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DTNSRDC/SPD-0936-03

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

VALIDATION OF THE STANDARD SHIP MOTION PROGRAM, SMP: SHIP MOTION TRANSFER FUNCTION PREDICTION

by

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and
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SHIP PERFORMANCE DEPARTMENT

July 1981

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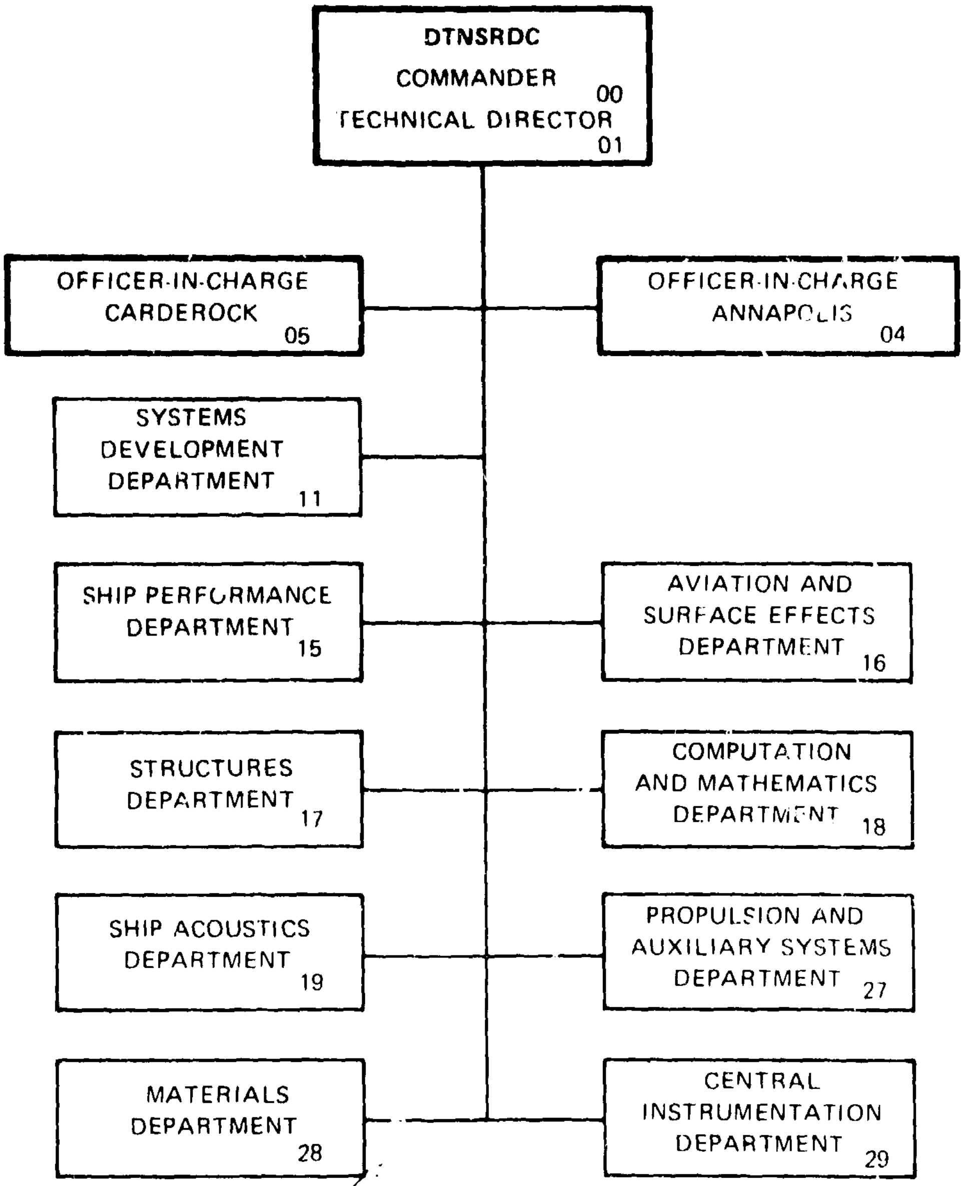

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NDW-DTNSRDC 3960/43 (Rev. 11-75)
GPO 905-679

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
DTNSRDC/SPD-0936-03

2. GOVT A NO.
AD

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
VALIDATION OF THE STANDARD SHIP MOTION PROGRAM
SMP: SHIP MOTION TRANSFER FUNCTION
PREDICTION

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RFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
A. E. Baitis
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W. G. Meyers

NTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Ship Performance Department
David W. Taylor Naval Ship R&D Center
Bethesda, Maryland 20084

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
(See reverse side)

11. CONTROLLING OFFICE NAME AND ADDRESS
Naval Sea Systems Command
Washington, D.C. 20362

12. REPORT DATE
July 1981

13. NUMBER OF PAGES
29

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
[illegible]
[illegible]
[illegible]

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ship Motion Prediction	DE-1006
Transfer Functions	Roll Nonlinearities
Computer Program	
CVA-59	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(Block 10)

Work Unit Numbers	1568-124	Project Number	62766N
	1568-806		
	1504-100		62543N
	1500-104		62543N
	1507-101		62543N

(Block 20 continued)

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The nonlinear characteristics of roll are also investigated in this report. Comparison of experiment and theory demonstrates improved prediction of roll at resonance.

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

A newly revised ship motion computer program has been developed for Navy-wide use, which incorporates the state-of-the-art prediction techniques. Validation of the calculated six-degree-of-freedom responses is essential to substantiate the accuracy of the program as well as to establish its value as a practical prediction tool.

Measured and analytical transfer function data are compared for two Navy ships. Although overall good agreement is found between experiment and theory, future comparisons of a wider range of ship configurations will be required.

The nonlinear characteristics of roll are also investigated in this report. Comparison of experiment and theory demonstrates improved prediction of roll at resonance.

ADMINISTRATIVE INFORMATION

The David W. Taylor Naval Ship Research and Development Center (DTNSRDC) was authorized and funded over a period of years to perform this investigation. For fiscal years 1977 and 1978, funding was provided by the Independent Exploratory Development (IED) Program under Project Number 62766N and Block Number ZF-61-412-001, identified at DTNSRDC as Work Unit 1568-124. For fiscal 1978, funding was also provided by the Naval Sea Systems Command (NAVSEA) under Work Request 81650 and identified at DTNSRDC as Work Unit 15[illegible]-606. In addition, the Conventional Ship Seakeeping Research and Development Program funded this investigation under Project Number 62543N, Block Numbers SF-43-421-001 and SF-43-411-212 in 1978 and 1979, respectively. Work Unit identification at DTNSRDC for this funding was 1504-100. Funding for 1980 was provided by the Ship Performance and Hydromechanics Program under Project Number 62543N, Block Number ZF-43-421-001, identified as Work Unit 1500-104. Fiscal 1981 work is funded by the Surface Ship Hydromechanics Program under Project Number 62543N, Block Number SF-43-400-001, identified as Work Unit 1507-101.

INTRODUCTION

In 1977, DTNSRDC began to revise and rewrite its Ship-Motion and Sea-Load (SMSL) Computer Program.[1*] Refinements in ship response prediction methods, current mathematical modeling, and more extensive ship performance calculations were to be

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*A complete listing of references is given on page 11.

included. For example, changes such as improved roll damping,^{2} incorporation of spline-fitting routines, and the inclusion of irregular sea ship motion predictions as well as relative motion computations were to be a part of this enhanced analytical tool. The result of this sizable effort is the Standard Ship Motion Program, SMP.*

Because of the many changes and improvements, SMP requires validation of its accuracy as a prediction tool. In Reference 2, a comparison of roll damping is made between predicted SMP values and experimental results. In this document, an attempt is made to verify, albeit by a somewhat limited analysis, the accuracy of SMP in its computation of basic ship responses to a sinusoidal wave. Motion transfer functions from SMP and from model experiments for two Navy ships are compared for a variety of ship headings and speeds. Surge, sway, heave, roll, pitch, and yaw motions are presented for a destroyer hull and an aircraft carrier, the DE-1006 and CVA-59.

In addition, a closer scrutiny is given to roll for nonlinear behavior, characteristics at resonance, and the effects due to GM, bilge keel, and heading/speed changes.

It is to be noted that the comparison between analytical and experimental data demonstrates generally good agreement. Model test techniques must also be considered when comparing predicted and experimentally measured motions. For example, lateral motions in quartering waves can be significantly influenced by rudder activity when using a free-running model. Also it should be noted that analytical results depend on an accurate description of the candidate ship model particulars and conditions, in addition to the accuracy of the programed prediction tools and computation techniques. Though encouraging, the results of the analysis presented herein are considered too limited for comprehensive conclusions. As data becomes available, future comparisons between SMP predictions and experimental data need to be made before the validation process can be considered complete.

SHIP PARTICULARS

Comparisons are made for the DE-1006 and CVA-59. Particulars for these two ships are provided in Table 1, and the SMP-computed underwater hull lines are presented in Figure 1. Table 1 presents the experimental model characteristics for

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*Meyers, W.G., T.R. Applebee and A.F. Baitis, "User's Manual for the Standard Ship Motion Program, SMP," Report DTNSRDC/SPD-0936-01 (to be published).

the two ships and the corresponding SMP-computed, full-scale particulars. Variations of the loading and bilge keel size for the DE-1006, as originally tested,[3] can also be found in Table 1. Note specifically that the designation "BK4" refers to the ship without bilge keels.

DATA ACQUISITION

EXPERIMENTAL TECHNIQUES

The experimental techniques employed for the CVA-59 and DE-1006 model tests were similar though not identical. Both models were self-propelled in the Maneuvering and Seakeeping Facility at DTNSRDC. Details regarding the experimental techniques can be found in References 3 and 4 for the DE-1006 and CVA-59, respectively.

The CVA-59 model tests employed a mechanical, counterbalanced heave staff attached at the vertical center of gravity of the model. A series of gimballed joints instrumented with potentiometers permitted the model unrestricted movement, in all six degrees of freedom, within limits of the mechanical travel of this motion measurement equipment. The longitudinal and lateral position and attitude of the model relative to the moving test carriage was obtained by a combination of manual propeller RPM control and automatic steering. Automatic steering was attained by the superposition of a combination yaw angle and sway displacement on a rudder position servomotor. The combination of motion measurement equipment, automatic steering, and manual propeller RPM adjustment served in general to retain the model in a desirable steady state position relative to the test carriage. As a result of this experimental technique, the yaw and sway responses of the model were affected at low frequencies of wave encounter by the automatic steering control employed; whereas surge was similarly affected by the manual setting of propeller RPM. In this context, it should be noted that these experimental effects on the motion responses were minimized by analyzing and presenting only steady state motion data from experimental runs which contained ten cycles of pitch or more. Furthermore, the resulting motions were cross-faired as a function of wavelength, speed, and heading angle. The four-dimensional motion/speed/heading/wavelength surface was assumed to be smooth and without discontinuities. This data fairing or smoothing process was performed by means of a computer program.

The DE-1006 experiments were conducted with a free-running model for which the only physical attachment to the test carriage was the umbilical model power and instrumentation cable. Roll, pitch, and yaw were accordingly measured with gyroscopes rather than with potentiometers, as were the CVA-59 experimental motions. Heave, sway, and surge of the DE-1006 were measured with ultrasonic sensors mounted on the model.

The lateral and longitudinal position of the DE-1006 model was controlled in the same fashion as was the earlier CVA-59 experiments. There was, however, a substantial difference in the automatic steering control signals. The DE-1006 automatic steering employed yaw angle and rate for the steering, whereas the CVA-59 employed yaw angle and sway displacement. The differences in these steering techniques are likely to be reflected in the yaw and sway responses of the models.

The data analysis for the DE-1006 employed a Fourier analysis of the steady state data runs. Unlike the CVA-59 experiments, these runs averaged only five to eight cycles of pitch in length. The 10-cycle criterion used for the CVA-59 model test could not be duplicated since the physical limitations of the test facility prevented the significantly larger DE-1006 model (in terms of scale) from achieving 10 cycles of pitch at high speeds and quartering wave conditions Furthermore, the results were plotted without any type of data smoothing or fairing. Not enough data points for all the conditions, which (in addition to the parameters of motion, speed, wavelength, and heading of the CVA-59 experiments) included different bilge keel sizes and GM variations, were collected to effectively cross-fair the results. Thus, data presented for the DE-1006 represents the actual motion measurements as originally recorded.

ANALYTICAL TOOLS

The new SMP is utilized to compare theoretical ship responses with the measured model data. Minor modifications to SMP were required in order to present the data in the form of nondimensional transfer functions. Wave steepness (slope) and wavelength (frequency) have been adjusted to reflect experimental conditions. Hull configuration, loading characteristics, and appendage specifications are matched as closely as possible to the model test particulars (see Table 1). Additionally, in many cases, the earlier SMSL program predictions are included in the figures. Since SMP represents an improved, albeit more extensive, version of the SMSL program, comparison between the two is considered informative.

COMPARISON OF RESULTS

TRANSFER FUNCTIONS

Two comparisons of the calculated and measured nondimensional transfer functions for the DE-1006 are made in Figures 2 and 3 for speeds of 9 and 27 knots, respectively. The data represents the DE-1006 in the base ship condition (GM1, BK1). Each figure presents the six motion components (surge, sway, heave, roll, pitch, and yaw) by row, while heading angle defines each column. Experimental data is identified by the open circles whereas the solid lines are the predicted motion curves. Each plot compares the transfer functions for a particular motion versus the nondimensional wavelength-to-ship length ratio. The angular transfer functions are nondimensionalized by wave slope and the translational transfer functions are nondimensionalized by wave amplitude. All motion results in this report have been nondimensionalized.

The best agreement between predicted and measured motion as shown in these figures is for the motions of heave and pitch. Consistently, the theory successfully predicts the actual ship response regardless of speed or heading. The vertical motions (i.e., heave and pitch as well as surge) represent little in the way of change in the prediction methods from the SMSL program. Figures 4 and 5 for heave and pitch, respectively, show the differences between the revised (solid line) and original (dashed line) programs. For three speeds and the two head/bow wave conditions, more accurate agreement is illustrated using SMP for both heave and pitch, though the difference in predicted heave is small. Predicted surge at low ship speed shows realtively good agreement. However, the experimental difficulties inherent in the manual positioning of the free-running model below the carriage at high speeds is clearly evident from the large scatter of data points for both surge and sway (see Figure 3).

No experimental data is available at high speed for 45 degrees (quartering waves), or for surge, sway, and yaw at zero degrees (following waves). What is prominent for predicted surge and sway at these conditions is the "clipping" of the transfer function magnitudes by the program. In Appendix A of Reference 5, the criteria are defined which are used for limiting the values of surge, sway, and yaw for the higher ship speeds in quartering and following waves. This corresponds to a near-zero encounter wave frequency where present strip theory cannot adequately model ship response for these motions. The result is a maximum value based on empirically derived equations in terms of Froude number and heading angle.

For the DE-1006, the lateral motions of roll, sway, and yaw do not demonstrate the same good agreement illustrated in the vertical responses. First, no clear pattern to the experimental sway data can be readily discerned in Figures 2 and 3, yet SMP-predicted results show little coincidence with any of the measured points. A similar pattern of scatter, particularly in beam waves, was also observed in experiments with the LCU-1610.[6] The large amplitudes in the experimental sway data points appear to occur very near the peak frequency of the roll transfer function. This is believed to be due to the coupling of sway and roll. Yaw motion seems to be overpredicted consistently at all headings and speeds for this ship.

Only roll shows adequate correlation between the measured and calculated data. Nevertheless, in the low speed case, see Figure 2, SMP roll fails to accurately predict the magnitude of the measured roll, falling well below the experimental points at all headings except 150 degrees, where it slightly overpredicts the peak value. At high speed, see Figure 3, actual roll is again underpredicted, but a shift of the predicted peak frequency to the larger wavelengths is also evident. The small magnitudes exhibited by predicted roll indicate too much damping. This indeed appears to be the case since the roll damping computed by SMP for this ship at this load/bilge keel combination is too high.[2] However, the frequency shift, at this time is unexplained.

Two additional figures are presented to emphasize the effect of damping on the roll transfer function predictions. Figure 6 shows the roll transfer functions for three speeds and the three bilge keel configurations. Note that as the bilge keel gets larger (BK4→BK1) the increased damping causes the transfer function to decrease in magnitude. Note also that the bilge keel is most effective in reducing roll at low speeds, becoming inconsequential at 27 knots. Frequency shift here is observed only for the high speed case. The large scatter of experimental points in the vicinity of roll resonance in Figure 6, particularly at zero ship speed, is an indication of the nonlinear viscous damping. These points represent the roll motion at various wave steepnesses. More discussion of the effects of nonlinear viscous roll damping will be presented in the next section.

Figure 7 illustrates the effect of decreasing GM on the roll transfer function. Though the magnitude appears satisfactory, as the GM becomes smaller, the frequency shift becomes more pronounced. The dashed line is the roll prediction from SMSL. It can be seen that the magnitude of the SMSL-computed transfer function overpredicts for this high speed. This occurs because of the inaccurate prediction of roll damping (i.e., insufficient dynamic lift damping) in the SMSL program. Though some shift in the peak frequency of the experimental data should be noted, SMSL underpredicts and SMP overpredicts this frequency change.

Figure 8 presents a summary of the natural roll periods measured during the systematic roll decay experiments with the DE-1006. These results suggest a tendency of the natural roll period to increase with both forward speed and bilge keel size at constant GM values. These tendencies are particularly pronounced for the model with the smallest GM, i.e., GM3. The increase in the natural roll period with increasing bilge keel size is attributed to the increasing added mass associated with the larger bilge keels. This latter effect is accounted for in the SMP roll motion calculations by incorporating the bilge keel added mass empirical computational technique due to Blagoveshchensky as suggested in Reference 7.

In addition to the destroyer-type hull represented by the DE-1006, the CVA-59, an aircraft carrier, is also evaluated to determine the accuracy of predicted versus measured motion transfer functions. Figures 9 and 10, for ship speeds of 5 and 25 knots, respectively, present this comparison. The format of these figures is identical to Figures 2 and 3 previously described, though heading angles are different.

Similar to the DE-1006, the CVA-59 results show excellent agreement for pitch and heave at both speeds. Moreover, very close correlation between experimental and computed transfer functions can be seen for surge, sway, and yaw. Results with this hull for these particular motions are far superior to the DE-1006 predictions. Specifically, the cross-fairing method and/or the different experimental arrangements for this model appear to have been effective in eliminating the extraneous effects due to rudder action so conspicuous in the DE-1006 data. Finally, predicted roll shows only a mediocre fit with the model test data. A frequency shift in the peak of the calculated transfer function is quite apparent at 60 degrees for both 5 and 25 knots, and at 120 degrees for 25 knots. An overprediction of the roll amplitude at 30 degrees for 5 knots, and 30 and 90 degrees for 25 knots is also evident.

ROLL NONLINEARITIES

Prior to examining roll nonlinearities it should be recalled that the angular ship motions presented in this report have been nondimensionalized by wave slope. As a consequence, if roll is linear the nondimensional roll should be identical at a given ship speed, heading and wavelength when wave height in the form of wave steepness is varied. Systematic variations of the nondimensional roll with wave steepness thus indicate that roll is nonlinear. A measure of the severity of the roll nonlinearity is considered to be represented by the range of (nondimensional) roll that corresponds to a range of wave steepnesses of 1/50 to 1/200, i.e., frequently occurring wave steepnesses.

One of the original goals of SMP was to improve the roll prediction technique over the methods used in the SMSL program. It was observed from experiments that the roll transfer function at resonance exhibited nonlinear tendencies for a range of wave steepnesses: the steeper the wave, the smaller the roll-to-wave slope ratio. For example, Figure 11 shows this nonlinear characteristic for the DE-1006 without bilge keels as the wave steepness (wave height-to-wavelength ratio) is varied experimentally between 1/40 and 1/280. Two GM's are presented at a heading angle of 90 degrees (beam waves) and a ship speed of zero knots. Note that as the ratio becomes smaller, i.e., the waves become less steep, roll response increases. This is due to the nonlinear qualities of viscous roll damping. As wave steepness increases, the viscous damping also increases, thus dampening the roll motion. The SMSL program estimated this nonlinear effect, but is lacking in accuracy. The new SMP, though failing to predict exactly the nonlinear phenomenon for this ship, does come significantly closer than the SMSL program in modeling the viscous damping (see Figure 11) related roll nonlinearities at zero ship speed. SMP accounts for the roll nonlinearities solely by modeling nonlinearities associated with roll damping. Thus nonlinearities at extreme roll angles associated with the roll restoring moment are not included.

A second fact to be noted from the results of Figure 11 is that the severity of the roll nonlinearity is sensitive to GM variations. Both the predictions of SMP and SMSL as well as the experimental results clearly demonstrate that roll nonlinearity increases as GM decreases. The SMP results predict this experimental trend substantially better than do the SMSL results. Thus the DE-1006 would tend to experience substantially larger resonant rolling in small waves when ballasted to the smallest or "worst" GM, GM3, than would be the case for the same ship with the larger GM.

In addition to the nonlinear characteristics of roll at zero ship speed, there is also a speed effect on the roll nonlinearities. This effect is due both to the dynamic lift damping of the hull and appendages[2] as well as to the viscous damping.[8]

The speed effect is illustrated in Figure 12 for the DE-1006 without bilge keels in beam waves at the "worst" GM, GM3. The range of roll corresponding to the 1/50 and 1/200 range of wave steepnesses is shown for the experimental roll as well as for comparable predictions made with SMSL and SMP. The experimental range of roll is represented for a particular ship speed by a vertical line capped by a bar for a wave steepness of 1/200 at the top and a similar bar corresponding to a 1/50 wave steepness at the bottom. Continuous pairs of lines connect the 1/200 and 1/50 wave steepness roll predictions. The zero speed results of Figure 12 correspond to the GM3 data shown in Figure 11. Note, for example, the experimental roll of 7.7 and 17.0 corresponding to wave steepnesses of 1/50 and 1/200, respectively, are denoted in Figure 12 by the capped vertical line.

Both the experimental data and the SMP predictions indicate that roll and the nonlinear roll effects decrease very markedly with forward speed. A similar trend is not noted in the SMSL results. As the ship speed increases above zero knots, the roll damping due to lift tends to overshadow the decrease in the viscous damping[2] such that the total roll damping increases. This fact, in turn, tends to decrease both the roll response and the nonlinear effects due to viscous damping. SMP predicts this trend, although the severity of the decrease is overpredicted. The overprediction of lift damping for these conditions is considered to be the primary cause of the SMP inaccuracies. These inaccuracies are most pronounced at 9 knots and are relatively unimportant at the 18 and 27 knot speeds, where SMP slightly underpredicts roll. The SMSL program failed to take speed-dependent lift damping into account and thus shows a wider range of roll motion for all forward speeds. Note also the improvement, previously illustrated in Figure 11, in predicting nonlinear roll at zero speed between SMP and the SMSL program.

It should be recognized that the roll validation results discussed represent a very limited set of data primarily for a single hull. Further, in order to demonstrate potential inaccuracies of the SMP roll predictions, data which illustrates these inaccuracies is emphasized, i.e., attention is focused on the worst cases.

CONCLUDING REMARKS

In summarizing the results presented in this investigation, attention is drawn to the following remarks: (1) motion predictions are for a ship without thrusters proceeding on a straight course at constant speed; (2) model test data for certain motions should be viewed in light of the experimental techniques, effects of rudder activity and subsequent manipulations used to acquire the data; (3) analytical ship descriptions need to reflect precisely the actual model tested in order to make meaningful comparisons; (4) comparisons presented herein show relatively good agreement, particularly for pitch and heave; (5) improved damping prediction techniques have resulted in a more accurate description of roll with respect to speed; however, overprediction of damping and an unexplained frequency shift remain to be satisfactorily resolved between analytical and measured data; (6) many more comparisons with a variety of ship types need to be performed before the SMP motion validation is complete.

RECOMMENDATIONS

Additional ship motion validation experiments should be performed in order to improve the existing computational techniques in the areas of roll damping, roll motions, as well as relative motions.

The validation experiments should concentrate on the measurement of eddymaking and lift damping of major appendages such as rudders and skegs for low to moderate ship speeds. Further, the lateral ship response validation experiments need to focus on establishing the causes of the overpredicted frequency shift at higher ship speeds. In this context, the validation experiments should measure both the rudder activity as well as the rudder-induced roll, yaw moment, and sway force. Clearly, the experiments need to measure not only the lateral ship responses and wave height but should also measure the rudder excitation.

Future motion validation should also be extended into long-crested irregular seas of different wave heights and modal wave periods.

REFERENCES

1. Meyers, W.G. et al., "NSRDC Ship-Motion and Sea-Load Computer Program," Naval Ship Research and Development Center Report 3376 (1975).

2. Baitis, A.E. et al., "Validation of the Standard Ship Motion Program, SMP: Improved Roll Damping Prediction," Report DTNSRDC/SPD-0936-02 (Jun 1981).

3. Baitis, A.E. and R. Wermter, "A Summary of Oblique Sea Experiments Conducted at the Naval Ship Research and Development Center," 13th International Towing Tank Conference (1972).

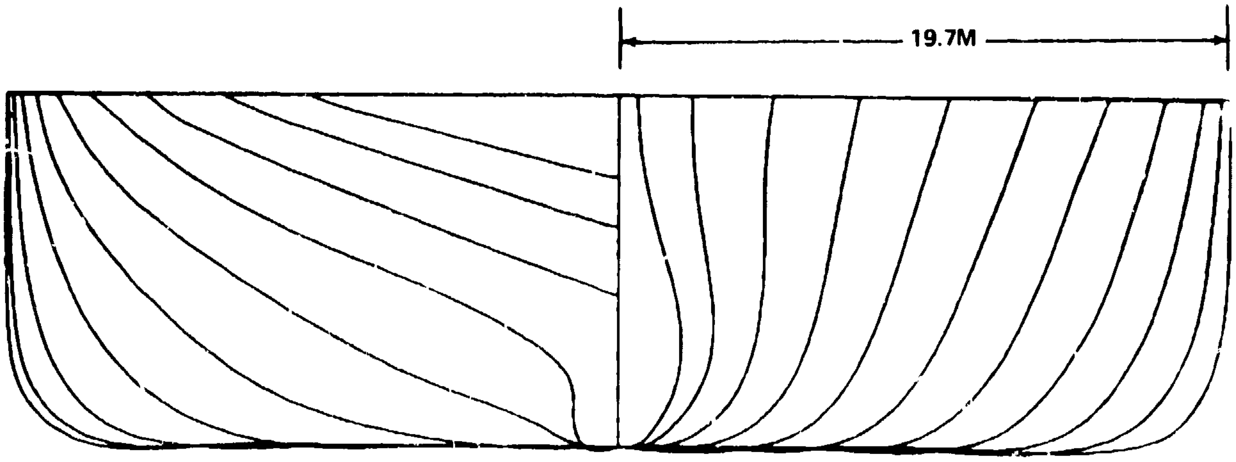
4. Wachnik, Z.G. and E.E. Zarnick, "Ship Motions Prediction in Realistic Short-Crested Seas," Society of Naval Architects and Marine Engineers Annual Meeting (Nov 1965).

5. Bales, S.L. et al., "Rigid Body Ship Responses and Associated Periods for a Series of Liquid Natural Gas (LNG) Ships," Naval Ship Research and Development Center Report SPD-517-04 (Apr 1975).

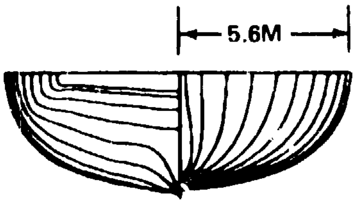
6. Baitis, A.E. and T.R. Applebee, "Comparisons Between Measured and Predicted Surge, Sway, and Yaw for LCU 1610 and FF 1006," Report DTNSRDC/SPD-694-01 (Jun 1976).

7. Cox, G.G. and A.R. Lloyd, "Hydrodynamic Design Basis for Navy Ship Roll Stabilization," Society of Naval Architects and Marine Engineers Annual Meeting (Nov 1977).

8. Ikeda, Y. et al., "Components of Roll Damping of Ship at Forward Speed," Journal of the Society of Naval Architects of Japan, Vol. 143 (1978).



CVA-59



DE-1006

Figure 1 - Computer-Generated Body Lines for the CVA-59 and DE-1006 Ship Hulls

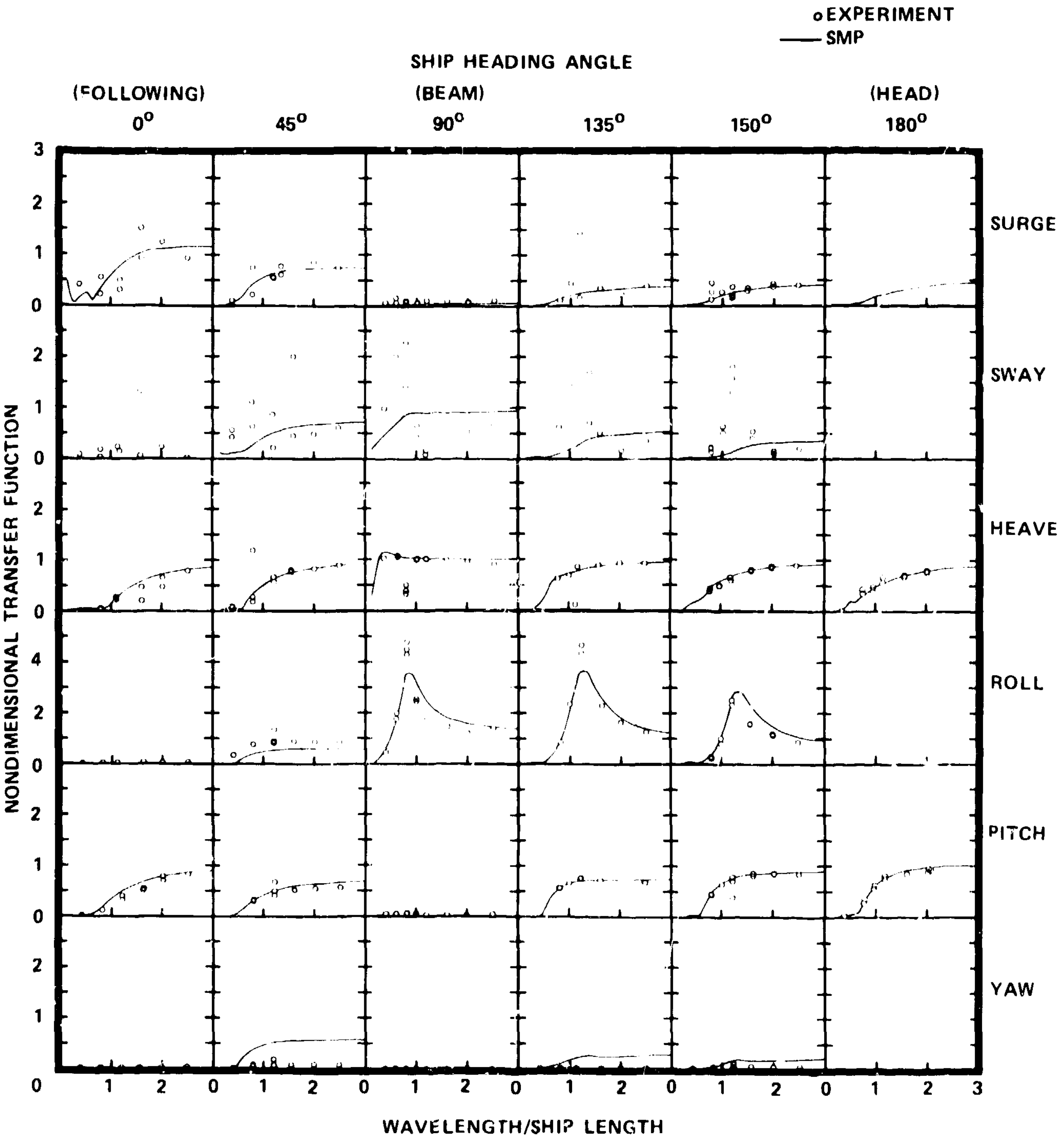


Figure 2 - Comparison of Measured and Predicted Nondimensional Transfer Functions for the DE-1006, GM1, BK1, at 9 Knots (F_n = 0.15)

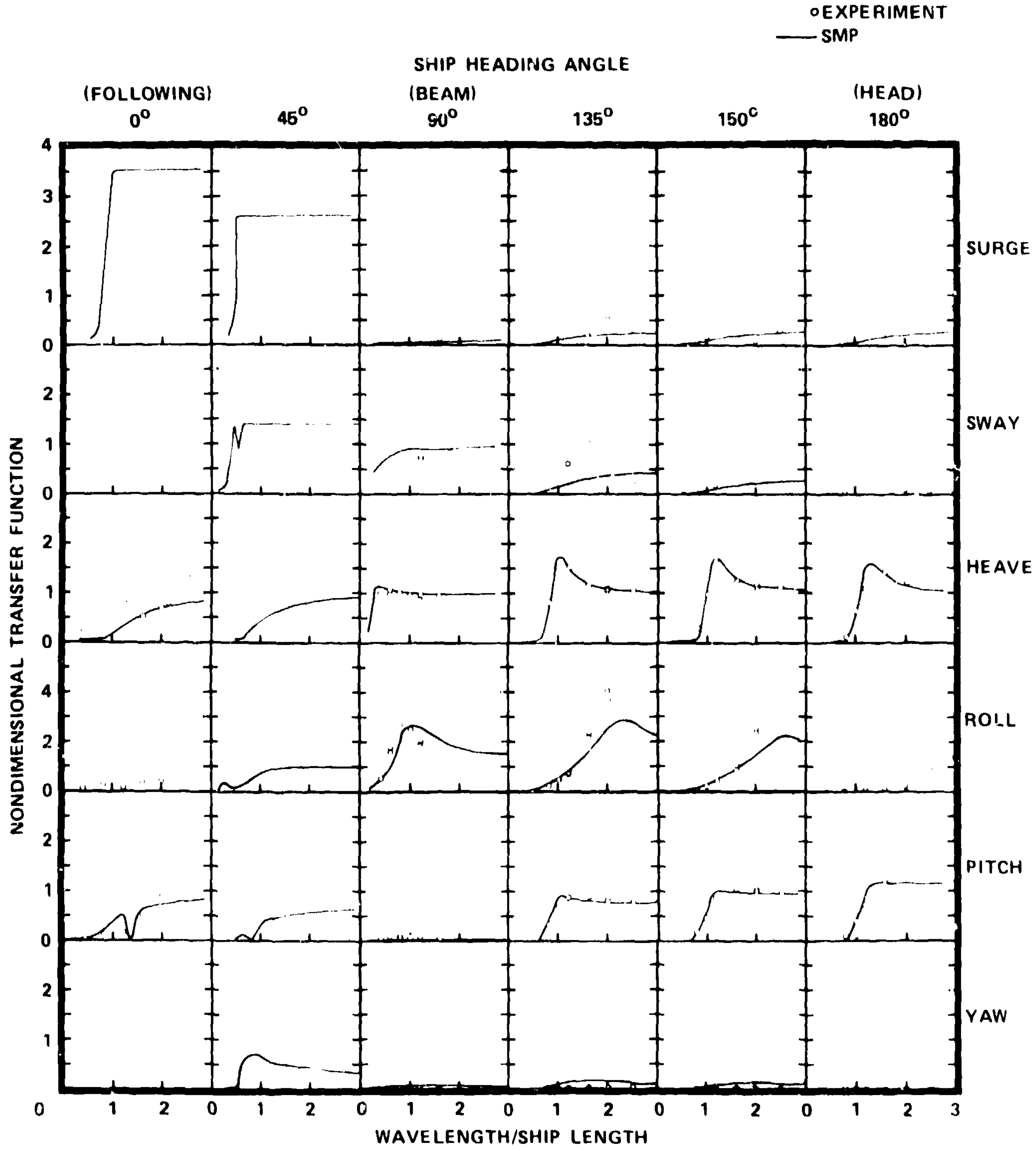


Figure 3 - Comparison of Measured and Predicted Nondimensional Transfer Functions for the DE-1006, GM1, BK1, at 27 Knots (F_n = 0.46)

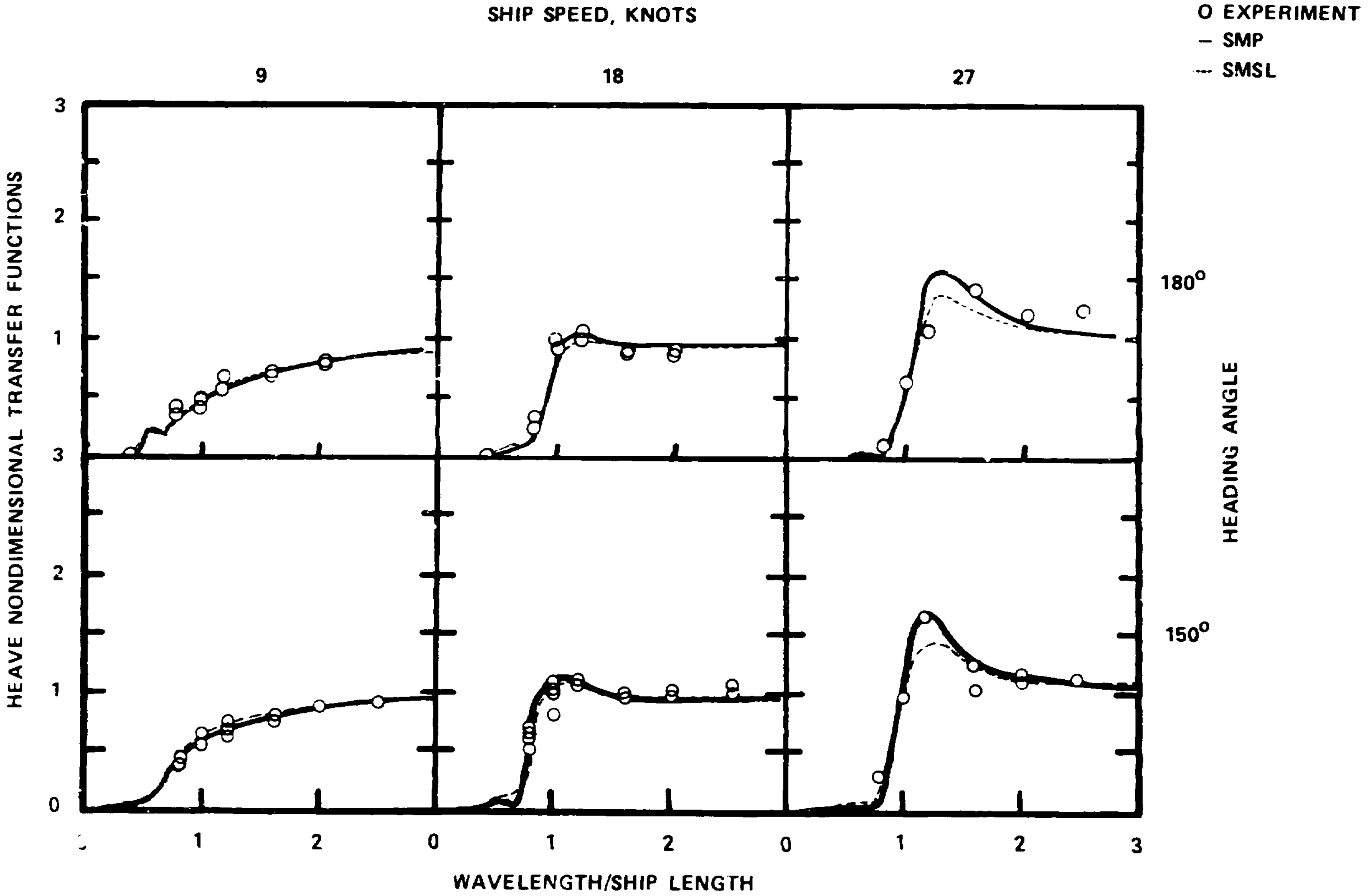


Figure 4 - Comparison of Measured and Predicted Nondimensional Heave Transfer Functions Across Speed for the DE-1006, GM1, BK1, in Bow Waves

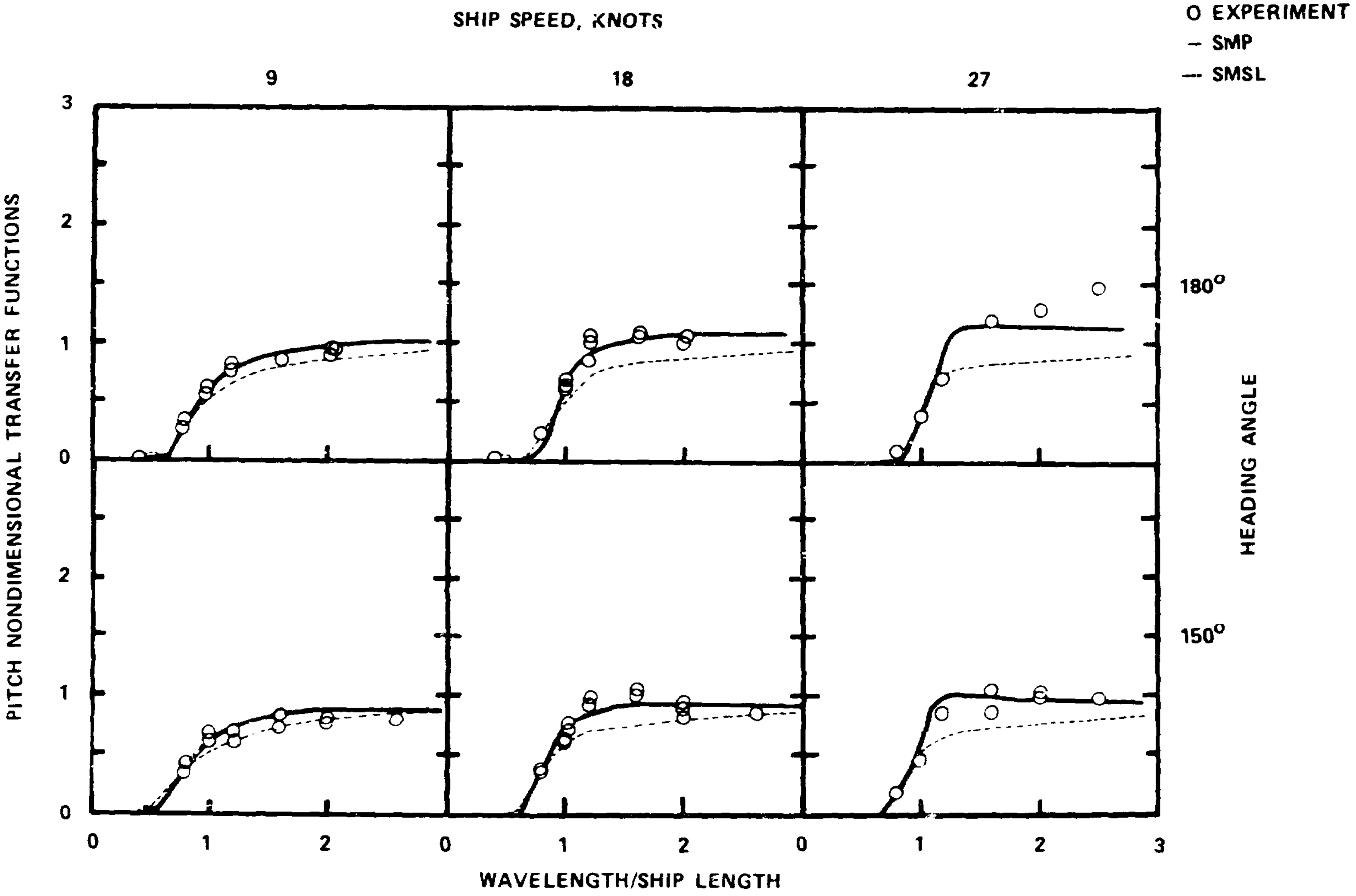


Figure 5 - Comparison of Measured and Predicted Nondimensional Pitch Transfer Functions Across Speed for the DE-1006, GM1, BK1, in Bow Waves

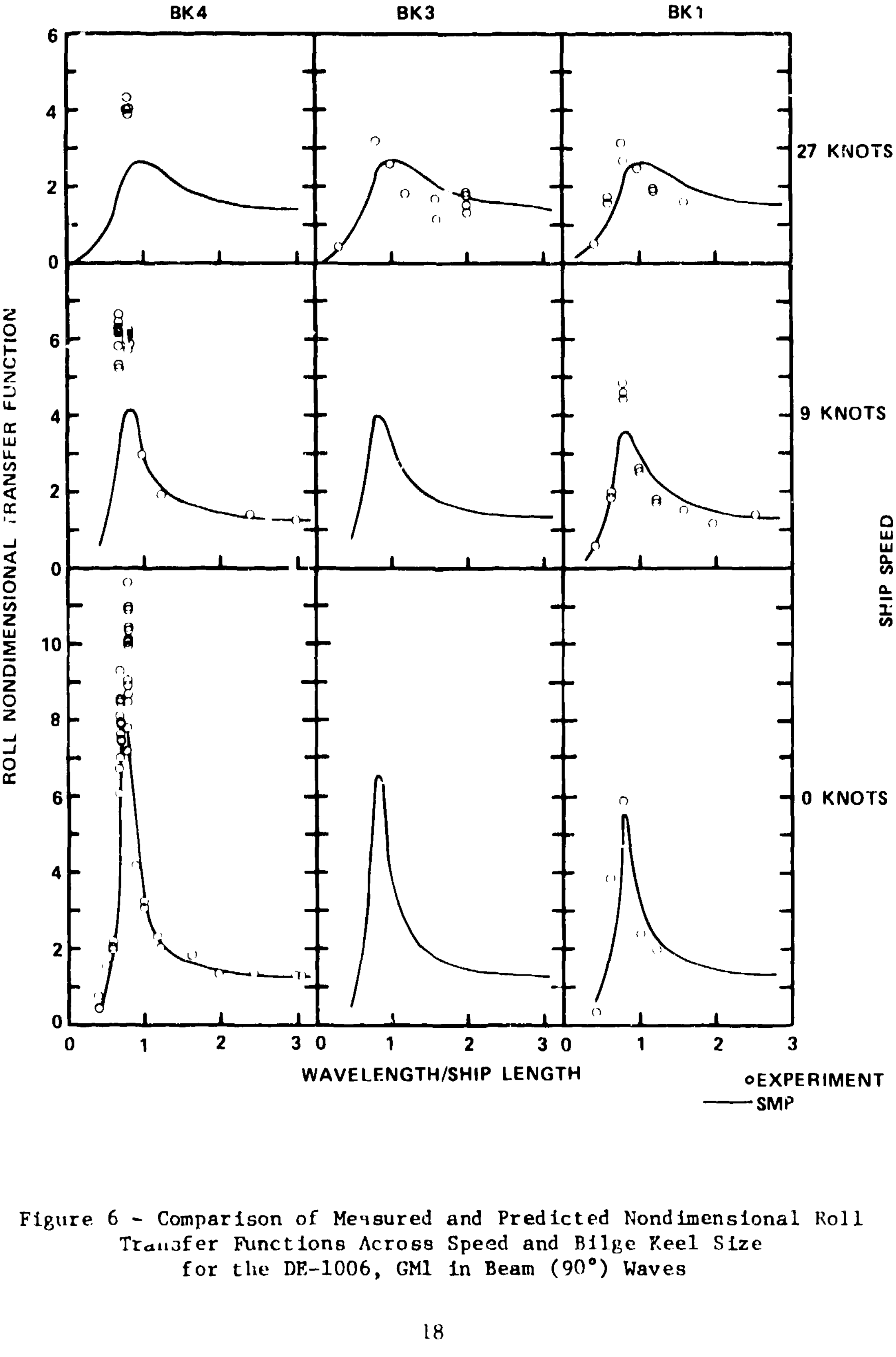


Figure 6 - Comparison of Measured and Predicted Nondimensional Roll Transfer Functions Across Speed and Bilge Keel Size for the DE-1006, GM1 in Beam (90°) Waves

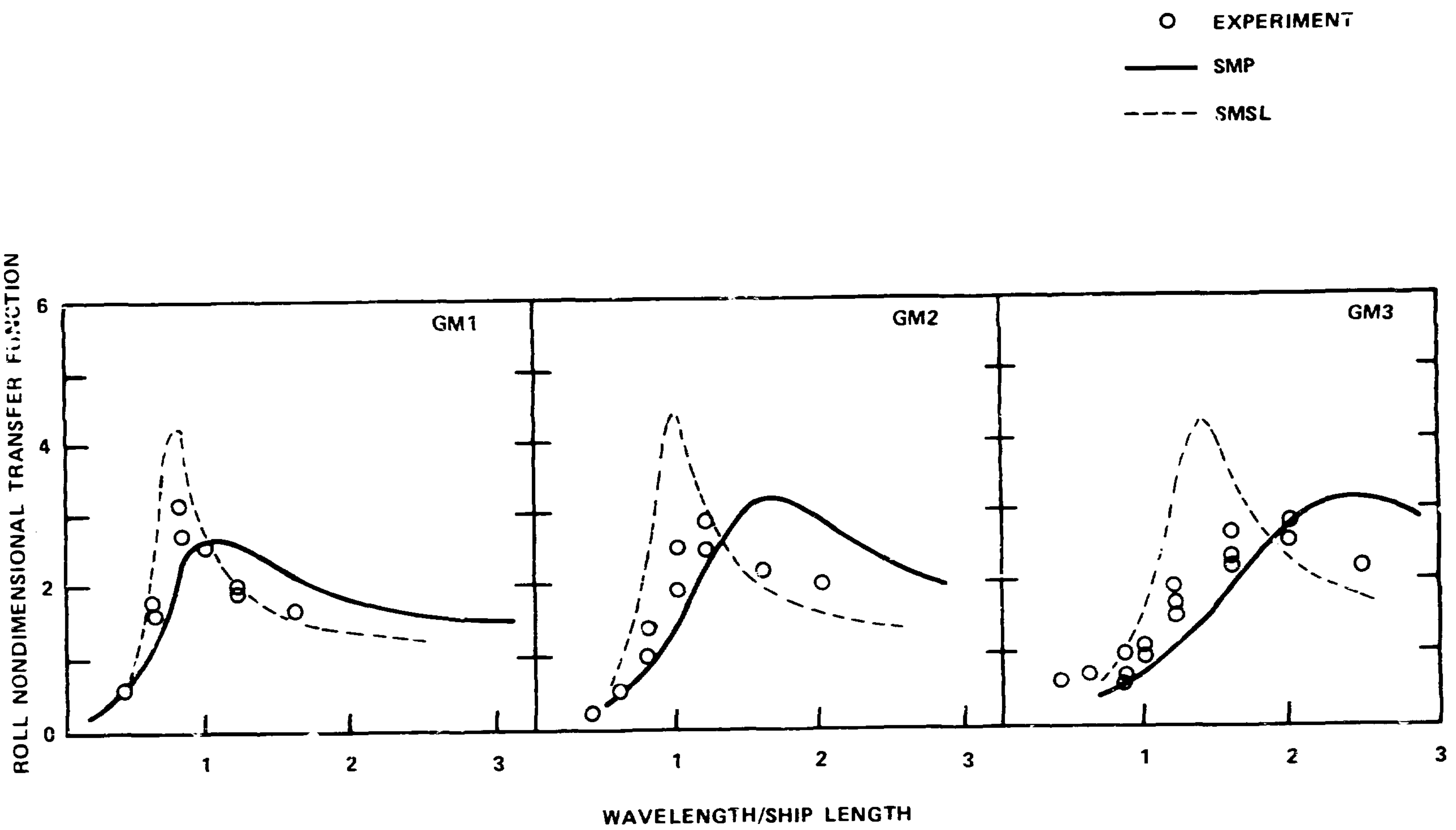


Figure 7 - Comparison of Measured and Predicted Nondimensional Roll Transfer Functions for the DE-1006 at Three GM Values, BK1, 27 Knots ($F_n = 0.46$) in Beam (90°) Waves

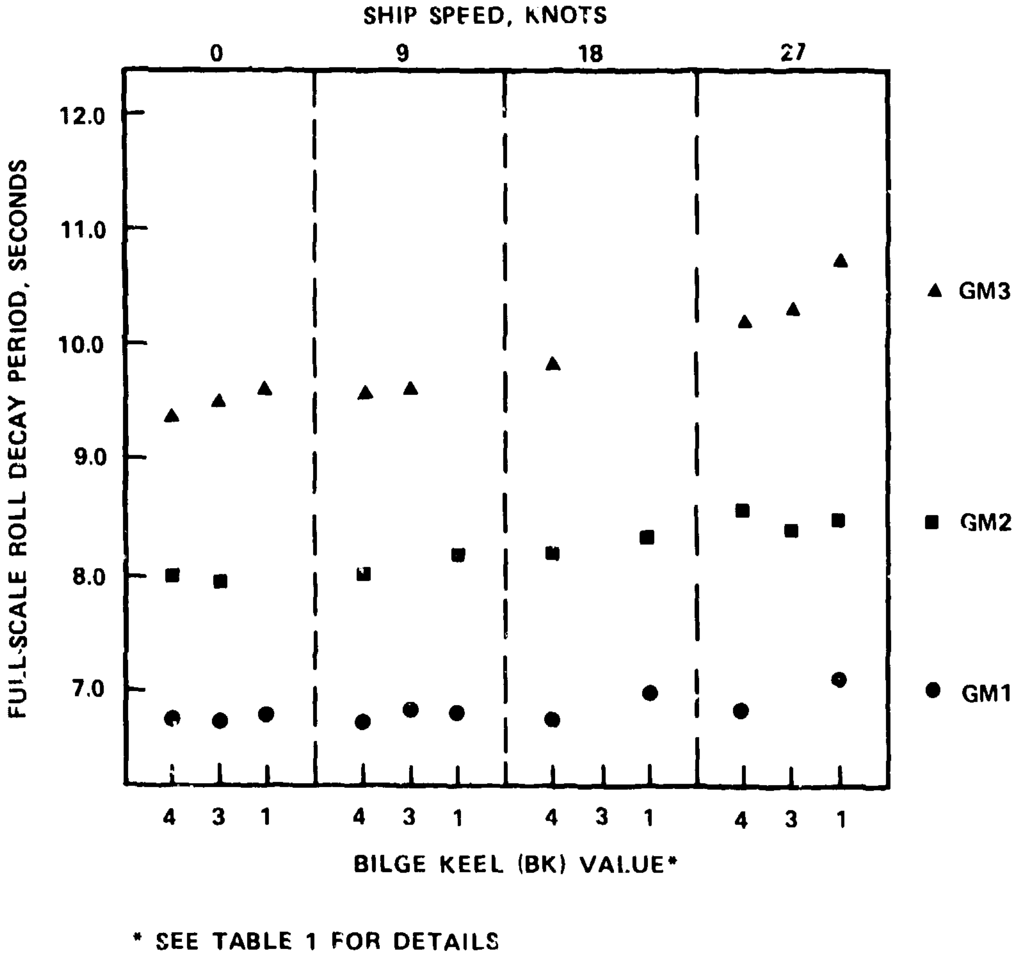


Figure 8 - Variations in the Measured Roll Periods for the DE-1006 at Three GM Values, Three Bilge Keel Configurations, Across Speed

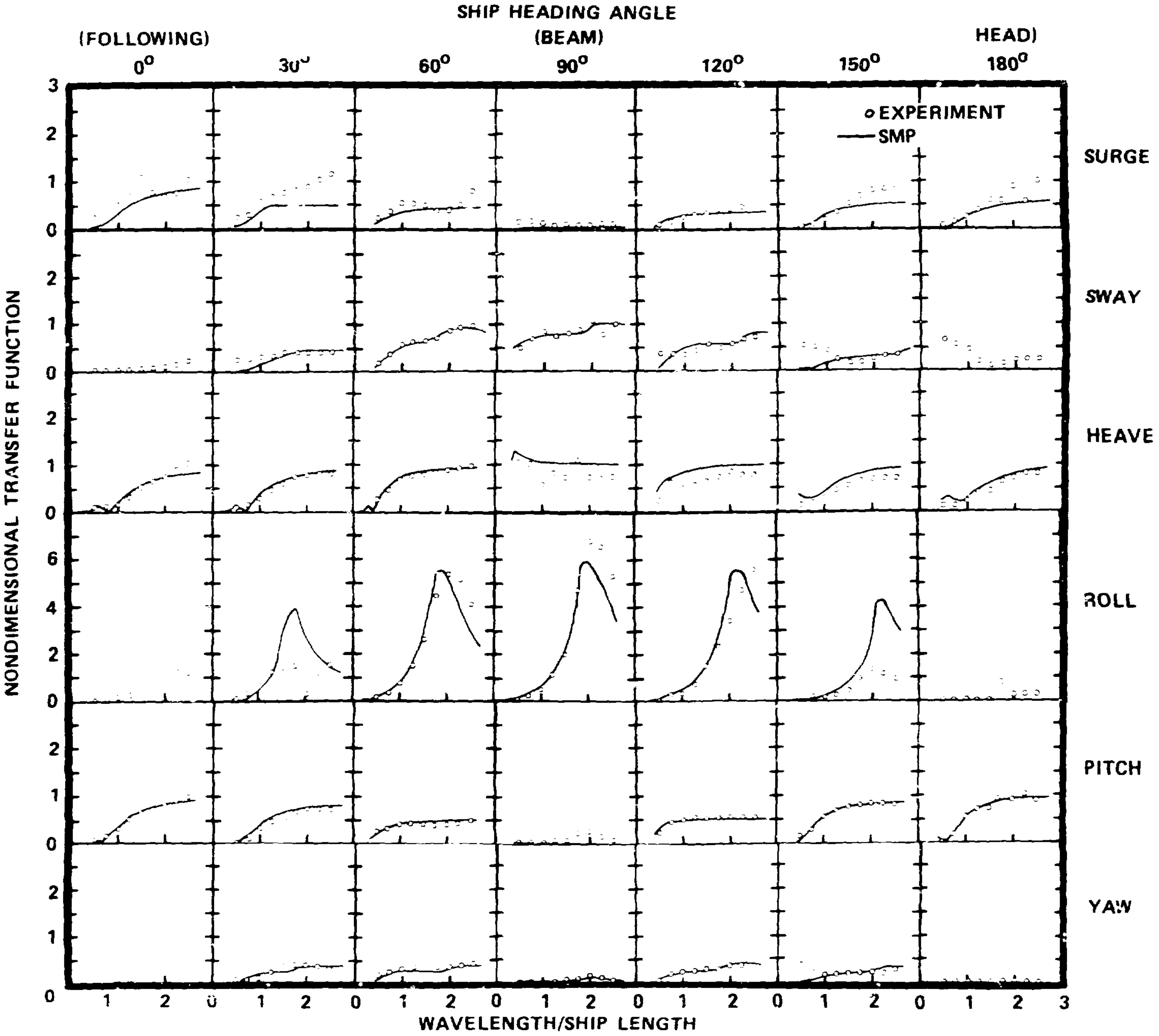


Figure 9 - Comparison of Measured and Predicted Nondimensional Transfer Functions for the CVA-59 at 5 Knots ($F_n = 0.05$)

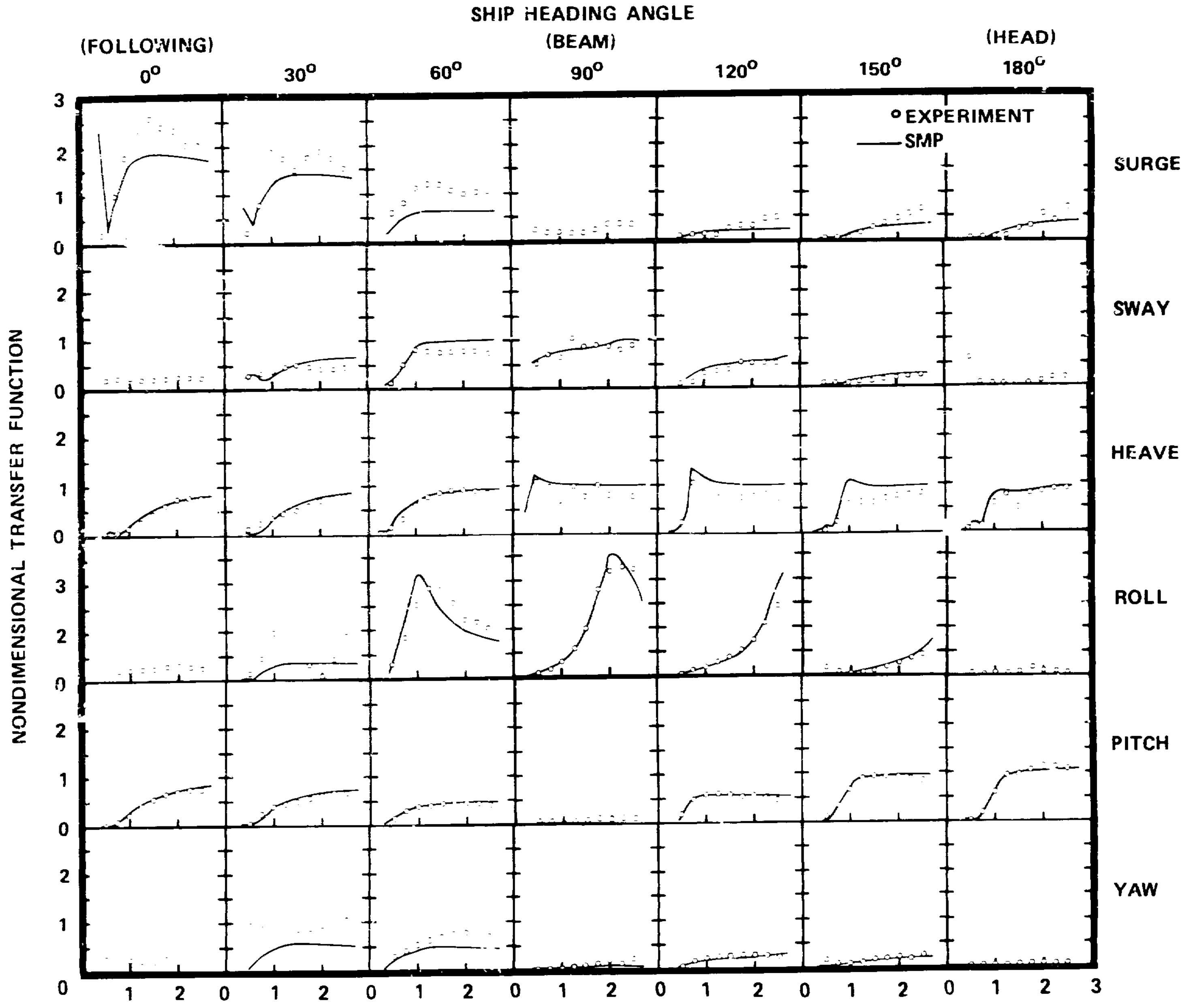


Figure 10 - Comparison of Measured and Predicted Nondimensional Transfer Functions for the CVA-59 at 25 Knots (F_n = 0.24)

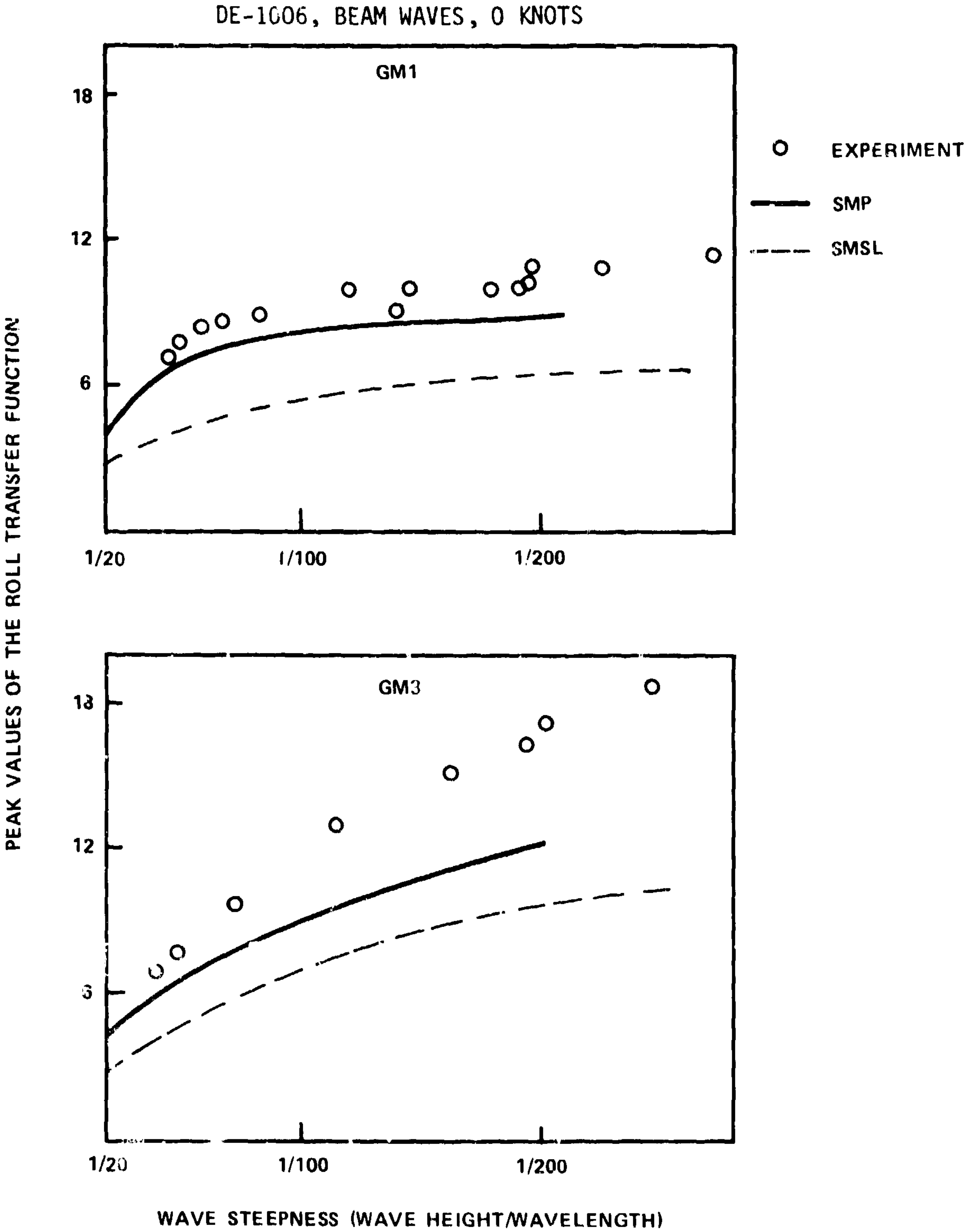


Figure 11 - Comparison of Measured and Predicted Nondimensional Roll Transfer Functions as an Example of Nonlinear Roll at Resonance for the DE-1006 Without Bilge Keels

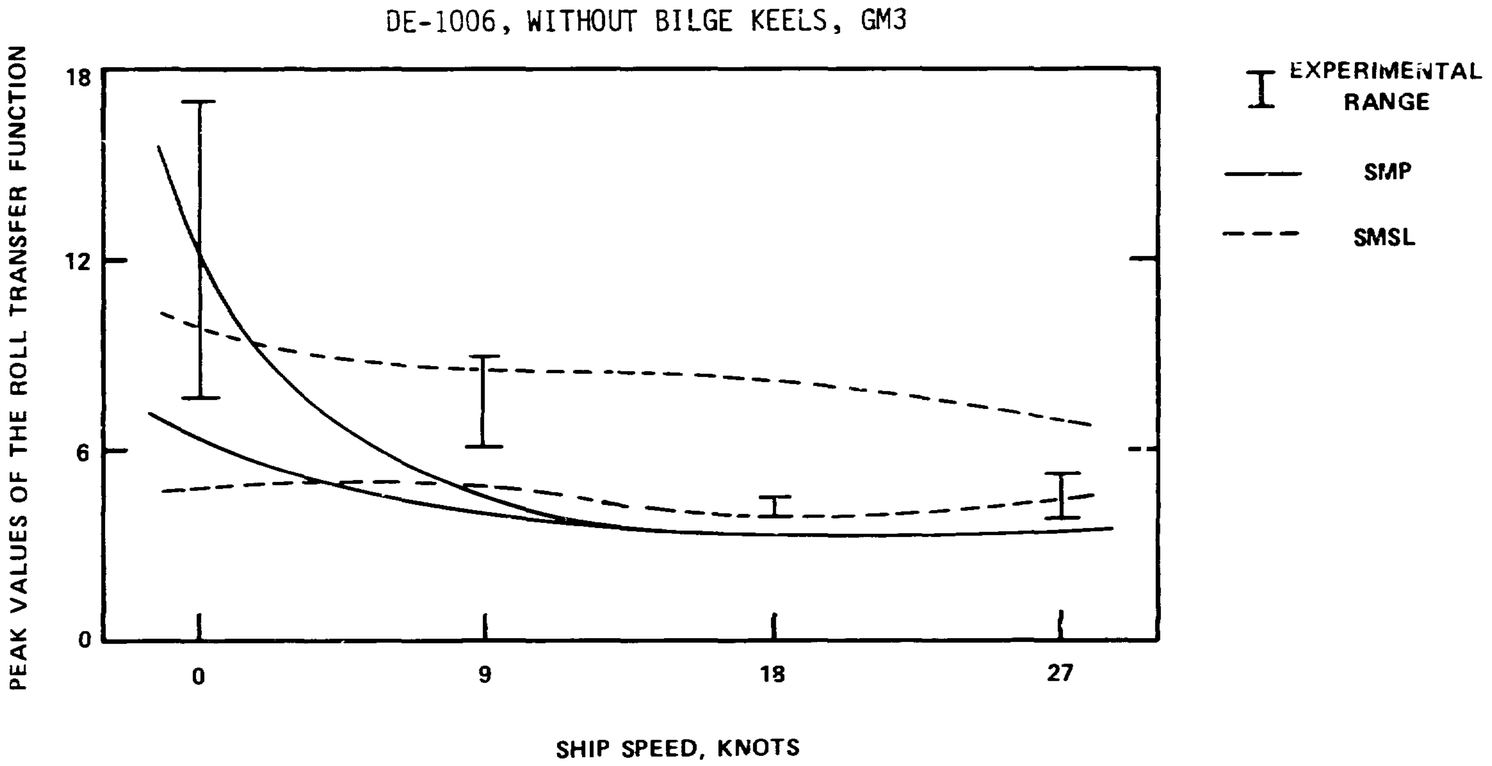


Figure 12 - Comparison of Measured and Predicted Nondimensional Roll Transfer Functions for the DE-1006 Showing Speed Effect on Roll Nonlinearities in Beam Seas

Table 1 - Table of Ship Particulars

	DE-1006		CVA-59	
	Model	Computer Full-Scale	Model	Computer Full-Scale
Length (L_{PP}), meters	5.54	93.9	4.57	301.8
Beam (B), meters	0.66	11.1	0.60	39.4
Draft (T), meters	0.22	3.7	0.17	10.9
Displacement (Δ) S.W., metric tons	0.38	1835.0	0.26	74487.0
LCG*	0.515 L_{PP}	0.517 L_{PP}	0.517 L_{PP}	0.517 L_{PP}
Pitch Gyradius (K_{θ})	0.249 L_{PP}	0.249 L_{PP}	0.251 L_{PP}	0.251 L_{PP}
Block Coefficient (C_B)	0.485	0.510		0.600
Metacentric Height (GM1)**	0.121 B	0.121 B	0.097 B	0.095 B
(GM2)	0.090 B	0.090 B	-	-
(GM3)	0.060 B	0.060 B	-	-
Bilge Keel Length (BK1)**	0.296 L_{PP}	0.296 L_{PP}	0.315 L_{PP}	0.315 L_{PP}
(BK3)	0.170 L_{PP}	0.170 L_{PP}	-	-
(BK4)	None	None	-	-
Linear Scale Ratio (λ)	16.94	-	66.00	

* Referenced to F.P.
**Base Ship Condition

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