ARTICLE NO. 79-4107

Seakeeping Quality of Advanced Marine Vehicles for Design Applications

M. D. Ochi* and D. D. Moran†
David W. Taylor Naval Ship Research and Development Center, Bethesda, Md.

The results of experiments concerned with linearity in the pitch, heave and roll motions of air-cushion-supported vehicles are presented. Response linearity is demonstrated through regular wave response data with varying wave amplitude at a fixed frequency of encounter. Regular wave seakeeping transfer functions are correlated with spectral analysis results from irregular seas. Response operators are applied to appropriate sea spectra to demonstrate the response of the vehicles in a seaway. Finally, a vertical plane frequency domain simulation based upon captive model results shows reasonably good correlation with regular wave seakeeping transfer functions.

Nomenclature

a = wave amplitude
A = cushion area
A_{ij} = added mass or inertia coefficient
B = bag
B_e = effective beam
B_{ij} = damping coefficient
B_{oa} = beam overall
C_{ij} = restoring coefficient
F = finger
FLS = full length sidewall
F_i = wave exciting force in the ith mode
F_n = Froude number
g = gravitational constant
I_i = mas moment of inertia about the ith mode axis
ka = wave slope
L_c = cushion length
L_{oa} = length overall
m = displacement
M = heave added mass
p_c = cushion pressure
P = planing
PC = peripheral cell
PLS = partial length sidewall
SF = sealed fingers
λ = wave length
ξ = response variable
ρ = density of cushion fluid
ω_e = frequency of encounter

Introduction

THE primary purpose underlying the development of air-cushion-supported ships in recent years has been the attainment of high speed. The design of these ships, therefore, has been largely dictated by considerations of ship resistance and powering capabilities. Static pitch, roll and heave stiffness are important design considerations, but the dynamic performance of the vehicles has been examined primarily as a post-design characteristic. Direct irregular wave experimentation, on the one hand, or application of superposition theory to regular wave results on the other, are both applicable to the problem of motion prediction of air-cushion-supported ships. The question to be resolved in the latter case is the extent to which these craft may be accepted as linear systems. Justification of the application of superposition to air-cushion-supported ships is only necessary when linearized analytic methods are applied to motions prediction. The major impediment to the inclusion of seakeeping performance in the direct design process for air-cushion ships has been the relatively small base of data and experience compared with that available to surface ship designers and the lack of evidence of the extent to which accepted seakeeping performance procedures can be applied to these vehicles. It is shown here that the seakeeping characteristics of an air-cushion-supported ship in irregular seas may be examined through techniques which are well known from displacement-ship seakeeping technology, employing the superposition principle first applied to ship dyanmics by St. Denis and Pierson.[1]

Analysis Techniques

Prediction of nonlinear seakeeping behavior of air-cushion-supported ships can be obtained through direct time domain analysis of the physical systems which interact to produce the experimentally observed response to the known time-dependent wave excitation. Verification of system linearity is not necessary as long as the mathematical models formulated to describe the various functions of the dynamic system are shown to be valid. The technique can be applied to either regular or irregular excitation, but since the method is inherently nonlinear, the most fruitful analysis concerns irregular wave response. The first motion simulation model of this type for air-cushion-supported craft was developed by Kaplan et al.[2-4] to represent low length-to-beam ratio prototype rigid sidewall craft.

Similar numerical formulations for fully skirted air-cushion vehicles have been published in recent years. Doctors[5] has developed a two-degree-of-freedom nonlinear model which incorporates the effects of cushion air compressibility and presents a solution for the free surface compliance. A three-degree-of-freedom model has been developed by Moran[6] to predict the overland dynamic response of fully skirted craft. Similar problems have been treated by Lavis et al.,[7] by Schneider and Bono[8] and by the Bell Aerospace Co.,[9] for overland dynamic simulation. In general, the validity of time domain analytic modeling for advanced marine vehicles is dependent upon the accuracy of the mathematical modeling of the cushion system.

Alternatively, the ship motion problem may be solved in the frequency domain using linearized thory. Analytic prediction of regular wave seakeeping response for displacement ships

Received March 28, 1978; revision received Feb. 8, 1979.

Index categories: Hydrodynamics; Marine Hydrodynamics, Vessel and Control Surface; Marine Vessel Design (including Loads).

*Supervisory Naval Architect, Ship Performance Department.
†Research Naval Architect, Ship Performance Department.

Table 1 Model descriptions

	Model R	Model K	Model A	Model B
Type of side cushion seal	*FLS*	*PLS*	*B+PC*	*PLS*
Type of bow cushion seal	*P*	*B+F*	*B+PC*	*P*
Type of stern cushion seal	*P*	*P*	*B+SF*	*P*
Cushion compartmentation	No	No	No	No
Active cushion control	No	No	No	Yes
Hydrodynamic motion control	No	Yes	No	Yes
Lift parameter $p_c A/m$	0.81	0.97	1.08	0.87
Length/beam A/B_e^2	1.87	2.20	1.78	1.97
Cushion block coefficient $A/B_e L_c$	1.00	0.95	0.98	0.88
Cushion density $p_c/\rho g L_e$	14.77	15.28	13.43	17.32
Loop/cushion pressure				
Bow	1.27	1.54	1.35	1.40
Stern	1.29	1.21		1.31
Gyrad/cushion length				
Pitch	0.34	0.29	0.30	0.32
Roll		0.15	0.17	0.23

Table 2 Equivalent full-scale ships

	Model R	Model K	Model A	Model B
Displacement, m, mtons	340	305	259	317
L_{oa}, m	37.2	36.0	35.1	34.4
L_e, ft	100	100	100	100
m	30.5	30.5	30.5	30.5
B_{oa}, m		16.2	18.3	17.1
B_e, m	13.7	14.6	17.4	14.9
Cushion depth, m	2.9	2.9	1.8	3.0

was initiated by Korvin-Kroukovsky and Jacobs,[10] who pioneered the development of a strip theory which has been modified most notably by Gerritsma and Beukelman.[11] This theory has become the seed material for such new theoretical formulations as the slender body theory of Ogilvie and Tuck[12] and the work of Salvesen et al.[13] No similar theoretical formulations exist to describe the seakeeping motions and loads of air-cushion-supported ships, except to the extent that the linearized theory may be applied to the prediction of sidewall hydrodynamic loads. Prediction of frequency domain response may also be achieved through the application of a data-based method (Ref. 14), which avoids the difficulties of analytic determination of hydrodynamic inertial and damping coefficients (or stability derivatives) by employing quantities obtained through pitch-heave oscillation and captive-model wave excitation experiments. The stability derivatives appear as coefficients in the set of differential equations which describes the motion of the vehicle. This method is directly applicable to the prediction of the frequency domain motion response characteristics of air-cushion vehicles and has, in fact, been implemented successfully for a high length-to-beam ratio hard-sidewall craft by Moran et al.[15] In the following sections, a nonlinear time domain analysis and the linearized data-based technique outlined above are applied to a known set of experimentally derived stability derivatives, and the resultant response operators are compared with those obtained from model seakeeping experiments in the tow tank.

The principle of linear superposition states that "the sum of the responses of a ship to a number of sine waves is equal to the response of the ship to the sum of the waves." In its application, it is necessary to determine the transfer functions which are nondimensionalized values of the ship response to a series of regular waves of different frequency. It is customary to express these functions as squared values (so-called response amplitude operators or RAO's) to permit their direct multiplication by points on the wave spectrum. The area under the spectrum can be used to estimate the important statistical characteristics associated with the motion of the vehicle in the specific sea state.

The transfer functions may be determined either analytically or by carrying out seakeeping experiments. In the present paper, they are obtained for several craft by conducting seakeeping experiments in both regular and irregular waves; in addition, for one craft they are obtained through both a linearized frequency domain analysis and a nonlinear time domain analysis.

Seakeeping Experiments

There are two experimental methods which can be used to examine response linearity. The first method employs a direct comparison of experimental response in irregular seas with the response predicted using regular wave response operators and the known sea spectrum. The second method is to examine the linearity by performing regular wave seakeeping experiments for a variety of wave amplitudes at a fixed frequency using the pitch or roll resonant frequency. In the following sections, regular and irregular wave transfer functions obtained from seakeeping experiments on several air-cushion-supported vehicles are compared, and an assessment is made of the degree of linearity in their responses.

Experiments were carried out on models of several air-cushion-supported vehicles to obtain their response characteristics in waves and to determine the extent to which their response is linear or nonlinear. The vehicles chosen for investigation in this review encompass a variety of designs for air-cushion-supported ships. Three of these models have hard sidewalls with seals fore and aft and are identified in Table 1 as models B, R, and K. The fourth has a cellular peripheral-jet-type skirt system and is identified in the table as model A.

Six nondimensional characteristic parameters can be employed to quantitatively classify an air-cushion vehicle configuration, and six qualitative descriptors aid in the understanding and interpretation of the seakeeping performance of the vehicle. These twelve descriptors are given for the four craft in Table 1. Full-scale dimensions for a 100-ft (30.5-m) prototype corresponding to each of the four models are listed in Table 2. The overall geometry of the vehicle is characterized by the length-to-beam ratio, based upon an effective cushion length whose definiton is required, since most air-cushion-supported vehicles are longitudinally prismatic but may have curved bow and stern seals.

Linearity in the dynamic response of an air-cushion-supported craft is greatly influenced by the existence of cushion compartmentation and active cushion pressure control. These two items are required qualitative descriptors of such craft. Active cushion control may take the form of a pressure relief valve implemented on the full-scale craft represented by model B as a heave alleviation system, or of an active flow valve directing cushion fluid to individual regions of the cushion as required. Active cushion control was not employed

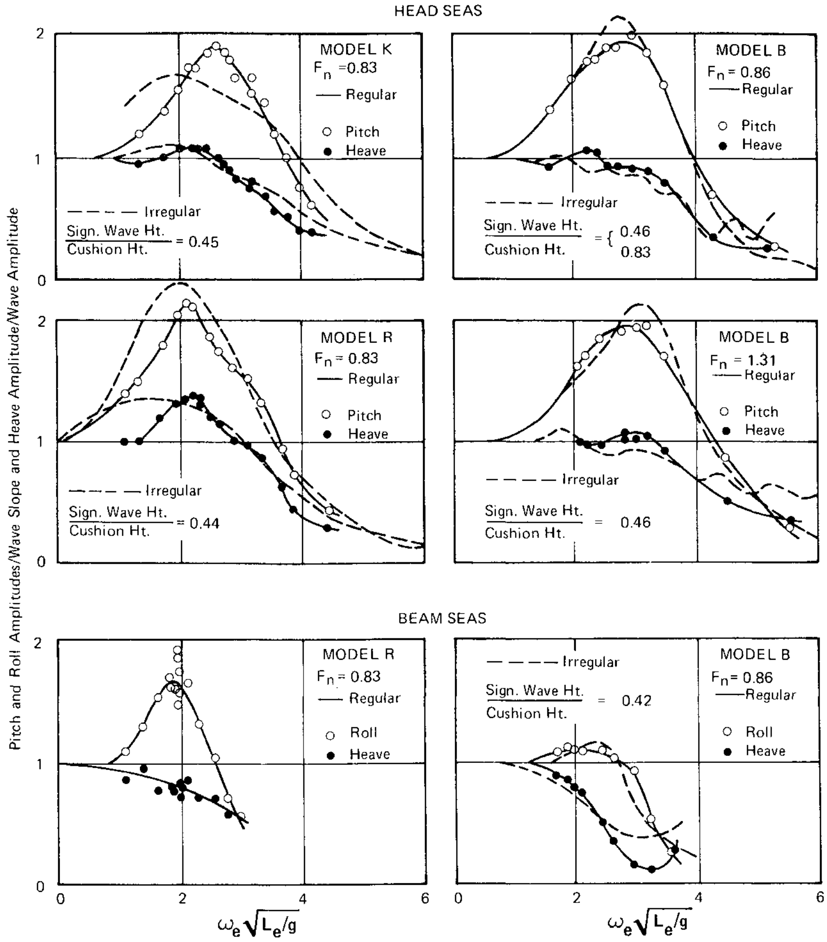

Fig. 1 Transfer functions measured in regular and irregular waves for rigid sidewall craft.

in the experiments on the models. In addition to the active cushion control, some air-cushion craft designs are appropriate for hydrodynamically or aerodynamically induced motion control.

Model experiments for the four craft identified in Table 1 were performed in regular and irregular head and beam waves in which the pitch, heave and roll motions were measured. Wave lengths examined generally ranged from about one to six times the model length. A wave length to wave height ratio ($\lambda/2a$) of 80 to 100 was used in the regular wave tests. The wave height was varied for the wavelength producing maximum response of the transfer function to examine the linearity of the response. For this, the range of $\lambda/2a$ was varied from about 30 to 300. Waves that are of practical interest are obviously the steeper waves. Generally, in a physical environment, most waves will not have an inverse wave slope much greater than 80. The examination of inverse wave slopes greater than 100 (up to 300) is of interest, however, in the determination of the asymptotic nature of air-cushion-supported craft response to assess the viability of linear modeling.

The dissimilarity between the transfer functions derived from mild regular waves and irregular wave excitation of a given severity is a measure of response linearity. The irregular seas in which the majority of these tests were carried out on the rigid sidewall craft had significant wave heights of slightly less than one-half cushion depth, though a more severe case was investigated for model B where the significant height was about 0.83 cushion depth. The irregular seas for model A were quite severe with a significant wave height to cushion depth ratio of 1.3 to 1.4.

Figure 1 shows the pitch, heave, and roll transfer functions for the hard sidewall craft in head and beam seas as a function of the frequency of encounter ω_e, normalized by $\sqrt{L_e/g}$ where g is the gravitational constant. These results are primarily for a Froude number (F_n) equal to 0.8, though results are also included for a higher speed ($F_n = 1.3$) for model B. Figure 2 shows similar results for model A at a Froude number of 1.13.

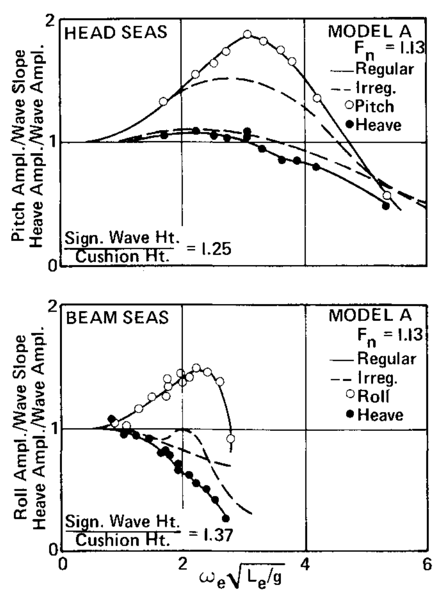

Fig. 2 Transfer functions measured in regular and irregular waves for peripherally skirted craft.

The pitch and roll transfer functions clearly demonstrate the underdamped character of the systems, although roll shows the underdamped character less than pitch. Roll for model B, for instance, is much more highly damped than it is for model R. The form of the transfer functions in heave

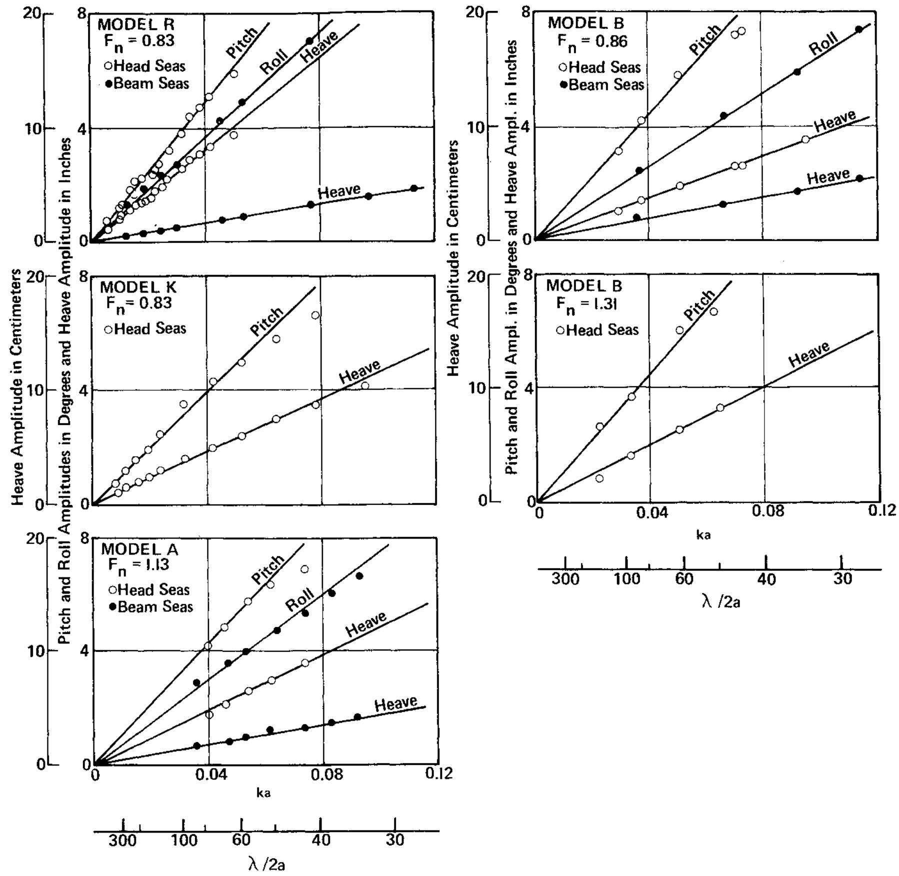

Fig. 3 Regular wave motion linearity at resonance.

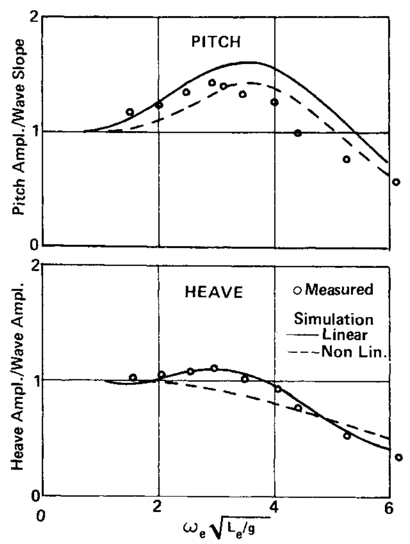

Fig. 4 Correlation of simulated motions with measurements for model A, $F_n = 1.13$.

indicates that the dynamic responses of the craft are overdamped in heave, with the exception of model R, in head seas. The peak responses for each of the three modes of motion occur roughly at the same nondimensional frequency for all four craft, and the magnification at the peak response frequency in pitch for all models is of the order of 2.0. Increasing speed to a Froude number of 1.31 for model B had no effect on the pitch and heave transfer functions. The overall agreement between the irregular wave and regular wave transfer functions for the hard sidewall craft is, in general, considered very good, though the irregular wave transfer function for model K indicates a peak less in magnitude and lower in frequency than the regular wave transfer function. The transfer functions do show increasingly better agreement at the higher frequency. It is evident, however, that the curves for both pitch and roll of model A are dissimilar. The irregular wave results indicate a classical nonlinear system wherein the transfer function decreases with increasing severity.

It may be well to relate the severity of the irregular seas in which the transfer functions were obtained to the real environment. If one considers a 100-ft (30.5-m) prototype, which is the approximate size of existing craft, the significant wave height at which the majority of the experiments were carried out corresponds to a mid- to high-Sea State 3 with a more severe Sea State 5 also included for model B in head seas. No degradation in the pitch and heave transfer functions was observed in this more severe sea state. For model A, the sea severity corresponds to a Sea State 5. Here the heave motion is still linear, but the pitch and roll motions show marked nonlinearity. It should be noted that the Sea State 5 is comparatively more severe for model A than for model B, in that the significant wave height is 30 to 40% greater than the cushion depth for the former while it is less than the cushion depth for the latter.

The results of the linearity experiments in regular waves performed at the peak motion-response encounter frequency are presented in Fig. 3. This figure shows the pitch, heave, and roll amplitudes vs wave slope, for constant wave length and speed. It is apparent that the heave and roll motions increase linearly with increasing wave height throughout the range of wave heights examined. The pitch motion, on the other hand, shows a constant relationship with wave height up to an inverse wave slope ($\lambda/2a$) of 45 and then shows mildly nonlinear behavior for $\lambda/2a<45$. In general, the air-cushion-supported ships tested may be considered to respond approximately linearly to regular wave excitations at the wave lengths and speeds investigated for steepnesses of the order of 30 to 40 or greater. The limiting criterion, however, appears to be the height of the wave in relation to the cushion depth.

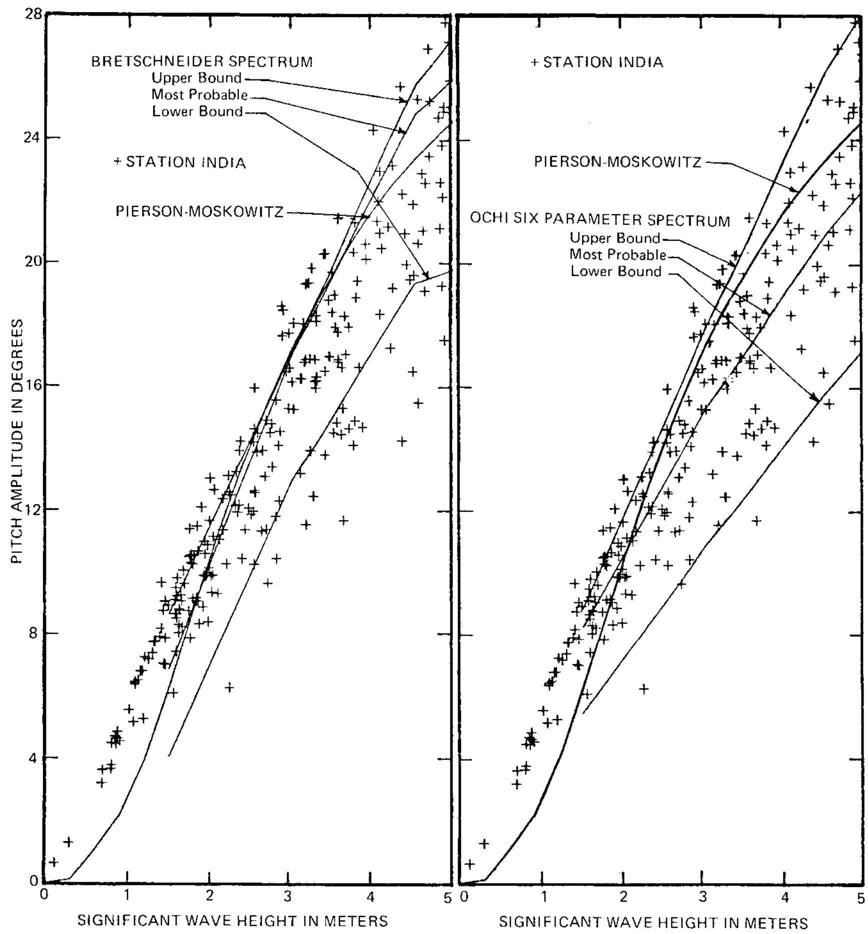

Fig. 5 Probable extreme pitch amplitudes for model B, head seas, $F_n = 0.86$.

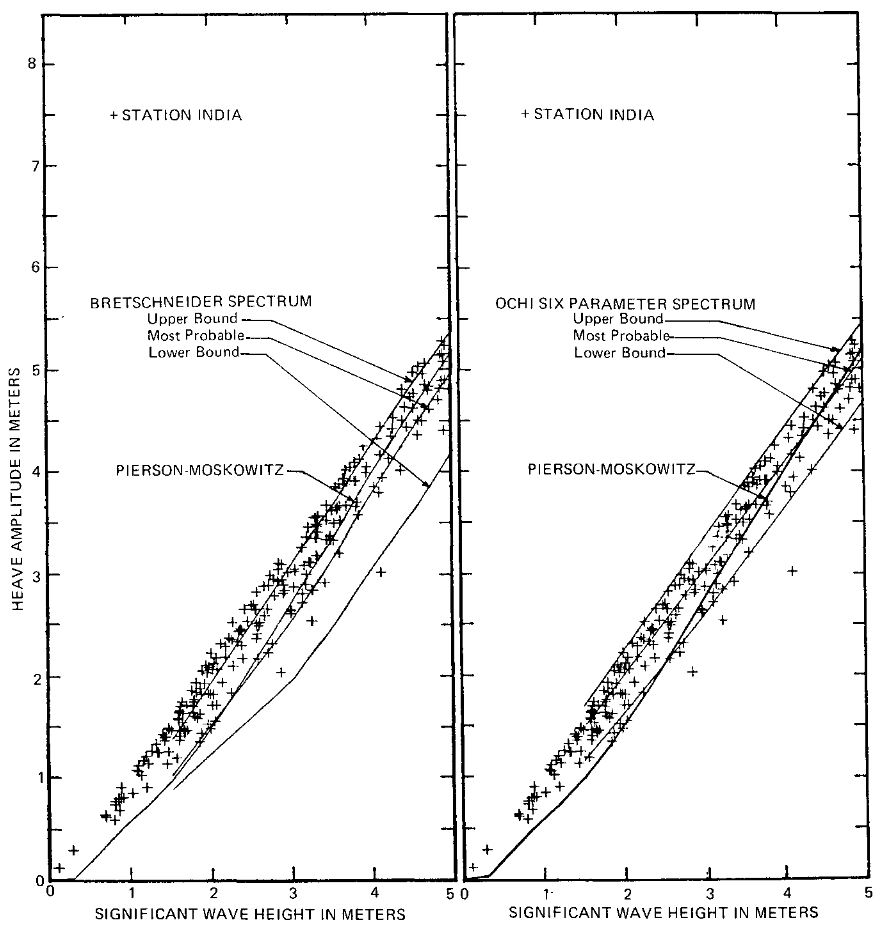

Fig. 6 Probable extreme heave amplitudes for model B, head seas, $F_n = 0.86$.

Prediction of Motions in Waves

Because the motion responses of air-cushion-supported vehicles to date have been assumed highly nonlinear, they have been treated through a nonlinear time domain approach. A nonlinear mathematical model for the coupled pitch and heave and roll motions of air-cushion vehicles is currently under development at DTNSRDC. The technique is being applied to several craft types, one of which is the single-cushion peripheral-jet air-cushion vehicle designated as model A. The governing nonlinear equations describing the motion of this vehicle were formulated by consideration of mass and flow relations and the adiabatic gas law. Solutions are obtained numerically following a procedure similar to the basic outline described in Ref. 16.

Because of the large computer costs entailed in the time domain approach, DTNSRDC is also developing a linearized model for use within the wave-height range where the craft responses are essentially linear. This model entails a linearized frequency domain analysis for predicting the pitch, heave and roll motions at arbitrary headings. It has been applied to model A using experimentally obtained force and moment coefficients and wave excitation forces and moments. The linearized equations for the rigid-body response of a ship to harmonic forces and moments may be written for heave, pitch, and roll, respectively, as follows:

$$(A_{33}+M)\ddot{\xi}_3+B_{33}\dot{\xi}_3+C_{33}\xi_3+A_{35}\ddot{\xi}_5$$

$$+B_{35}\dot{\xi}_5+C_{35}\xi_5=F_3(t)$$

$$(A_{55}+I_5)\ddot{\xi}_5+B_{55}\dot{\xi}_5+C_{55}\xi_5+A_{53}\ddot{\xi}_3+B_{53}\dot{\xi}_3+C_{53}\xi_3=F_5(t)$$

$$(A_{44}+I_4)\ddot{\xi}_4+B_{44}\dot{\xi}_4+C_{44}\xi_4=F_4(t)$$

where the notation is that traditionally used in seakeeping work.

In the linearized theory there is no coupling between the pitch and heave equations and the roll equation, because of the symmetry of the craft in the horizontal plane. The coefficients were obtained from calm-water oscillation experiments in pitch, heave, and roll, and the wave forces were obtained from captive-model experiments. The oscillation experiments were carried out with the craft on cushion at the equilibrium height and trim condition for the particular speed under investigation. The model was oscillated with small amplitude motion over a range of frequencies, and the forces and moments were measured. These forces and moments were then analyzed digitally to obtain the components in-phase (added mass and restoring) and out-of-phase (damping) with the oscillatory motion.

Captive-model experiments were also carried out in head waves. The model was held fixed at the calm-water design equilibrium height and trim condition, and run through low amplitude sinusoidal waves. Details of the experimental procedure, data analysis, and development of the analytical procedure are reported in Ref. 17.

The results of the vertical plane motions analysis for pitch and heave in head seas are shown in Fig. 4 as frequency response functions and are compared with data obtained from seakeeping experiments for a Froude number of 1.13. The pitch mass moment of inertia for the data in this figure is only 59% of the pitch inertia employed in the experiments represented in Fig. 2. In the linear analysis both pitch and heave show good qualitiative agreement. The quantitative agreement in heave is also excellent. The pitch is somewhat overpredicted, indicating less damping than the physical model, but the peak response is predicted within about 15%. The natural frequency is predicted within 1.5 rad/s. The results of the nonlinear analysis are also included in Fig. 4. It is seen that agreement with the experimental pitch data is somewhat better than that from the linear model, though the natural frequency is again overpredicted. The predicted heave response from the nonlinear model shows poorer correspondence with the physical model than that obtained from the linear model; the nonlinear model indicates an overdamped system where the physical model indicates a slightly underdamped response.

In order to examine the effect of wave spectral formulations on the magnitude of responses, computations of the probable extreme values (which are the largest values likely to occur in a specified ship operation time) of heave and pitch motions in a seaway were carried out for a 100-ft (30.5-m) prototype represented by model B, following the method recently presented by Ochi and Bales.[18] The computations were carried out in head seas at $F_n=0.86$ in three different mathematical spectra: the Bretschneider, Pierson-Moskowitz, and the Ochi[19] six-parameter spectra. These three spectral formulations are presented and discussed in Ref. 18, where they are applied to the prediction of responses of conventional displacement ships and platforms in the open ocean. The present paper represents the first attempt to determine the effect of various spectral formulations on the responses of high-performance vehicles.

Computations using the Bretschneider and the Ochi six-parameter representations were made for a family of wave spectra from which the upper and lower bounds of responses with confidence coefficient of 0.95, as well as those responses in the most probable wave spectrum for a given sea severity, were determined. These responses were then compared with those computed using measured spectra at Station India in the North Atlantic (Weather Station I), in order to determine how well the bounds cover the variation of responses in the measured spectra. The results are shown in Fig. 5 for pitch and in Fig. 6 for heave, for wave heights up to 15 ft (4.6 m). Included also in the figures are the responses in the Pierson-Moskowitz spectrum. Wave heights greater than 4.6 m (Sea State 6) were not investigated since craft linearity was not verified in seas of severity greater than Sea State 5.

The scatter of the responses computed in the measured Station India spectra indicates that the probable extreme values of both pitch and heave vary considerably for a given significant wave height. The Pierson-Moskowitz spectrum underpredicts the motions in the lower wave heights while it tends to predict values of pitch somewhat on the high side in wave heights of 8 to 15 ft (2.4 to 4.6 m). It is also apparent from the figures that, in general, for both pitch and heave the upper and lower bounds of the values computed using the six-parameter spectral formulation better encompass the data from the measured spectra in the Atlantic Ocean than do those obtained using the Bretschneider formulation. While the former appears to cover reasonably well the variation of magnitudes computed in the measured spectra, the latter underpredicts the upper bound of both modes of motion and overpredicts the lower bound in pitch. For design application, a nonconservative prediction of the upper bound of probable extreme responses is of more serious consequence.

Conclusions

The application of the response superposition principle has been studied through a double examination of the response linearity. Pitch, heave and roll linearity have been determined for several craft-types in regular and irregular waves. The linearity studies were made primarily at one speed ($F_n \cong 0.8$) in resonant regular waves, as well as in irregular waves having a significant height of the order of one-half the cushion height. For one specific vehicle (model B) a more severe sea state with a wave height equal to 80% of the cushion height was also investigated. This vehicle was also investigated at higher speed ($F_n=1.31$) in regular waves. A second vehicle (model A) was tested in irregular waves which were quite severe, having a significant height greater than the cushion height.

For the speeds examined the vehicles have been shown to respond approximately linearly to regular wave excitation in wave lengths producing resonance for wave steepness of the order of 30 to 40 or greater. Secondly, linearity has been reasonably well demonstrated for model B over the entire frequency response range through a comparison of transfer functions derived from a spectral analysis of irregular responses in two different sea states (Sea States 3 and 5 for a 100 ft craft). The irregular sea transfer functions also correspond closely to those obtained through regular wave tests. Reasonably linear seakeeping response was observed for model A in regular waves throughout the wave steepness range examined; however, the vehicle showed some nonlinear response in irregular waves where the significant height was greater than the cushion height.

The application of the linear seakeeping analysis process has been demonstrated through an appliction of the transfer functions in pitch and heave for a 100-ft prototype of model B to the sea spectra data of the North Atlantic Station India for wave heights through Sea State 5. The most probable response characteristics have been computed according to the Pierson-Moskowitz, Bretschneider, and Ochi six-parameter spectra; it has been found that although all spectral representations show good qualitiave agreement with the measured spectra, the six-parameter formulation better encompasses the data from actual spectra measured in the Atlantic than do the other two representations.

The results of this investigation suggest that there may be a significant range of practical operating conditions over which the normal seakeeping analysis process can be applied with reasonable confidence in the design of air-cushion-supported ships. This paper does not purport to define that range; however, a critical and perhaps limiting factor appears to be the height of the waves in relation to the cushion height. It is believed that the results obtained here show sufficient promise to justify additional effort in order to characterize the envelope of operating conditions where seakeeping response can be incorporated into the design process for air-cushion-supported ships as it presently is incorporated to displacement ship design.

References

[1] St. Denis, M. and Pierson, W. J., "On the Motion of Ships in Confused Seas," *Transactions of the Society of Naval Architects and Marine Engineers*, Vol. 61, 1953.

[2] Kaplan, P., Bentson, J., and Sargent, T. P., "A Study of Surface Effect Ship (SES) Craft Loads and Motions, Part 1—Equations of Motion of SES Craft with Six Degrees of Freedom," Oceanics, Inc., Plainview, N.Y., 71-84A, Aug. 1971.

[3] Kaplan, P., Bentson, J., and Sargent, T. P., "Advanced Loads and Motions Studies for Surface Effect Ship (SES) Craft, Part 1—General Development of Modified Mathematical Model," Oceanics, Inc., Plainview, N.Y., 73-97A, June 1973.

[4] Kaplan, P., Bentson, J., Silbert, M. N., and Jaslow, H., "Correlation of Computer Simulation for SES Model Test Data (FY 75 Loads and Motions Studies)," Oceanics, Inc., Plainview, N.Y., 75-118D, Sept. 1975.

[5] Doctors, L. J., "The Effect of Air Compressibility on the Nonlinear Motion of an Air-Cushion Vehicle Over Waves," *Proceedings of the Eleventh Symposium on Naval Hydrodynamics*, ONR, London, 1976.

[6] Moran, D. D., "A Nonlinear Vertical-Plane Mathematical Model for Air-Cushion-Supported Vehicles," DTNSRDC, Bethesda, Md., SPD 615-05, June 1976.

[7] Lavis, D. R., Bartholomew, R. J., and Jones, J. C., "On the Prediction of Acceleration Effects of the Cushion Inherent in Scale Models," AIAA/SNAME/USN Advanced Marine Vehicles Meeting, Paper No. 72-598, July 1972.

[8] Schneider, J. and Bono, P. S., "A Study of the Dynamics of Arctic Surface Effect Vehicles: Final Technical Report, Part II: Development of the ASEV Motions Program and the Analysis of Results of Numerical Studies for Selected Craft Configurations," Oceanics, Inc., Plainview, N. Y., 73-101B, Feb. 1974.

[9] "Arctic SEV Program Final Report: Vol. 4, Vehicle Dynamics," 7416-950001, Bell Aerospace Company, Feb. 1973.

[10] Korvin-Kroukovsky, B. V. and Jacobs, W. R., "Pitching and Heaving Motions of a Ship in Regular Waves," *Transactions of the Society of Naval Architects and Marine Engineers*, Vol. 65, 1957.

[11] Gerritsma, J. and Beukelman, W., "Analysis of the Modified Strip Theory for the Calculation of Motions and Wave Bending Moments," *International Shipbuilding Progress*, Vol. 14, 1967.

[12] Ogilvie, T. F. and Tuck, E. O., "A Rational Strip Theory of Ship Motion: Part 1," University of Michigan, Rept. 13, 1969.

[13] Salvesen, N., Tuck, E. O., and Faltinsen, O., "Ship Motions and Sea Loads," *Transactions of the Society of Naval Architects and Marine Engineers*, Vol. 78, 1970.

[14] Gerritsma, J., " An Experimental Analysis of Shipmotions in Longitudinal Regular Waves," *International Shipbuilding Progress*, Vol. 5, Dec. 1958.

[15] Moran, D. D., Fein, J. A., and Ricci, J. J., Jr., "Seakeeping Characteristics of a High Length-to-Beam Ratio Surface Effect Ship," *Journal of Hydronautics*, Vol. 11, July 1977, pp. 74-84.

[16] Carrier, R., Magnuson, A. H., and Swift, M. R., "Seakeeping Dynamics of a Single-Cushion, Peripheral Cell-Stabilized Air-Cushion Vehicle," *Journal of Hyrdonautics*, Vol. 12, April 1978, pp. 49-54.

[17] Magnuson, A. H. and Schechter, R. S., "Linear Analysis of the Pitch, Heave and Roll Motions of the 7/100 Scale JEFF(A) Amphibious Assault Landing Craft," DTNSRDC, Bethesda, Md., SPD 755-02, June 1977.

[18] Ochi, M. K. and Bales, S. L., "Effect of Various Spectral Formulations in Predicting Responses of Marine Vehicles and Ocean Structures," *Proceedings of the 1977 Offshore Technology Conference*, Houston, Texas, 1977.

[19] Ochi, M. K. and Hubble, E. N., "On Six-Parameter Wave Spectra," *Proceedings of the 15th Conference on Coastal Engineering*, 1976.