can be made:

1. The effects of varying LCB/L were minimal.

2. Motions and natural periods vary with the separation of LCB and LCF. Natural periods are smaller when the LCF is aft of the LCB, and in head seas the pitch amplitudes are large. Following seas motions are altered.

3. An increase in GM_L greatly damps the heave response although the heave natural period is changed slightly. The change in pitch is even more remarkable. The pitch natural period is greatly reduced as GM_L increases. At the same time the pitch transfer function becomes significantly broader.

4. As WPA increases the transfer functions broaden somewhat but remain essentially the same; yet the restoring force and stability increase.

5. In head waves variation of L/D has little effect on heave; however, for the smallest value of L/D the pitch response becomes very large. In following waves heave is greatly reduced with speed for the smallest L/D.

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6. The changes in GM_T had little effect on the sway, roll or yaw transfer functions except at low wave frequencies. In this narrow region, however, the peaks occurred at the roll natural frequency and the magnitude varied with GM_T.

There are two important considerations which have not been explored in this study but will be in the future. The effects of stabilizing fins on the trends discussed above must be considered. It is expected that fins will reduce the peak amplitudes of responses but will not greatly alter the trends discussed above. In addition, evaluation must include the responses of the various appended configurations in random seas. The distribution of energy of a given seaway will obviously amplify or reduce the importance of a change in the transfer functions.

ACKNOWLEDGMENTS

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TABLE 1 - FIXED SHIP PARAMETERS

Length (L)	68.58 m (225.0 ft)
Displacement	1828.88 MTSW (1800.0 LTSW)
Strut Length (Single)	54.86 m (180.0 ft)
Strut Length (Tandem)	24.00 m (78.75 ft)
Mid-Strut Thickness	2.13 m (7.00 ft)
KG	9.14 m (30.0 ft)
Mid-Ship Draft	6.29 m (20.625 ft)
K_{yy}/L	.24
$K_{xx}/$(Hull Separation)	.52

TABLE 2 - NOMINAL VALUES OF VARIED PARAMETERS

LCB/L		0.44	0.49*	0.54	
(LCB-LCF)/L	-0.20	0.00	0.05*	0.07	
GM_L, m			5.49*	11.58	29.26	33.83
(ft)			(18)*	(38)	(96)	(111)
Waterplane Area, m^2		129.49	153.29*	164.44	
(ft^2)		(1340)	(1650)	(1770)	
L/(Diameter at Midship)		13.1	18.0*	21.0	
GM_T, m		1.22	2.44*	3.66	
(ft)		(4.0)	(8.0)	(12.0)	

*Baseline Characteristics

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TABLE 3 - SWATH CRAFT CHARACTERISTICS

PARAMETRIC VARIATION	STRUT(S) HULL	DISPLACEMENT		$\frac{LCB}{L}$	$\frac{LCB-LCF}{L}$	GM_L		WPA		S_D	
		MTSW	LTSW			m	ft	m²	ft²	m	ft
Baseline	1	1760	1732.	.489	.045	5.58	18.3	152.8	1645.	20.08	65.87
$\frac{LCB}{L}$=.445	1	1750	1722.	.445	.053	5.43	17.8	152.4	1640.	19.89	65.26
$\frac{LCB}{L}$=.532	1	1761	1733.	.532	.039	5.58	18.3	152.8	1645.	19.91	65.33
$\frac{LCB-LCF}{L}$=-.196	1	1796	1768.	.490	-.196	5.39	17.7	150.2	1617.	20.07	65.85
$\frac{LCB-LCF}{L}$=.001	1	1759	1731.	.491	.001	6.68	21.9	153.4	1651.	19.96	65.50
$\frac{LCB-LCF}{L}$=.065	1	1767	1739.	.486	.065	5.49	18.0	155.1	1669.	20.01	65.64
GM_L=11.25 m	1	1735	1708.	.488	.049	11.25	36.9	143.7	1547.	20.59	67.56
GM_L=11.64 m	2	1797	1769.	.487	.051	11.64	38.2	148.0	1593.	20.56	67.46
GM_L=29.38 m	2	1760	1732.	.485	.045	29.38	96.4	145.4	1565.	20.42	67.01
GM_L=33.95 m	2	1744	1716.	.488	.038	33.95	111.4	138.9	1495.	20.44	67.06
WPA=124.3 m²	1	1732	1705.	.489	.050	5.49	18.0	124.3	1338.	22.14	72.64
WPA=164.2 m²	1	1764	1736.	.489	.044	5.76	18.9	164.2	1767.	19.27	63.22
$\frac{L}{D}$=13.1	1	1822	1793.	.488	.049	5.49	18.0	152.5	1641.	20.41	66.95
$\frac{L}{D}$=21.0	1	1808	1779.	.491	.050	5.33	17.5	152.1	1637.	20.10	65.93
GM_T=1.22 m	1	1760	1732.	.489	.045	5.58	18.3	152.8	1645.	18.60	61.02
GM_T=3.66 m	1	1760	1732.	.489	.045	5.58	18.3	152.8	1645.	21.34	70.01

TABLE 4 - CALM WATER STABILITY CHARACTERISTICS

PARAMETRIC VARIATION	INCEPTION SPEED FOR PITCH INSTAB. Kts	SPEED Kts	Heave T_3 (sec)	Pitch T_5 (sec)	ζ_3	ζ_5	$T_3^{(1/2)}$ (sec)	$T_5^{(1/2)}$ (sec)	D_3	D_5
Baseline	17.7	0	8.38	20.05	.049	.043	18.73	51.99	.0277	.0042
		5	8.36	20.95	.056	.060	16.54	38.34	.0315	.0054
		15	8.20	37.45	.066	.166	13.60	24.48	.0391	.0048
		20	8.09	-	.071	-	12.62	-	.0427	-
$\frac{LCB}{L} = .445$	16.8	0	8.26	20.50	.046	.051	20.02	44.42	.0264	.0048
		5	8.24	21.51	.053	.070	17.05	33.63	.0310	.0060
		15	8.08	44.17	.067	.216	13.33	22.08	.0404	.0045
		20	7.98	-	.072	-	12.18	-	.0448	-
$\frac{LCB}{L} = .532$	17.1	0	8.47	19.73	.048	.031	19.34	69.19	.0266	.0032
		5	8.45	20.69	.056	.050	16.67	45.54	.0309	.0046
		15	8.25	40.74	.068	.172	13.37	25.81	.0395	.0041
		20	8.12	-	.073	-	12.33	-	.0435	-
$\frac{LCB-LCF}{L} = -.196$	16.3	0	5.87	28.40	.001	.045	564.08	70.38	.0013	.0022
		5	5.87	30.12	.010	.067	65.61	49.43	.0113	.0029
		15	5.87	255.55	.027	.687	24.43	29.83	.0304	.0006
		20	5.87	-	.034	-	19.04	-	.0390	-
$\frac{LCB-LCF}{L} = .001$	19.4	0	8.60	17.76	.043	.041	21.96	48.05	.0231	.0051
		5	8.57	18.47	.051	.055	18.60	37.31	.0273	.0063
		15	8.33	29.23	.063	.128	14.52	24.94	.0360	.0060
		20	8.18	-	.068	-	13.26	11.56	.0401	-

TABLE 4 (CONT)

PARAMETRIC VARIATION	INCEPTION SPEED FOR PITCH INSTAB. (Kts)	SPEED (Kts)	T_3 Heave (sec)	T_5 Pitch (sec)	ζ_3	ζ_5	$T_3^{(1/2)}$ (sec)	$T_5^{(1/2)}$ (sec)	D_3	D_5
$\dfrac{LCB-LCF}{L} = .064$	17.6	0	7.98	20.69	.052	.079	16.80	28.64	.0325	.0073
		5	7.97	21.61	.059	.098	14.82	24.24	.0369	.0083
		15	7.87	38.52	.072	.224	12.02	18.49	.0461	.0061
		20	7.79	-	.077	-	11.08	-	.0505	-
$GM_L = 11.25$ m (1 Strut)	25.0	0	8.47	14.36	.038	.054	24.82	29.54	.0207	.0103
		5	8.44	14.71	.044	.067	21.33	24.27	.0242	.0122
		15	8.26	18.34	.055	.112	16.60	17.94	.0318	.0132
		20	8.14	24.51	.059	.170	15.08	15.72	.0355	.0113
$GM_L = 11.25$ m (2 Struts)	25.9	0	8.50	14.28	.053	.075	17.66	21.05	.0290	.0145
		5	8.48	14.61	.058	.089	16.01	17.99	.0321	.0166
		15	8.30	17.92	.069	.138	13.27	14.18	.0396	.0171
		20	8.18	23.15	.074	.196	12.24	12.80	.0435	.0147
$GM_L = 29.38$ m	40.6	0	9.44	7.18	.002	.005	710.67	148.99	.0006	.0041
		5	9.52	7.17	.011	.010	97.51	75.83	.0047	.0080
		15	10.22	7.12	.034	.019	32.97	42.09	.0129	.0145
		20	7.09	10.83	.022	.051	36.38	23.85	.0169	.0167
$GM_L = 33.93$ m	43.5	0	9.32	6.74	.002	.010	466.18	71.85	.0010	.0090
		5	9.38	6.74	.012	.015	88.46	48.88	.0052	.0132
		15	9.89	6.76	.035	.023	30.95	32.41	.0142	.0199
		20	10.42	6.77	.051	.026	22.35	29.32	.0187	.0219

TABLE 4 (CONT)

PARAMETRIC VARIATION	INCEPTION SPEED FOR PITCH INSTAB.	SPEED	T_3 Heave	T_5 Pitch	ζ_3	ζ_5	$T_3^{(1/2)}$	$T_5^{(1/2)}$	D_3	D_5
	Kts	Kts	(sec)	(sec)			(sec)	(sec)		
WPA = 124.3 m^2	17.2	0	9.39	21.01	.032	.045	32.24	51.07	.0144	.0041
		5	9.36	22.03	.038	.067	27.06	36.43	.0172	.0054
		15	9.12	42.60	.049	.198	20.42	23.22	.0234	.0044
		20	8.97	-	.054	-	18.33	-	.0265	-
WPA = 164.2 m^2	18.0	0	8.02	19.44	.073	.043	12.13	50.12	.0448	.0045
		5	8.00	20.28	.079	.059	11.08	37.68	.0491	.0057
		15	7.86	34.96	.090	.159	9.62	23.98	.0576	.0052
		20	7.76	-	.094	-	9.11	-	.0616	-
$\frac{L}{D}$ = 13.1	14.6	0	8.48	17.95	.033	.019	28.56	102.12	.0180	.0024
		5	8.44	19.18	.046	.046	20.30	46.13	.0254	.0049
		15	8.14	-	.065	-	13.84	-	.0387	-
		20	7.97	-	.071	-	12.35	-	.0443	-
$\frac{L}{D}$ = 21.0	17.1	0	8.54	21.54	.052	.059	17.96	40.52	.0284	.0050
		5	8.51	22.57	.059	.079	15.84	31.52	.0323	.0061
		15	8.36	44.39	.071	.223	12.96	21.42	.0402	.0046
		20	8.24	-	.076	-	11.99	-	.0441	-

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TABLE 5a - WAVE ENCOUNTER PERIODS (SEC) OF MAXIMUM HEAVE AND PITCH RESPONSE IN HEAD WAVES AT VARIOUS CRAFT SPEEDS

PARAMETRIC VARIATION	Fn = 0.0 HEAVE	Fn = 0.0 PITCH	Fn = 0.1 HEAVE	Fn = 0.1 PITCH	Fn = 0.3 HEAVE	Fn = 0.3 PITCH	Fn = 0.4 HEAVE	Fn = 0.4 PITCH
Baseline	8.61	19.65	8.66	22.66	8.54	8.48	8.39	8.25
$\frac{LCB}{L}=.445$	8.42	20.87	8.48	22.94	8.29	8.28	8.17	8.12
$\frac{LCB}{L}=.532$	8.68	19.02	8.74	21.93	8.64	8.58	8.51	8.38
$\frac{LCB-LCF}{L}=-.192$	6.04	6.02	5.96	6.11	6.08	6.07	6.09	6.05
$\frac{LCB-LCF}{L}=.001$	8.77	18.43	8.80	18.62	8.68	8.65	8.52	8.43
$\frac{LCB-LCF}{L}=.065$	8.02	22.49	8.08	23.28	8.06	8.06	8.02	7.98
$GM_L=11.25$ m	8.76	15.07	8.76	15.06	8.61	8.55	8.45	8.30
$GM_L=11.64$ m	8.85	14.97	8.81	14.97	8.67	8.60	8.54	8.40
$GM_L=29.38$ m	6.83	6.81	11.73	6.88	8.05	7.30	7.92	7.19
$GM_L=33.93$ m	6.67	6.68	6.67	6.68	6.70	6.70	6.74	6.72
WPA=124.3 m^2	9.77	22.65	9.77	23.47	9.53	9.44	9.20	9.07
WPA=164.2 m^2	8.12	18.87	8.33	21.18	8.18	8.12	8.06	7.99
$\frac{L}{D}=13.1$	8.78	18.38	8.76	18.55	8.54	8.27	8.26	8.09
$\frac{L}{D}=21.0$	8.71	23.26	8.77	23.63	8.71	8.69	8.64	8.56

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TABLE 5b - WAVE ENCOUNTER PERIODS (SEC) OF MAXIMUM HEAVE AND PITCH RESPONSE IN FOLLOWING WAVES AT VARIOUS CRAFT SPEEDS

PARAMETRIC VARIATION	Fn = 0.0		Fn = 0.1	
	HEAVE	PITCH	HEAVE	PITCH
Baseline	8.61	20.59	8.39	21.61
$\frac{LCB}{L} = .445$	8.42	20.80	8.26	22.01
$\frac{LCB}{L} = .532$	8.69	20.23	8.46	21.43
$\frac{LCB-LCF}{L} = -.192$	6.05	6.03	24.09	30.59
$\frac{LCB-LCF}{L} = .001$	8.77	18.23	8.59	19.10
$\frac{LCB-LCF}{L} = .065$	7.98	21.10	8.11	22.87
$GM_L = 11.25$ m	8.79	14.92	8.36	15.57
$GM_L = 11.64$ m	14.77	14.79	15.54	15.54
$GM_L = 29.38$ m	10.11	6.79	37.39	8.09
$GM_L = 33.93$ m	10.11	6.69	9.36	6.73
$WPA = 124.3$ m^2	9.92	21.04	9.27	9.36
$WPA = 164.2$ m^2	8.08	19.84	8.23	21.30
$\frac{L}{D} = 13.1$	8.81	18.29	19.35	19.36
$\frac{L}{D} = 21.0$	8.71	22.21	8.54	23.41

TABLE 5c – WAVE ENCOUNTER PERIODS (SEC) OF MAXIMUM ROLL RESPONSE IN BEAM WAVES AT VARIOUS CRAFT SPEEDS

PARAMETRIC VARIATION	Fn=.0	Fn=.1	Fn=.3	Fn=.4
Baseline (GM_T=1.22 m)	18.54	18.58	18.63	18.60
GM_T=2.44 m	23.81	23.98	23.97	23.91
GM_T=3.66 m	15.33	15.41	15.55	15.61

BASELINE

FP   AP
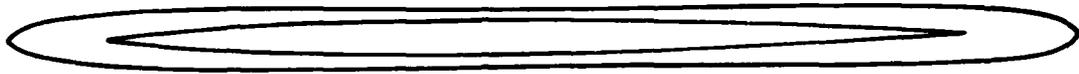
$\dfrac{LCB}{L} = .445$
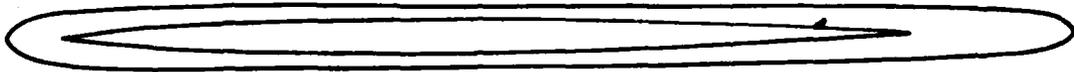
$\dfrac{LCB}{L} = .532$
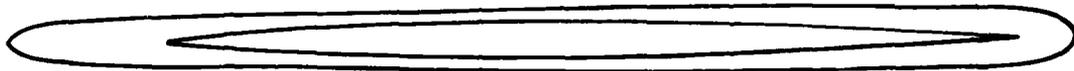
$GM_L = 11.25m$ (1 Strut)
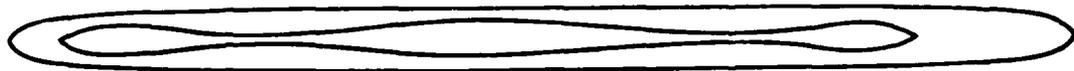
$GM_L = 11.64m$ (2 Struts)
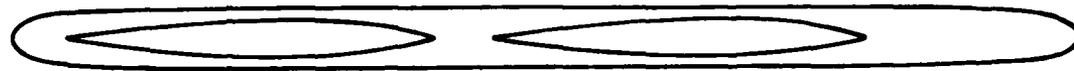
$GM_L = 29.38m$

$GM_L = 33.95m$
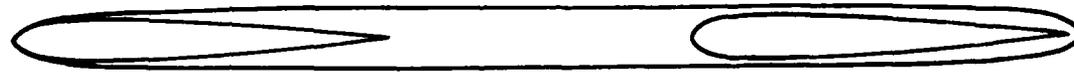
Figure 1 - Sketches of SWATH Configurations

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FP

AP

$$\frac{LCB\text{-}LCF}{L} = -.196$$

$$\frac{LCB\text{-}LCF}{L} = .001$$
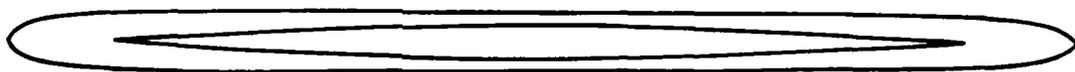
$$\frac{LCB\text{-}LCF}{L} = .065$$
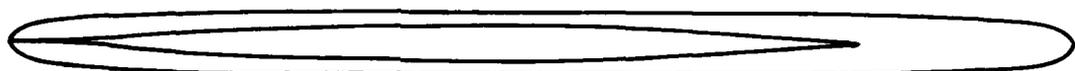
WPA = 124.3m^2
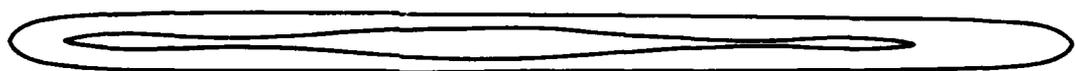
WPA = 164.2m^2
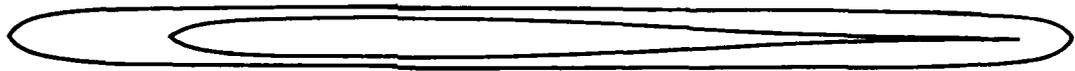
$$\frac{L}{D} = 13.1$$
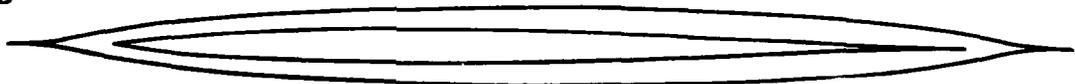
$$\frac{L}{D} = 21.0$$
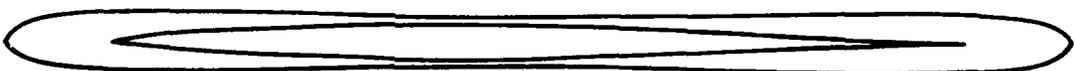
Figure 1 - Continued

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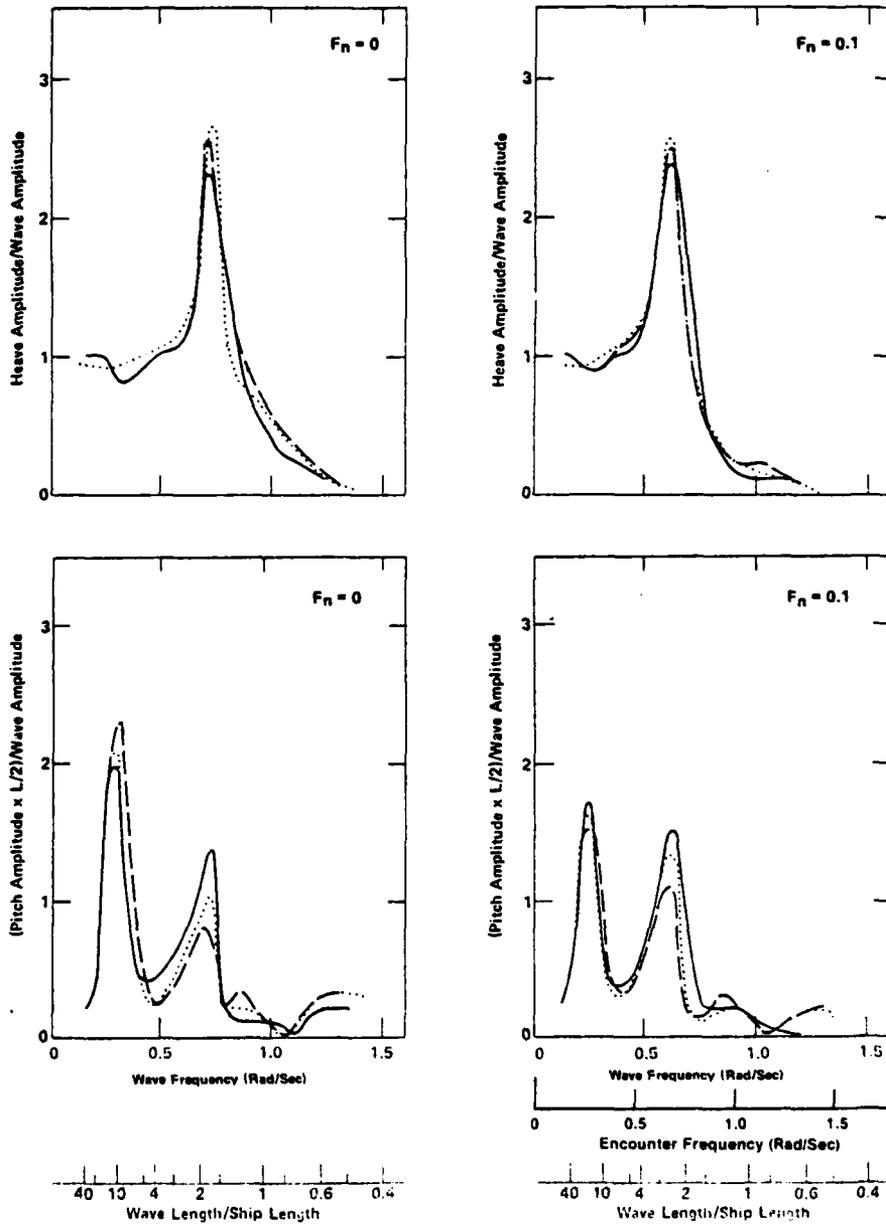
Figure 2 - Heave and Pitch Transfer Functions in Head Seas at
Fn = 0.0 and 0.1 for LCB/L Variations

Figure 3 - Heave and Pitch Transfer Functions in Head Seas at
Fn = 0.3 and 0.4 for LCB/L Variations

LCB/L VARIATIONS
HEAVE/PITCH
FOLLOWING SEAS

——— .445
·········· .489 Baseline
– – – – .532
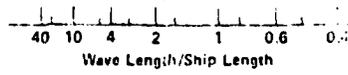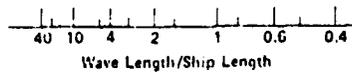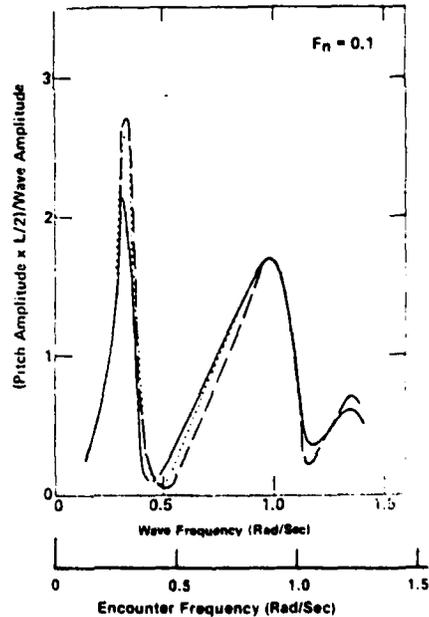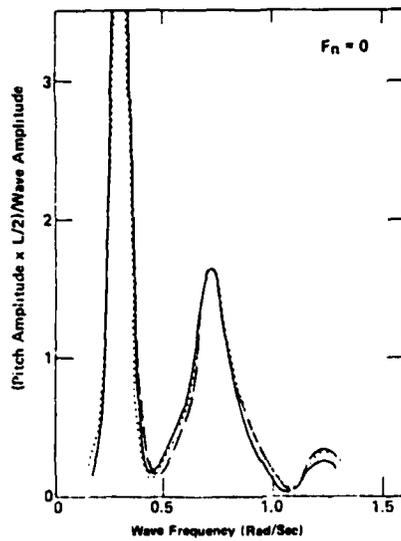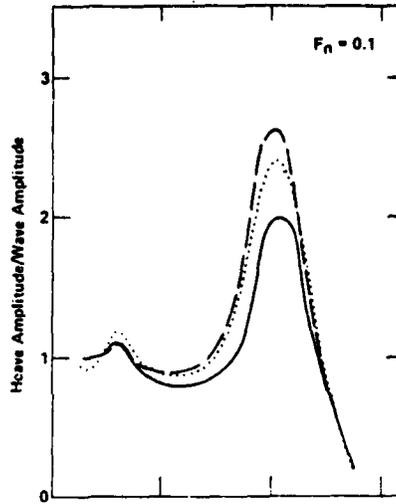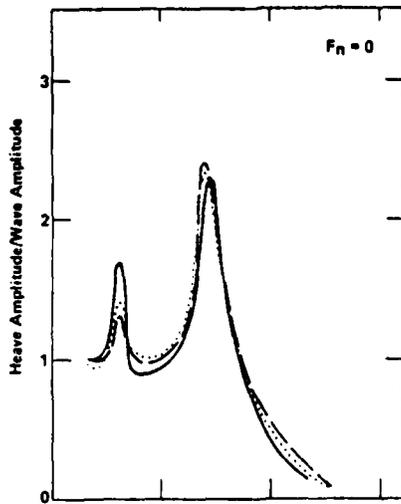
Figure 4 - Heave and Pitch Transfer Functions in Following Seas
for LCB/L Variations

Figure 5 - Heave and Pitch Transfer Functions in Head Seas at
Fn = 0.0 and 0.1 for (LCB-LCF)/L Variations

(LCB-LCF)/L VARIATIONS
HEAVE/PITCH
HEAD SEAS
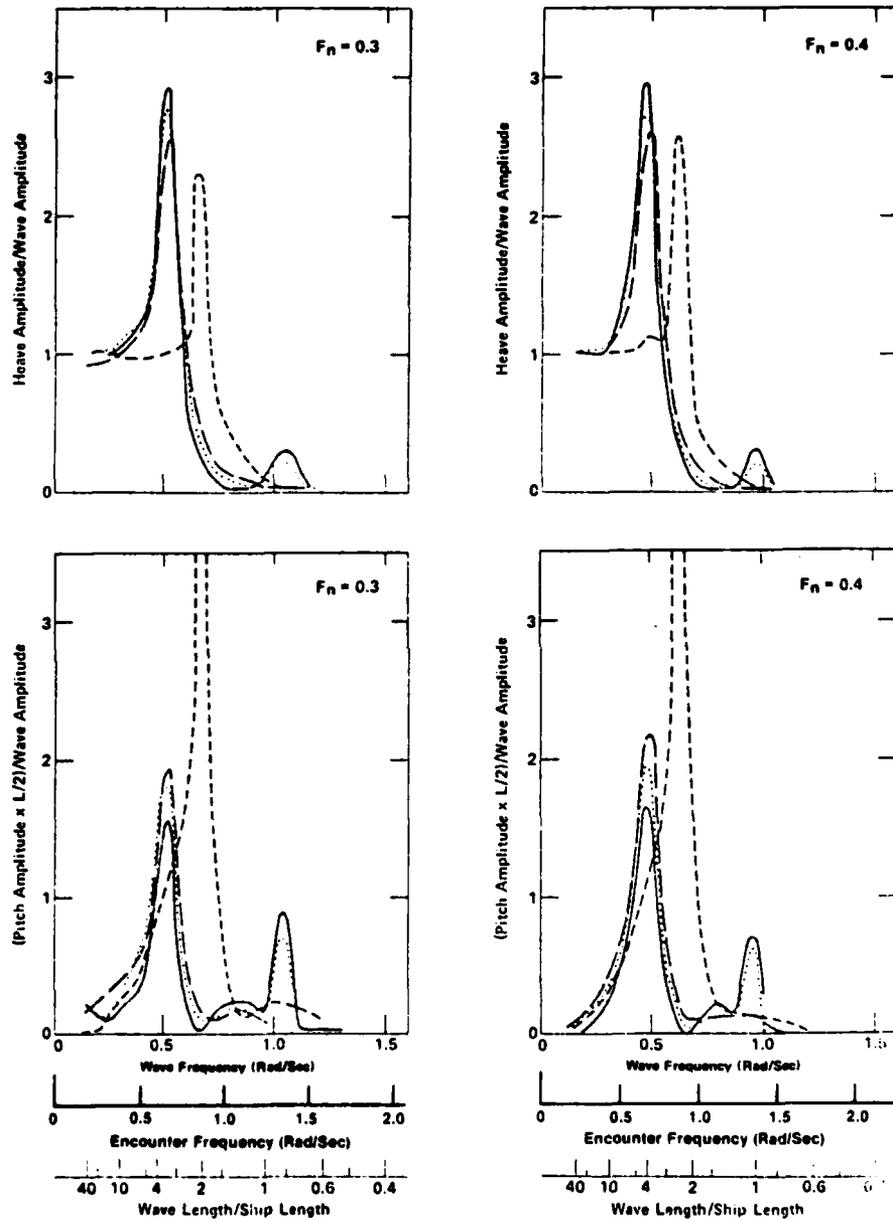
Figure 6 - Heave and Pitch Transfer Functions in Head Seas at
Fn = 0.3 and 0.4 for (LCB-LCF)/L Variations
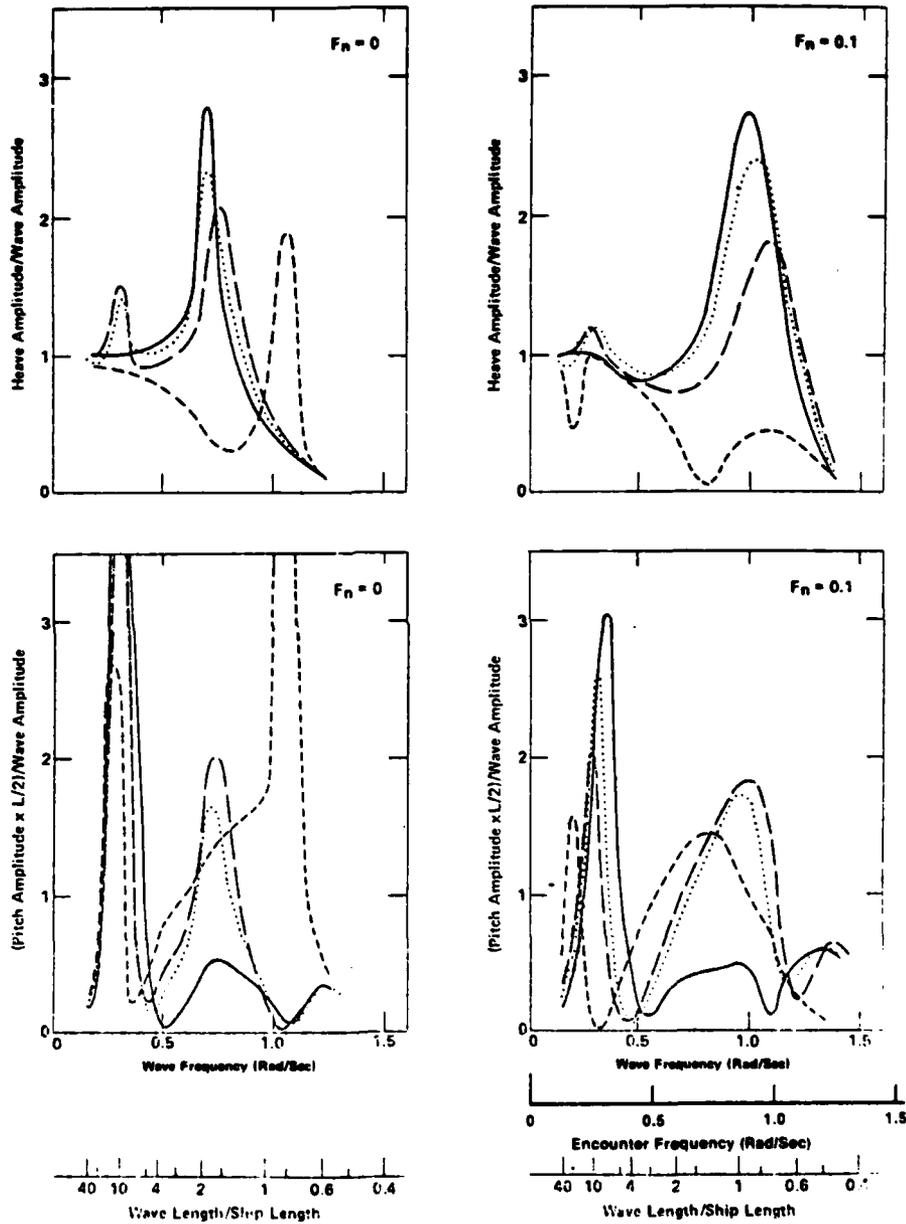
Figure 7 - Heave and Pitch Transfer Functions in Following Seas
for (LCB-LCF)/L Variations

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GM_L VARIATIONS
HEAVE/PITCH
HEAD SEAS

——————— 11.25m (36.9 ft.)   SINGLE STRUT
– – – – – 11.64m (38.2 ft.)   TWIN STRUT
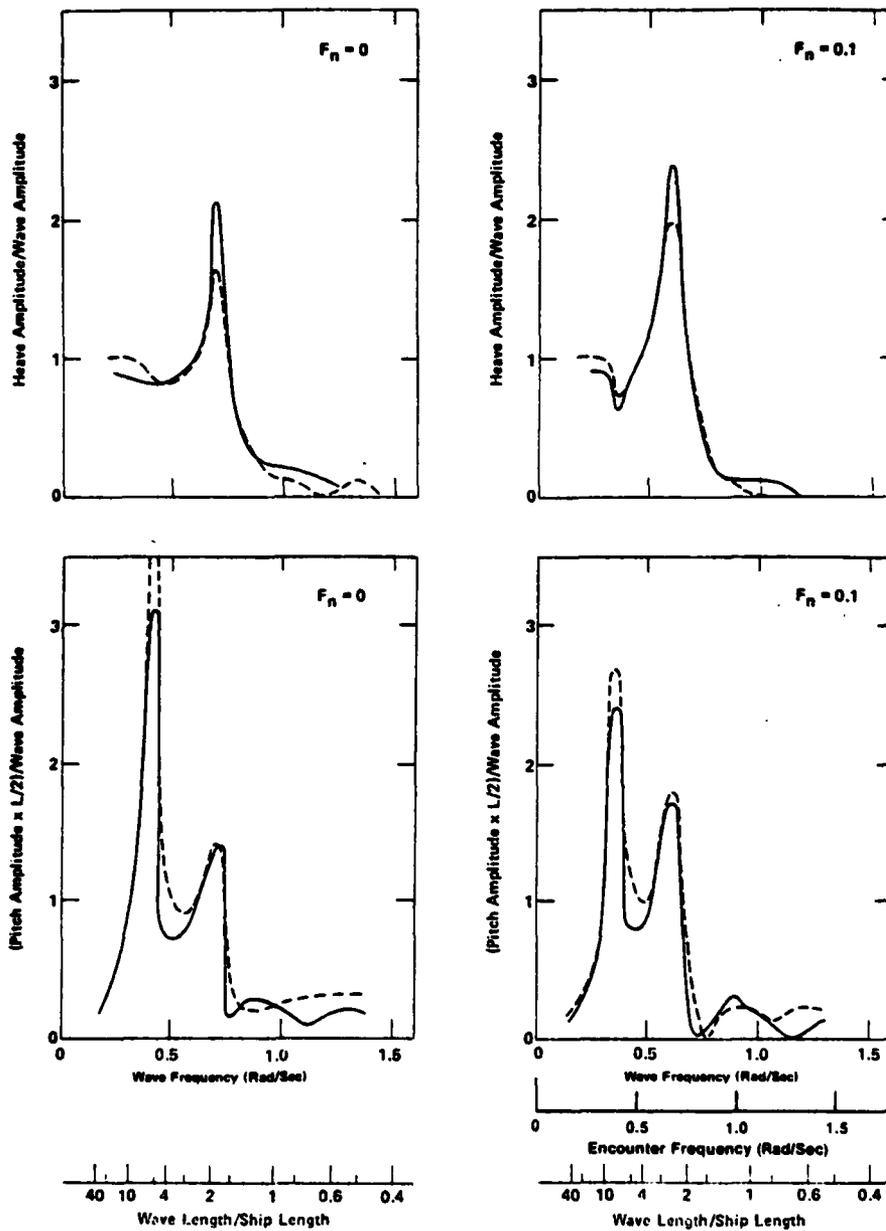
Figure 8 - Heave and Pitch Transfer Functions in Head Seas at
Fn = 0.0 and 0.1 for Single and Twin Strut Comparison

40
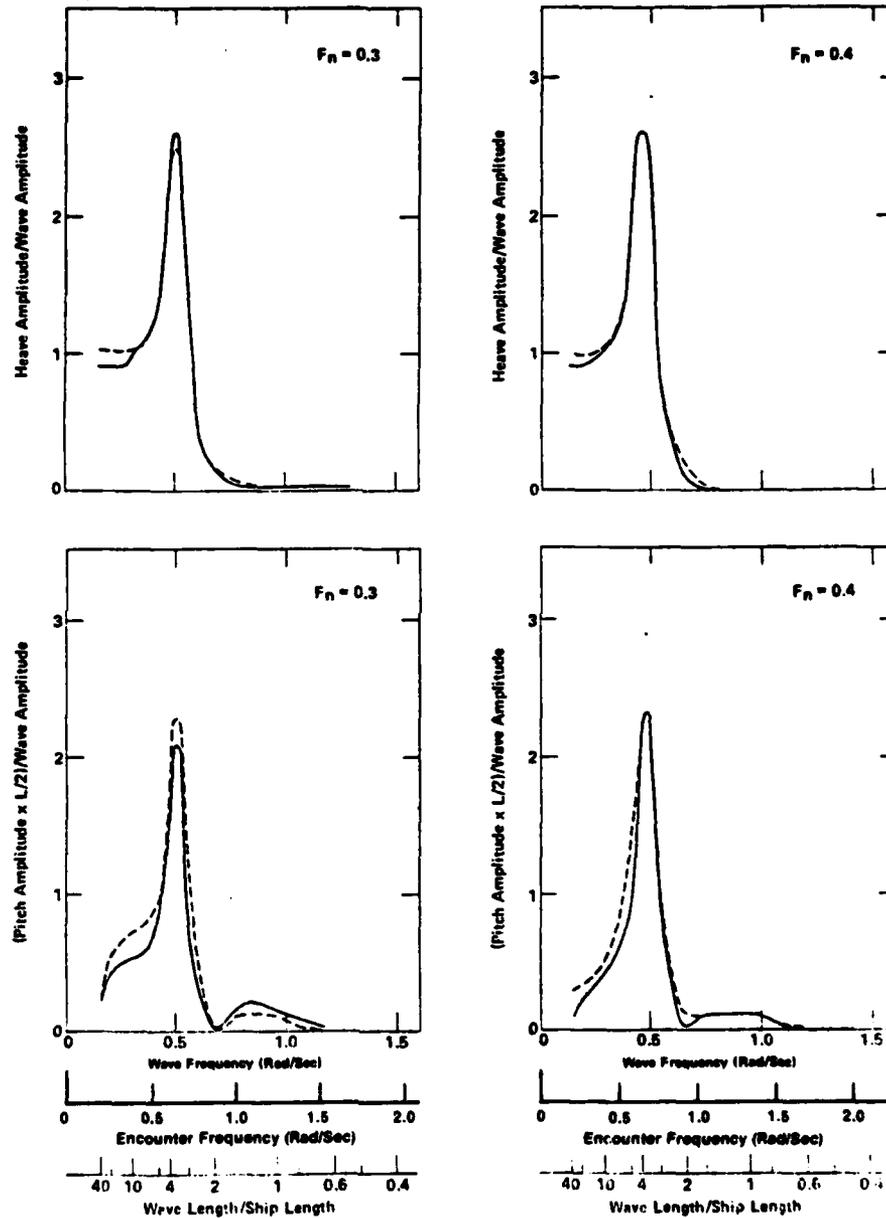
Figure 9 - Heave and Pitch Transfer Functions in Head Seas at
Fn = 0.3 and 0.4 for Single and Twin Strut Comparison

41
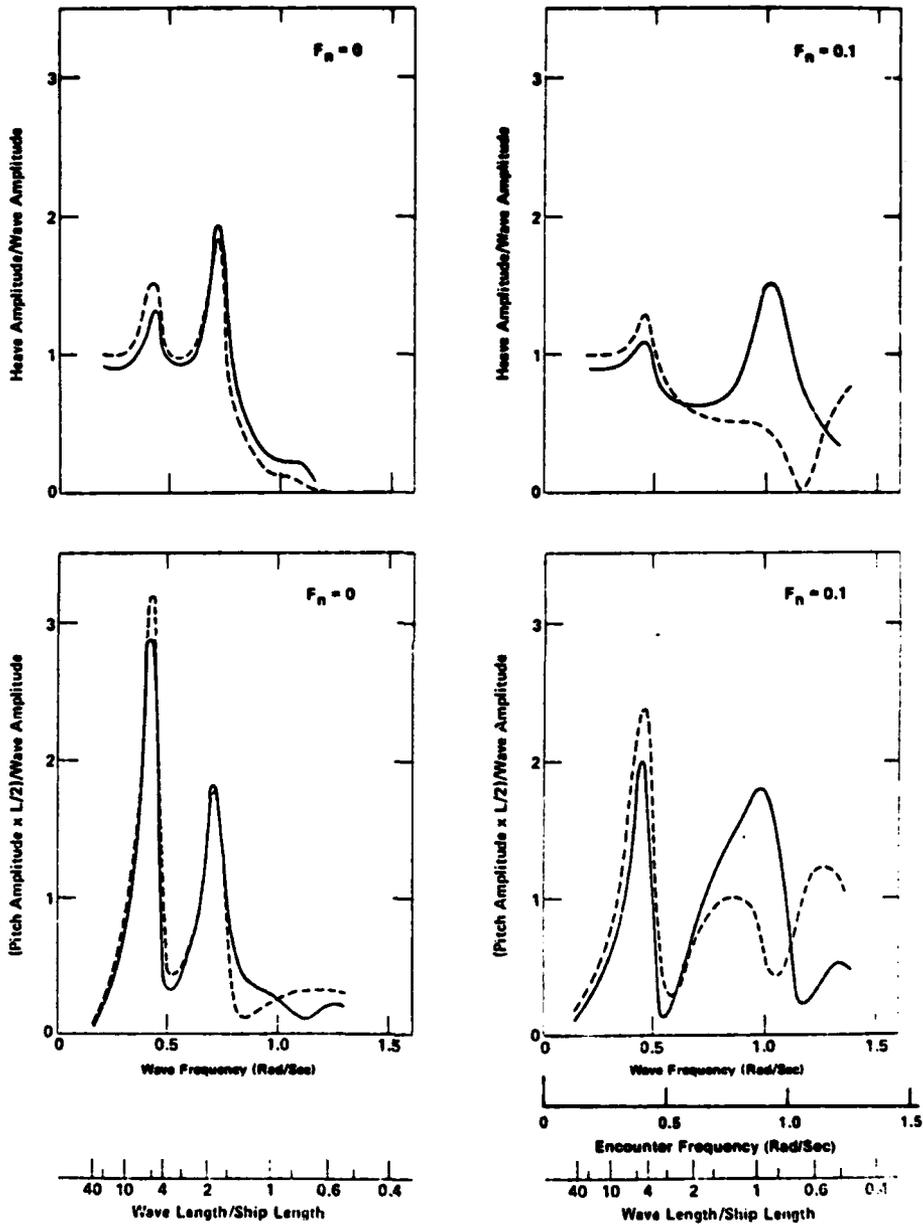
Figure 10 - Heave and Pitch Transfer Functions in Following Seas
for Single and Twin Strut Comparison

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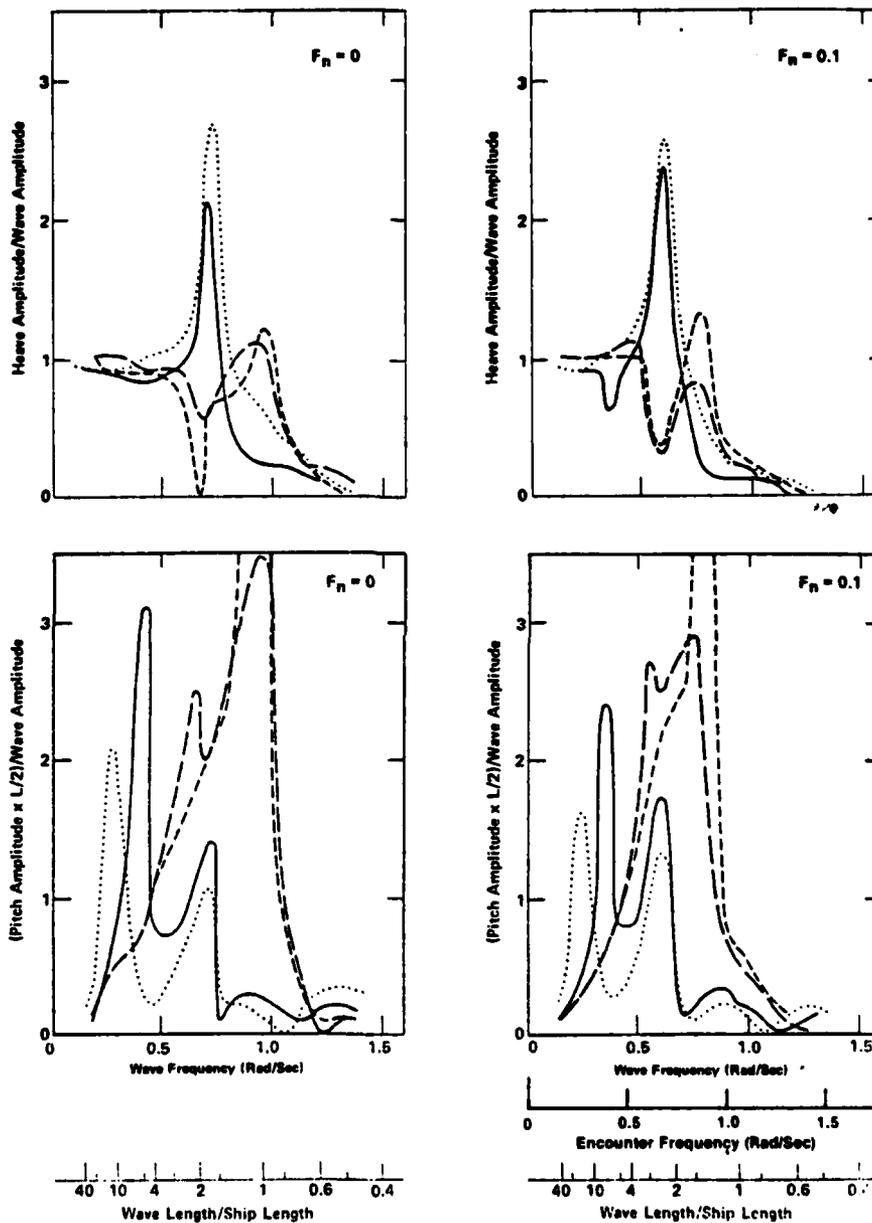
Figure 11 - Heave and Pitch Transfer Functions in Head Seas at
Fn = 0.0 and 0.1 for GM_L Variations
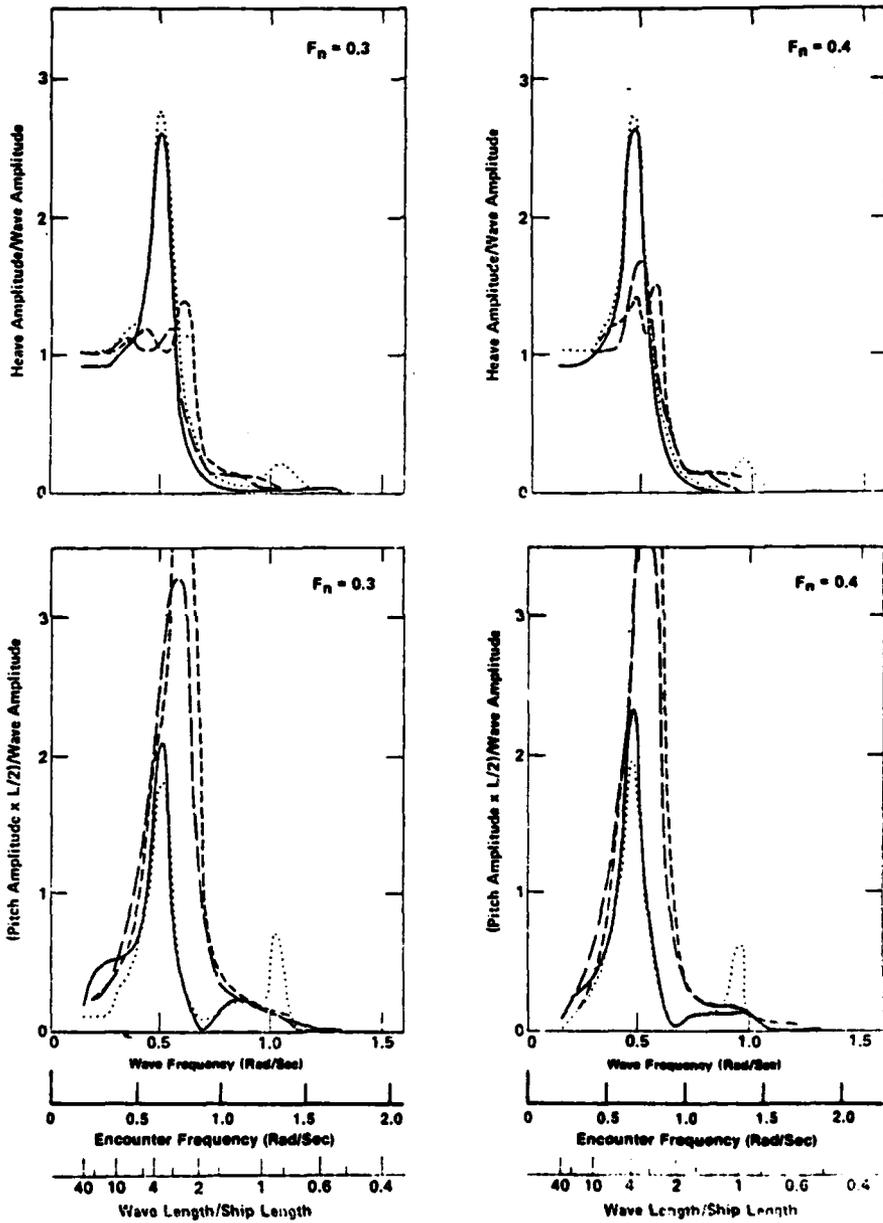
Figure 12 - Heave and Pitch Transfer Functions in Head Seas at
Fn = 0.3 and 0.4 for GM_L Variations
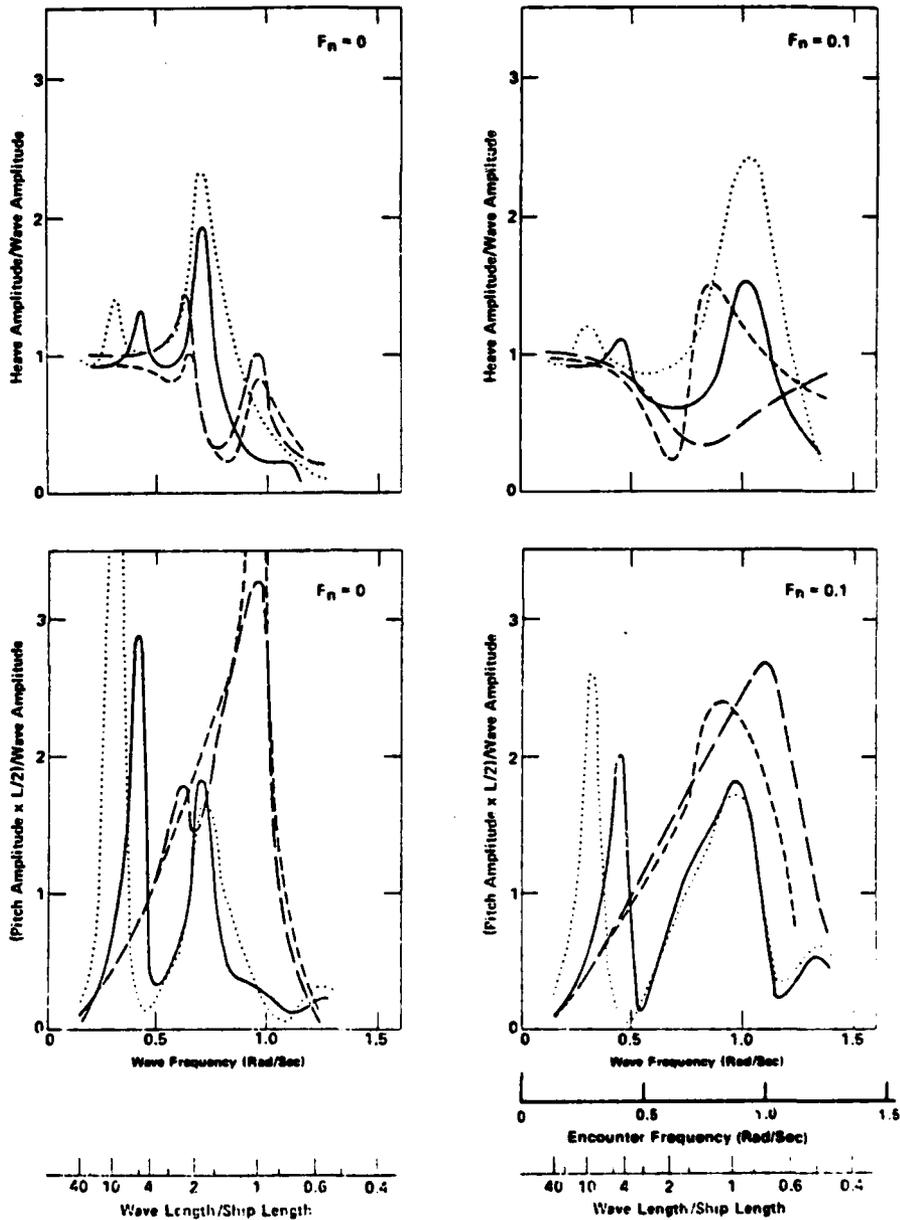
Figure 13 - Heave and Pitch Transfer Functions in Following Seas for GM_L Variations

WPA VARIATIONS
HEAVE/PITCH
HEAD SEAS

—————— 124.3m² (1338 ft.²)
·············· 152.8m² (1645 ft.²)   Baseline
— — — 164.2m² (1767 ft.²)
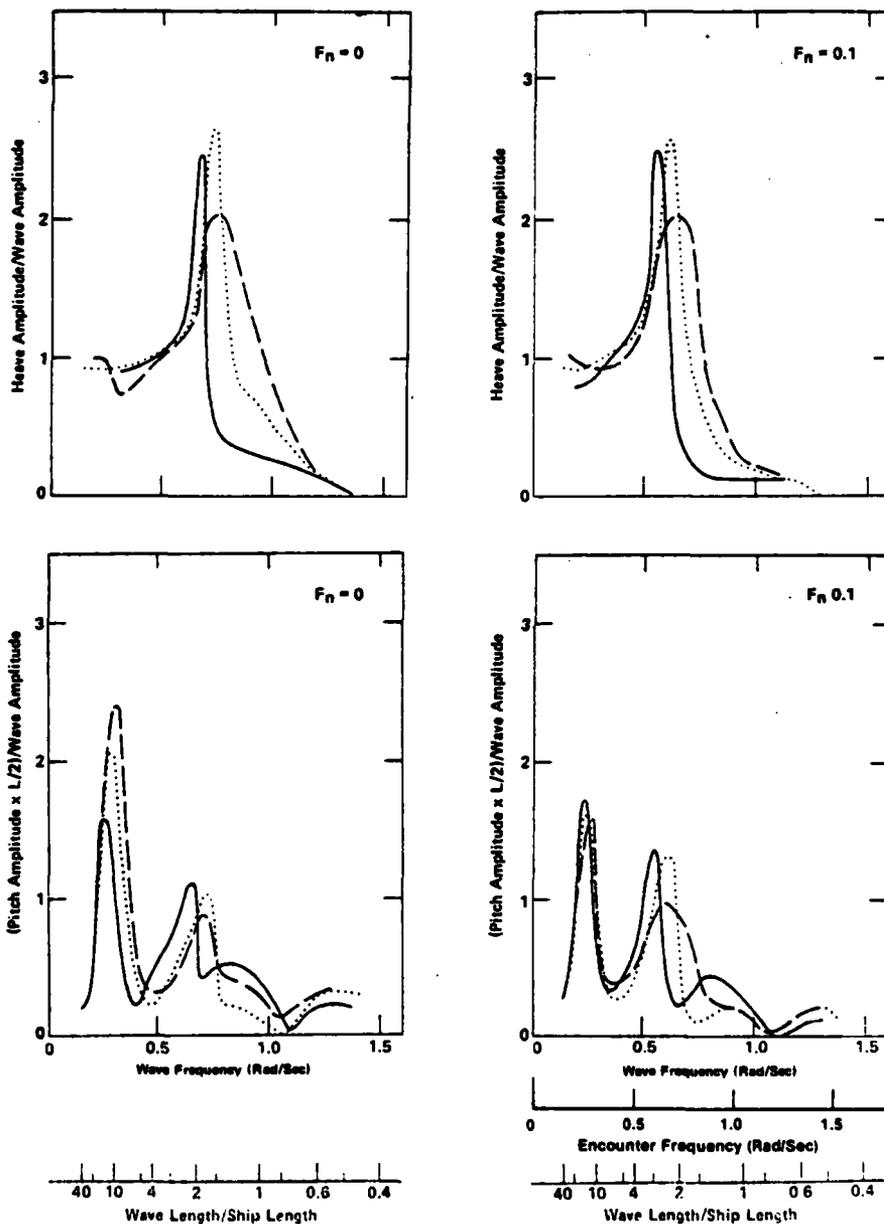
Figure 14 - Heave and Pitch Transfer Functions in Head Seas at
Fn = 0.0 and 0.1 for WPA Variations

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WPA VARIATIONS
HEAVE/PITCH
HEAD SEAS

——— 124.3m² (1338 ft.²)
·········· 152.8m² (1645 ft.²)   Baseline
— — — 164.2m² (1767 ft.²)
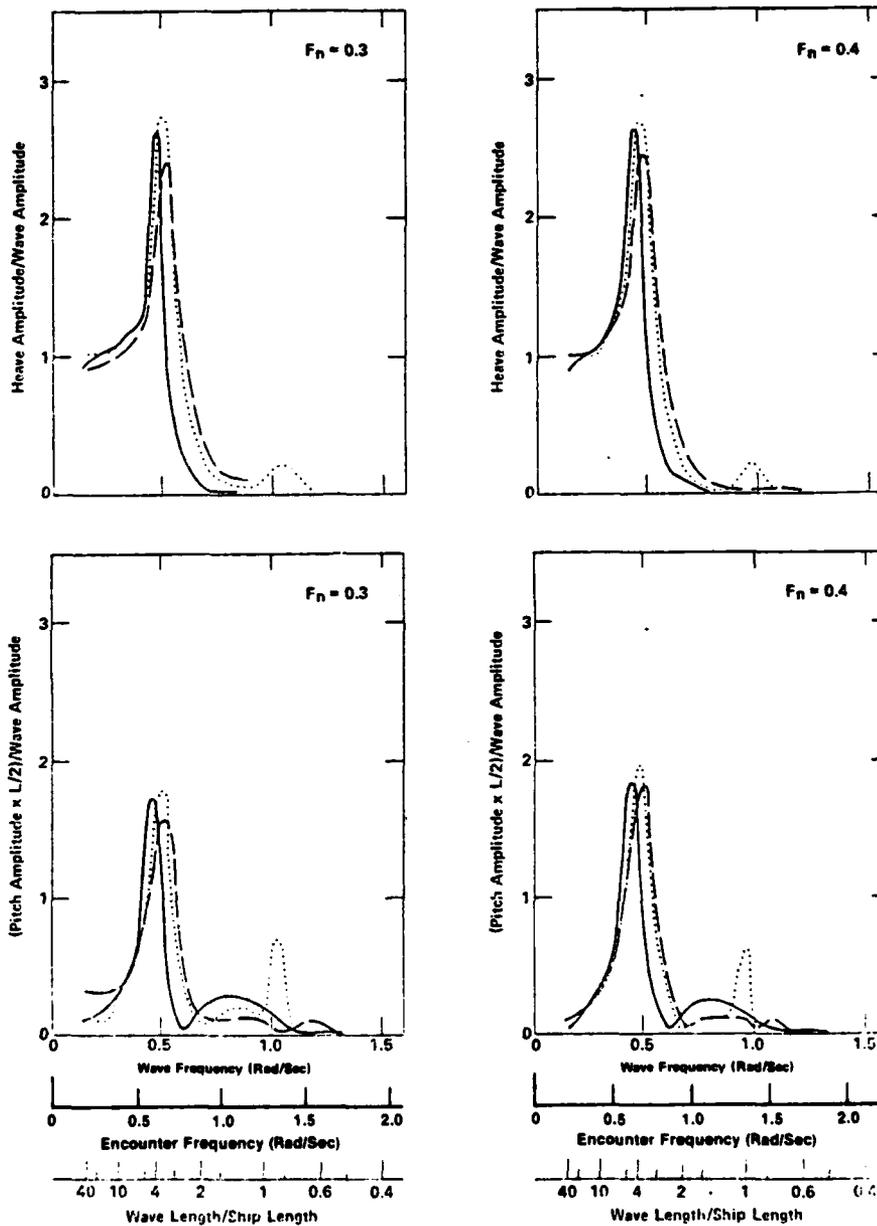
Figure 15 - Heave and Pitch Transfer Functions in Head Seas at
Fn = 0.3 and 0.4 WPA Variations

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WPA VARIATIONS
HEAVE/PITCH
FOLLOWING SEAS

——— 124.3m² (1338 ft.²)
·········· 152.8m² (1645 ft.²)   Baseline
— — — 164.2m² (1767 ft.²)
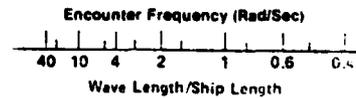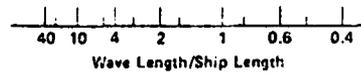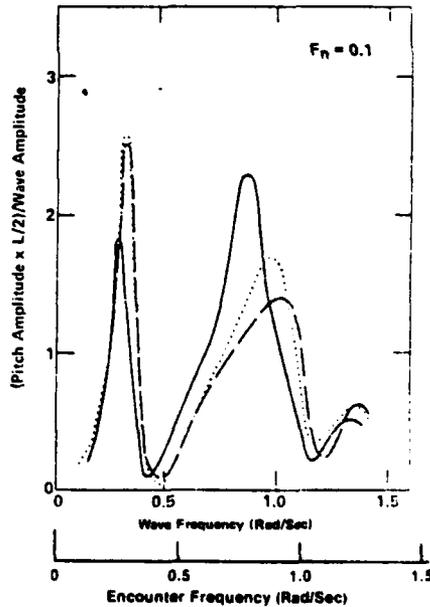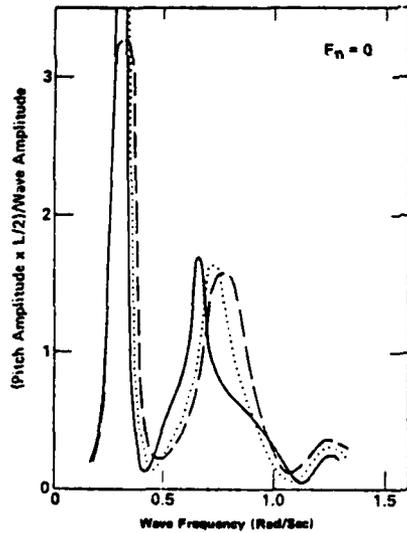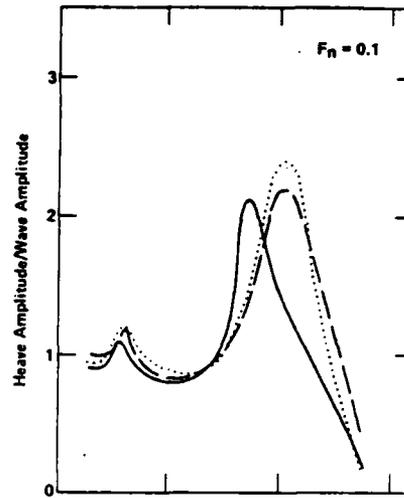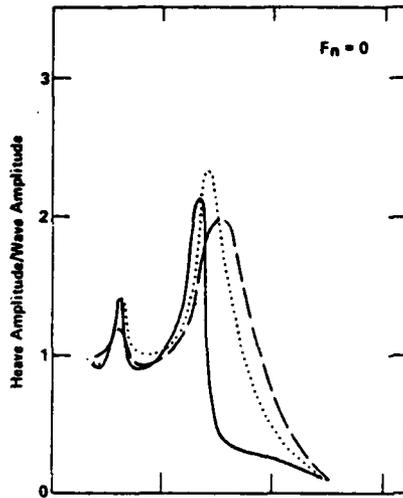
Figure 16 - Heave and Pitch Transfer Functions in Following Seas for
WPA Variations

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L/D VARIATIONS
HEAVE/PITCH
HEAD SEAS

——— 18.0
············ 13.1   Baseline
— — 21.0
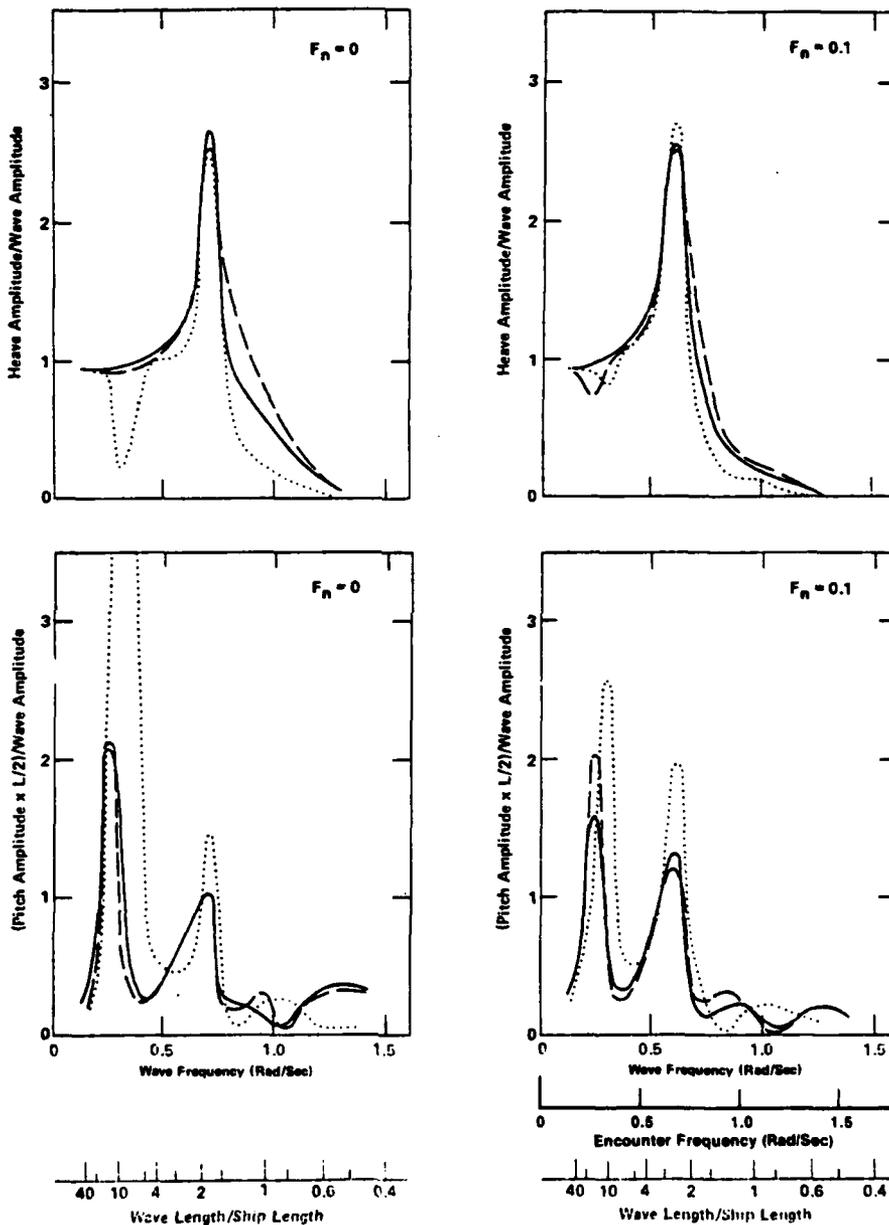
Figure 17 - Heave and Pitch Transfer Functions in Head Seas at
Fn = 0.0 and 0.1 L/D Variations

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L/D VARIATIONS
HEAVE/PITCH
HEAD SEAS

———— 18.0
············ 13.1 Baseline
— — 21.0
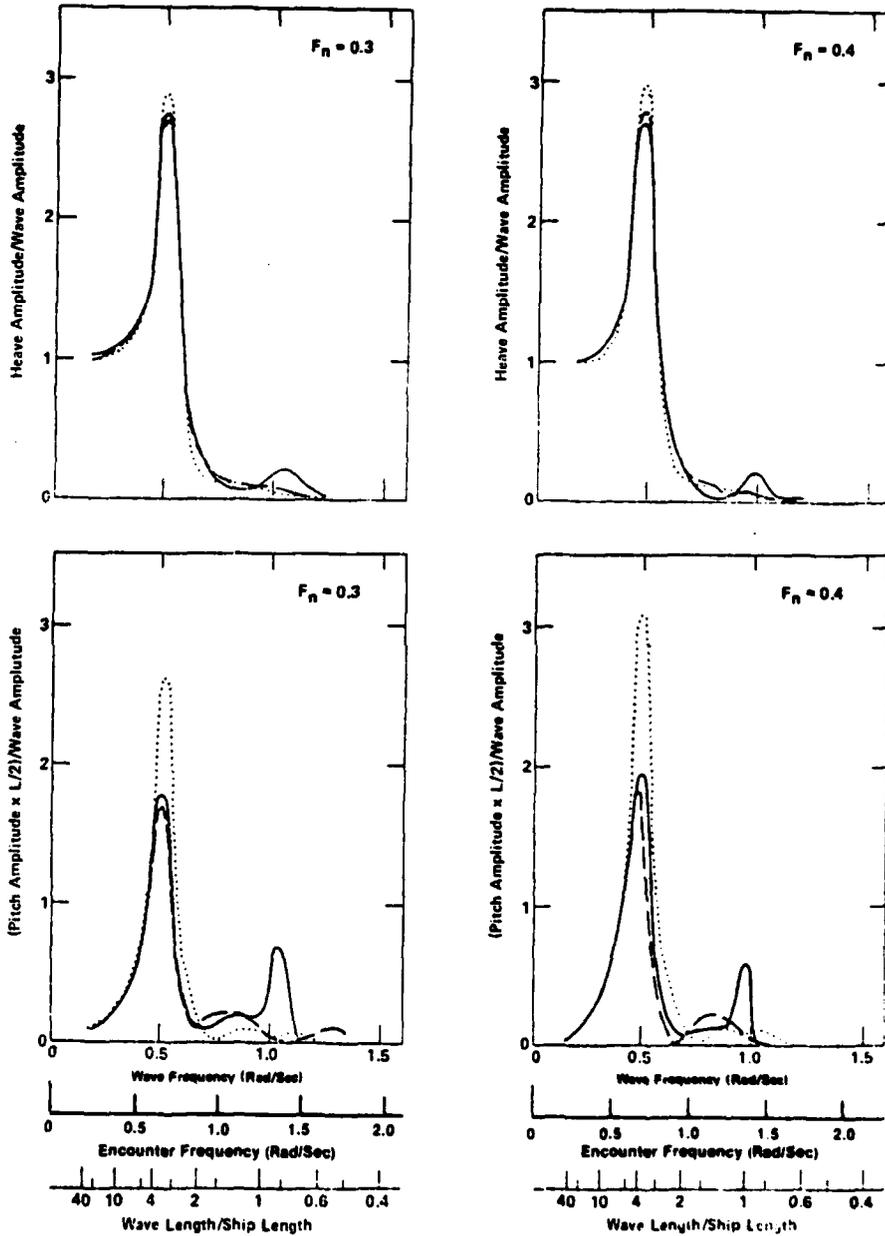
Figure 18 - Heave and Pitch Transfer Functions in Head Seas at
Fn = 0.3 and 0.4 for L/D Variations

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L/D VARIATIONS
HEAVE/PITCH
FOLLOWING SEAS
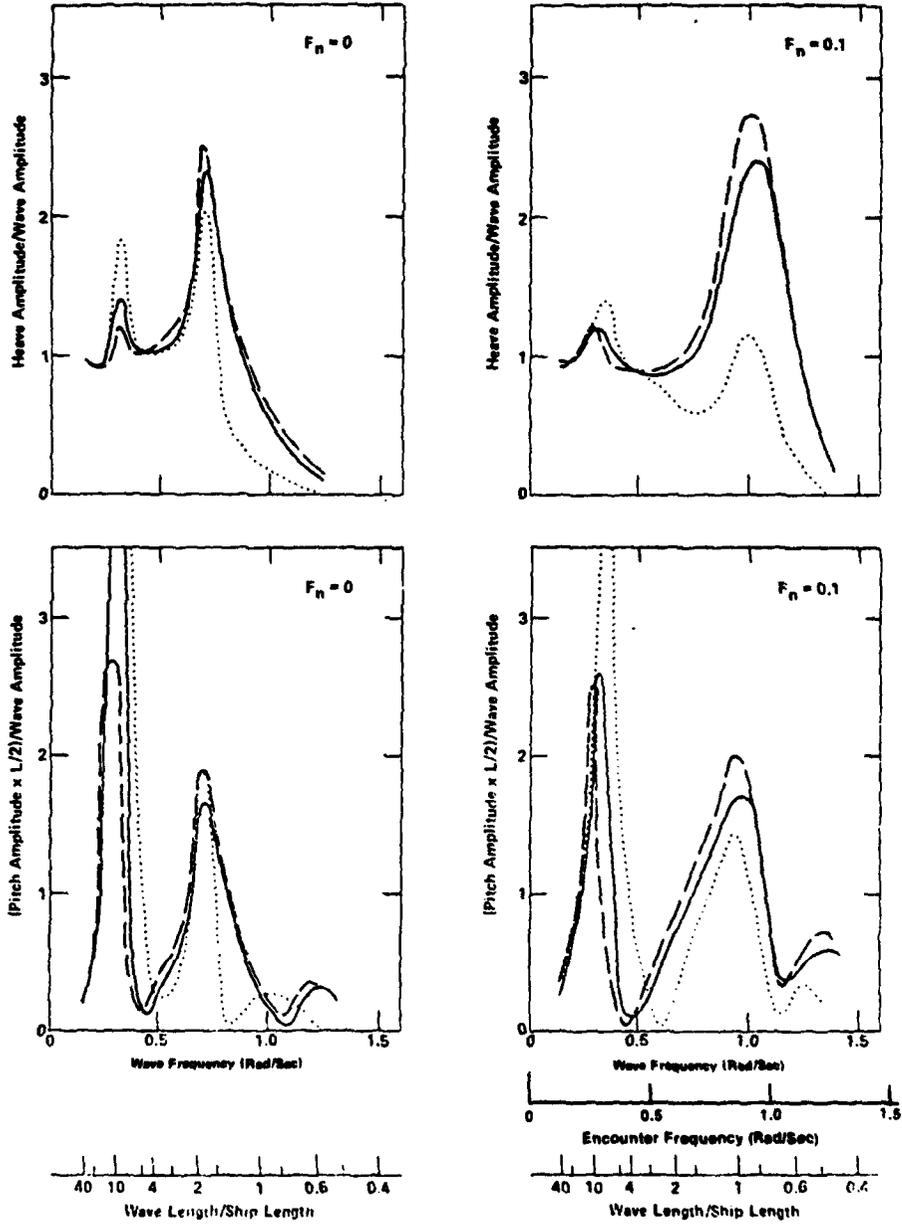
Figure 19 - Heave and Pitch Transfer Functions in Following Seas
for L/D Variations

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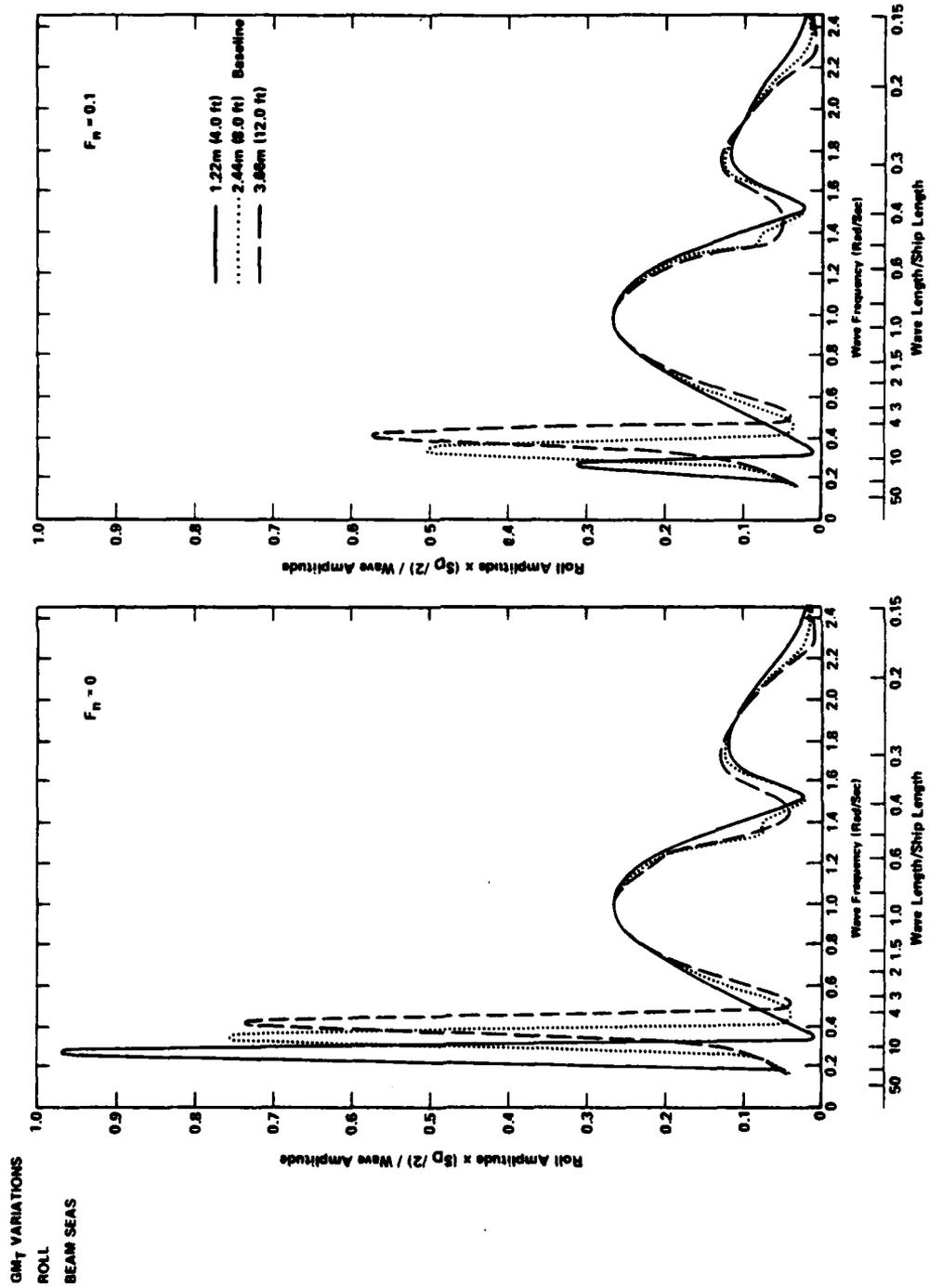
Figure 20 - Roll Transfer Functions in Beam Seas for GM_T Variations

Figure 21 - Roll Transfer Functions in Beam Seas for GM_T Variations

GM_T VARIATIONS
ROLL
BEAM SEAS