Seakeeping Committee

Committee Chair: Mr. S.G. Tan
Session Chair: Prof. W.C. Webster

I DISCUSSIONS

Discussion of ITTC Seakeeping Committee Final Report and Recommendations to the 21st ITTC

by Prof. Grant E. Hearn
Professor of Hydrodynamics
University of Newcastle upon Tyne, UK

Firstly the committee is to be congratulated for providing a wide ranging report and for presenting it in such a clear style concerning good use of headings etc.

Next, I would like to make some points concerning the subject matter of Section 9, Full Scale Measurements and Real Time Forecasting, Section 10, Seakeeping Assessment and Section 11, Uncertainty Analysis and Validation Procedures.

Section 9

During late November and early December 1995 I was able to undertake full scale seakeeping analysis (with wave and wind observations) on a trawler off the Faroes in sea-states 4 to 10/11. The use of GPS facilities and the modern bridge layout allowed a desired hexagonal course to be continuous displayed and through the use of the GPS allow the track rather than the course heading to be maintained. That is, as indicated in the report, the GPS allowed improved control in the full scale trials.

Section 10

Assessment of the seakeeping characteristics of the trawler were provided a ‘priori´ through the use of both 2D and 3D analysis. Using published scatter diagram data the predicted “down” times of the trawler were significantly larger using 3D rather than 2D analysis, and as the vessel moved from near-shore to off-shore conditions so the theoretical assessment indicated a less desirable hull form design. Improvements to the hull form geometry could be made using design charts based on displacement and acceleration related criteria. However, the optimal design does depend upon the operability criteria used. Hence it might be appropriate that the 22nd ITTC look at the criteria available and their relevance to hull form optimisation.

Analysing the collected data to identify the sea spectra, and hence the transfer functions of the trawler, was undertaken initially using the statistical package SSPS. May I warn users of this package that the total energy under the resulting spectra and the variance of the time series were not in agreement due to a failure to normalise weightings in the SSPS package when smoothing. SSPS have been told of this problem and hopefully having accepted the veracity of our findings will modify the package.

For this trawler, which is short and very full, to by-pass the 24 m rules the 3D analysis and the measured transfer functions are in closest agreement.

However, as a result of pure observation whilst on the trawlers one could see that the roll and pitch were coupled (even in head seas) due to the generation of large products of inertia as a consequence of storage and compensation provided by emptying ballast tanks on opposite sides of the trawler. Hence mass distribution is critical to the analysis of such hull forms as in practice it may not be possible to simplify, with justification, the associated inertia matrix.

I think that the causes of differences between the theoretical predicted and experimentally measured transfer functions may be identified using generic algorithms to minimise their differences at all frequencies.

Section 11

I would like to reinforce the statements under 11.2 associated with model accuracy and weight distribution. It is essential that weight distribution and hence the dynamics is conserved as one goes from full scale, to theoretical and model scale investigations. With modern transducers, imperfections in the symmetry of the model hull are readily detected in forward speed seakeeping analysis (180^0), hence methods of detecting and measuring imperfections is also required.

Section 12

Finally, regarding the recommendations to the conference (Section 12.2) may I suggest we replace "seakeeping model experiments" by "seakeeping model and full scale experiments"

I thank you for this opportunity to comment on the report.

Seakeeping Trial of a Catamaran using Strap-down Accelerometers and a Ultrasonic Wave Probe

by Sa Y. Hong, C. M. Lee and S.W. Hong
Korea Research Institute of Ships and Ocean Engineering .

1. Introduction

Since we developed KRISO's onboard ship motion measuring system which uses strap-down accelerometers and a ultrasonic wave probe in 1992, we have had some experiences of seakeeping trials for high speed passengers such as SESs and catamarans. In this discussion, we will show one of our experiences which will be presented in 96 autumn meeting of SNAK(Society of Naval Architecs in Korea). The importance of onboard measurement of incident waves is mainly investigated.

2. Seakeeping Trial

The subject ship is a car-ferry, 80m class high speed catamaran. The sensor arrangement is shown in Fig. 1. Table 1 summarizes the measurement conditions. Figs. 2 and 3 show an example of measured signals, and synthesized ship motions and incident wave, respectively. The incident wave signal is reproduced from the measured relative motion and the analyzed vertical local motion. Table 2 shows the seatrial results compared with the observations. We focused our interest on the quality of estimation of incident waves. As shown in Table 2, satisfactory results are achieved in the sense of engineering application.

3. Discussions

The ship was equipped with accelerometer, roll and pitch sensors, but unfortunately the sensors did not provide external output port, we could not directly compare the sea trial data with the equipped sensor results. Instead, we compared our results with the calculation results from SWAMO[2] which uses strip method. Since the sea state varies according to the routes during the measurement, calculation results are shown as lower and upper range for wave heights 2 and 2.5m. Fig. 4 compares the heave motion, the solid line denotes the case of significant height 2m. The dotted line denotes the case of significant wave height 2.5m. The upper limit of each line correspond to longer wave period(1.2Tz) while the lower one corresponds to shorter wave period(0.6Tz). Measured value approaches the lower limits which correspond the wave period=0.6Tz, Tz is nominal zero-upcrossing period of ITTC spectrum. This means that the measured wave period is shorter than nominal wave periods where ITTC spectrum generally uses in our case. The wave period 0.6Tz is almost the same as the zero-upcrossing period of incident wave obtained from the measurement in beam sea. The broad-banded calculation results implies that the wave period is important information as well as wave height in seakeeping trial. It is also worthy to note that the incident wave varies in height and period according to the trial route, and our measurement shows the magnitude of change of wave height is over 1m within 6 by 6km area.

4. Conclusions

Onboard ship motion measuring system was successfully applied to seakeeping trial of a high speed catamaran. The quality of measured data and analysis results show satisfactory agreement with calculation results and observations. The ultrasonic wave probe used in our ship motion measuring system provides reliable wave period as well as wave height as long as heading angle is confined in bow waves, which was verified through model tests[1]. Measurement of incident wave onboard provides merits such as an information on wave height and period directly acting on the ship. And this should be emphasized for the enhancement of the analysis of correlation between seakeeping trial results and theoretical estimations.

References

[1] Hong, S.Y. et al., " Development of a Digital Motion Measuring System in Real Seaway" , Trans. of SNAK, Vol. 29, No.3, 1992(in Korean)

[2] Hong, D.C. et al., "Development of a Computer Program for the Analysis of Motion Responses of Catamaran-type Ship or Offshore Structure", KIMM report UCE244-649.D, 1985(in Korean)

[3] Miles, M.C., "Measurement of Six Degree of Motions Using Strapdown Accelerometers", Hydraulic Laboratory, National Research Council, Otawa, Canada.

Table 1 Seakeeping Trial Conditions

Test No.	Ship Speed (kts.)	Wave Direction	Sampling Rate/No. of Block	Observed Wave Height
110	24	Following	10 Hz/3	1.5m
111	42	Following	10 Hz/3	1.5m
120	23	Head Quartering	10 Hz/3	2.0-2.5m
121	40	Head Quartering	10 Hz/3	2.0-2.5m
130	40	Beam	10 Hz/3	2.5m
131	23	Beam	10 Hz/3	2.5m
140	24	Stern Quartering	10 Hz/3	2.0-2.5m
141	40	Stern Quartering	10 Hz/3	2.0-2.5m
150	22	Head	10 Hz/3	below 2.0m
151	41	head	10 Hz/3	below 2.0m

Table 2 Seakeeping Trial Results of a Catamaran

Test No.	Observed Wave Height	Sig. Wave Height	Period (sec.)	Heave rms	Roll rms	Pitch rms	Acc1 rms	Acc2 rms	Acc5 rms
110	1.5m	1.71m	4.66	0.06	0.48	0.38	0.02	0.03	0.02
111	1.5m	1.86m	3.02	0.07	0.44	0.52	0.04	0.04	0.03
120	2.0-2.5m	2.77m	3.03	0.17	1.27	0.74	0.06	0.05	0.07
121	2.0-2.5m	2.71m	2.61	0.17	0.92	0.73	0.06	0.06	0.08
130	2.5m	2.55m	3.02	0.16	1.10	0.68	0.07	0.06	0.09
131	2.5m	2.53m	3.00	0.11	1.50	0.70	0.07	0.05	0.07
140	2.0-2.5m	2.40m	3.90	0.10	1.53	0.72	0.05	0.04	0.05
141	2.0-2.5m	2.19m	3.40	0.08	1.02	0.80	0.06	0.05	0.05
150	below 2.0m	1.84m	2.15	0.09	0.54	0.73	0.08	0.06	0.06
151	below 2.0m	1.68m	1.82	0.09	0.34	0.46	0.06	0.06	0.06

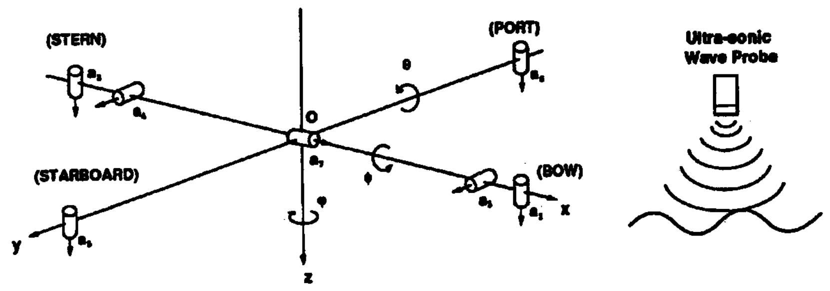

Fig. 1 Deployment of Sensors

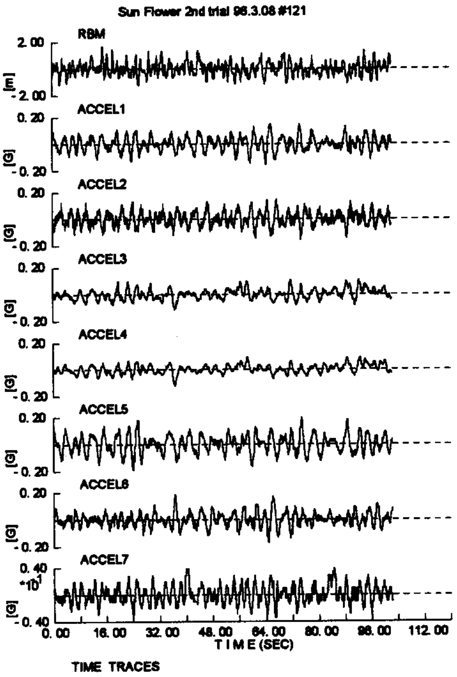

Fig. 2 Measured Data

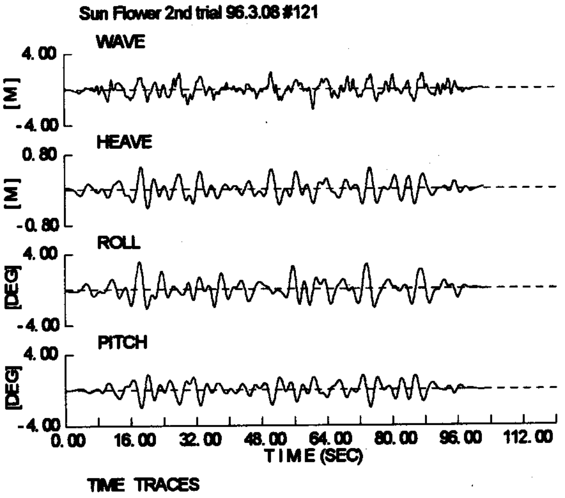

Fig. 3 Synthesized Ship Motion and Incident Wave

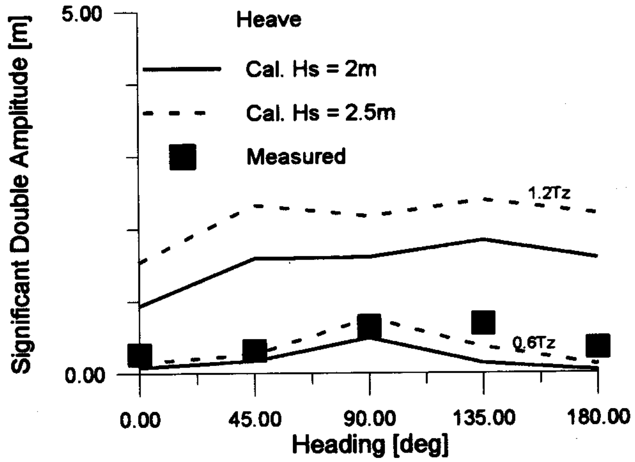

Fig. 4 Comparison of Heave Motion(Vs=23knots)

Validation of Numerical Method to Compute Motions of Shallow-Draft Vessels in Waves

bu C. C. Hsiung and Z. J.(Jerry) Huang
Centre for Marine Vessel Design and Research
Technical University of Nova Scotia

1. Introduction

Shallow-draft vessels are widely used in fishing industry, harbour operation and ocean engineering. However, research work on the seakeeping performance of this kind of vessels is not carried out as much as that on conventional deep-draft ships both theoretically and experimentally. Small amplitude motions cause large variations of the underwater hull geometry and consequently in the hydrodynamic force, and in turn it will affect ship motions. To study shallow-draft vessel seakeeping quality, the linear strip theory was formerly adopted, such as the work by Gerritsma & Keuning (1989). Very little theoretical study with three-dimensional methods has been carried out. An early work on the hydrodynamic force of a three-dimensional disk with an elliptic waterplane was studied by Kim (1963), where the disk was forced to oscillate with small amplitudes.

We are particularly interested in fishing vessels of shallow draft and low length-to-beam-ratio. Some results from our research have been applied to the capsize study of fishing vessels in rough seas when green water is shipping on deck (Huang & Hsiung 1996). The method we used can be summarized as follows: the time-domain added mass, hydrodynamic restoring force and damping coefficients are computed using the impulse potential function; whereas linear diffracted wave forces and retardation functions are computed based on the frequency-domain diffracted wave forces and damping coefficients, respectively. Froude-Krylov forces and hydrostatic restoring forces are computed at the instantaneous position. Other force components, such as viscous damping, resistance, cross-flow drag, thrust, rudder and maneuvering forces are considered. Finally, the nonlinear equations of ship motion solved in the time domain with the three-dimensional panel method. This paper presents our validation work on the numerical calculation to date.

2. Methodology

A typical shallow-draft hull form is shown in Fig. 1. Three coordinate systems are employed for the ship motion analysis as shown in Fig. 2. **OXYZ** is the space-fixed coordinate system with the **OXY** plane on the calm water surface and the **OZ** axis be positive upwards. The second coordinate system $o_m x_m y_m z_m$ is a moving system which moves with the same steady forward speed as the ship in the OX direction. The $o_m x_m y_m$ plane always coincides with the **OXY** plane, the $o_m x_m$ axis is in the same direction as the **OX** axis and the $o_m z_m$ axis is positive upwards. The third coordinate system $o_s x_s y_s z_s$ is fixed on the ship with the $o_s x_s y_s$ plane coincident with the **OXY** plane when the ship is at its static equilibrium position, and the $o_s z_s$ axis is positive upwards.

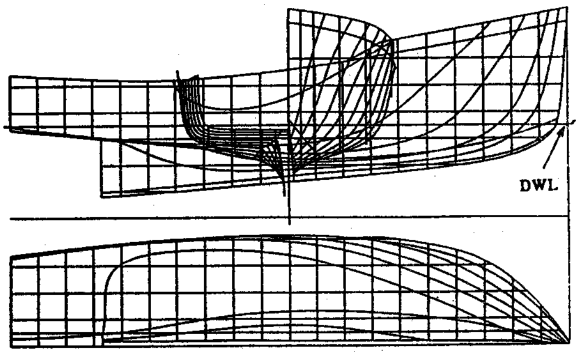

Fig. 1 Lines of a shallow draft vessel

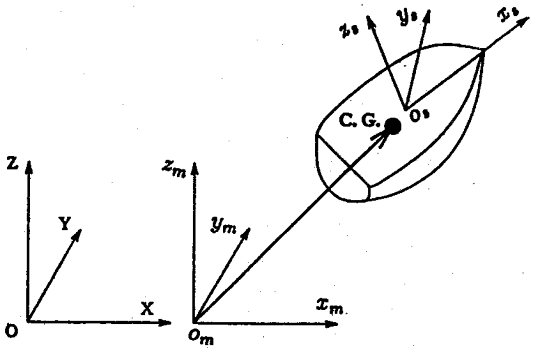

Fig. 2 Coordinate Systems for Ship Motions

The oscillatory ship motion is described in the $o_m x_m y_m z_m$ system. The ship motions are represented by $(\xi_1, \xi_2, \xi_3, e_1, e_2, e_3)$ in which, (ξ_1, ξ_2, ξ_3) are the displacements of the centre of gravity, and (e_1, e_2, e_3) are the Eulerian angles of the ship in space. The Eulerian angles are the measurements of the ship's

rotation about the axes which pass throught the centre of gravity of the ship. The instantaneous translational velocities of ship motion in the directions of o_gx_g, o_gy_g and o_gz_g are u_1, u_2 and u_3, respectively, and the angular velocities about axes parallel to o_gx_g, o_gy_g and o_gz_g and passing through the centre of gravity are u_4, u_5 and u_6, respectively.
The equations of ship motion are:

$$[m_{kj}]\begin{pmatrix}\dot{u}_1\\ \dot{u}_2\\ \dot{u}_3\\ \dot{u}_3\\ \dot{u}_4\\ \dot{u}_5\\ \dot{u}_6\end{pmatrix}+\begin{pmatrix}m\vec{\Omega}\times\vec{u}\\ \\ \vec{\Omega}\times([I_{kj}]\vec{\Omega})\end{pmatrix}=\begin{pmatrix}F_1\\ F_2\\ F_3\\ F_4\\ F_5\\ F_6\end{pmatrix} \qquad (1)$$

where $\vec{u}=(u_1, u_2, u_3)$, $\vec{\Omega}=(u_4, u_5, u_6)$, $[m_{kj}]$ is the generalized mass matrix, $[I_{kj}]$ is the moment of inertia matrix, and m is the mass of the ship. The total external forces on the ship are

$$\begin{aligned}F_k(t) = {}& F_k^{Rs}(t)+F_k^{FK}(t)+F_k^{D}(t)+F_k^{R}(t)\\ &+F_k^{V}(t)+F_k^{O}(t)\\ &\text{for } k = 1,2,\cdots,6\end{aligned} \qquad (2)$$

where F_k^{Rs} are the restoring forces; F_k^{FK} are nonlinear Froude-Krylov forces; F_k^{D} the diffracted wave forces; F_k^{R} the radiated wave forces; F_k^{V} the viscous damping forces; and the force component F_k^{O} may include the hydrodynamic manoeuvering forces, the rudder force, propeller thrust, resistance and cross-flow drag. Computational details of these forces are given by Huang & Hsiung (1996). The ship translational displacements $(\xi_1, \xi_2, \xi_3)^T$ in the steady moving system and the Eulerian angles $(e_1, e_2, e_3)^T$ are solved from:

$$\begin{pmatrix}\dot{\xi}_1\\ \dot{\xi}_2\\ \dot{\xi}_3\\ \dot{e}_1\\ \dot{e}_2\\ \dot{e}_3\end{pmatrix}=\begin{bmatrix}[R] & 0\\ 0 & [B]\end{bmatrix}\begin{pmatrix}u_1\\ u_2\\ u_3\\ u_4\\ u_5\\ u_6\end{pmatrix} \qquad (3)$$

where matrices **[B]** and **[R]** transform the velocity vectors from the body-fixed coordinate system into the steady moving coordinate system. The ship motions in the time domain are solved simultaneously from twelve equations in both (1) and (3).

The nonlinear restoring forces and the Froude-Krylov forces are computed by integrating the pressure over the instantaneous wetted panels. It has been found that, for shallow-draft vessels, the pressure variation in the wave field is large even at the small amplitude of motions. An example of the typical pressure field in the incident wave is shown in Fig. 3 and it is used to correct the Froude-Krylov forces and restoring forces.

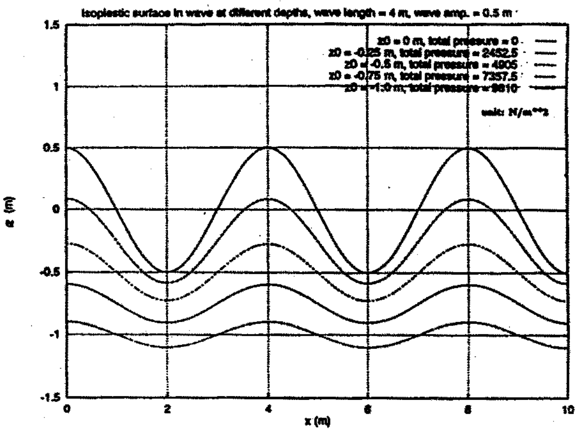

Fig.3 The Isopiestic Surface in a Incident Wave Field

The irregular waves are computed in the space-fixed coordinate system, **OXYZ**. When they are represented by superposition of a finite number of sinusoidal waves, sometimes, a non-Gaussian process could be generated.
In simulation of ship motion in large waves, it is important to make sure that the computer generated irregular waves are samples of the Gaussian process. The probability density function is calculated and a χ^2-test is

performed on the irregular wave elevation used in the ship motion simulation to ensure that a proper wave train is used.

In the time-domain simulation of ship motions, resistance and cross flow drag should be considered. These forces are important to surge and sway. Model resistance test results were obtained for nine Canadian inshore fishing vessels as shown in Fig.4 (Lacy 1995).

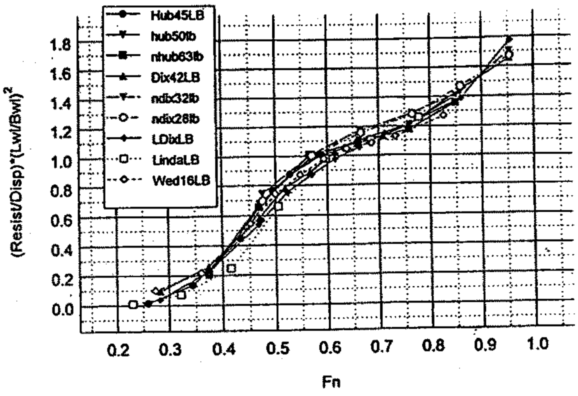

Fig. 4 Resistance for Inshore Fishing Vessels

Models were also towed transversely in the tank in order to measure the cross-flow drag (Huang 1995). Test results are used for the numerical simulation of vessel motions. If there are no test data available, empirical formulas, such as those given by Holtrop & Mennen (1982), are used for resistance estimation.

3. Results of Validation

A free running model test was carried out in the wave basin at the Institute for Marine Dynamics at St. John's, Newfoundland. The lines of this model is shown in Fig. 1. Heave acceleration, roll and pitch angles were measured during the test runs. The wave slopes, $2\zeta_0/\lambda$, up to 0.09 are used, where λ is the incident wave length and ζ_0 is the incident wave amplitude. The principal dimensions of the model are given in Table 1 and the panelized hull up to the bulwark is shown in Fig. 5. This type of vessels has very shallow draft, large skeg, flat bottom near the stern, as well as low length-to-beam-ratio. They are very stiff in waves, the typical full-scale natural period is only about 3 sec. Normally, for the displacement type ship hulls of deep draft, the roll added moment of inertia is 25% of the ship's moment of inertia. However, for the hull used in the model test, the added moment of inertia is 78% of the hull's moment of inertia according to our numerical computation. At a nominal forward speed of 5 knots, comparison between computed results and the measurements are given in Fig. 6 and Fig. 7 for the double amplitudes of heave acceleration and pitch motion. The double amplitude of heave acceleration is normalized by $2\omega_e^2\zeta_0$ and the double pitch amplitude by $2k\zeta_0$. The computed results agree well with the model test results.

Table. 1 Characteristics of Fishing Vessel A

Length, Loa (m)	1.846
Maximum beam, B (m)	0.717
Mean draft, D (m)	0.187
Volume ∇ (m^3)	0.0663
Radius of gyration r_{xx} (m)	0.236
Radius of gyration r_{yy} (m)	0.430
L.C.G. (m) (from F.P.)	0.996
V.C.G. (m) (from baseline)	0.378
Natural roll period T_0 (sec)	1.150

The nondimensional double amplitude of roll in beam seas with a nominal forward speed of 5 kts is given in Fig. 8. The numerical results agree well with the test results except in the long wave region.

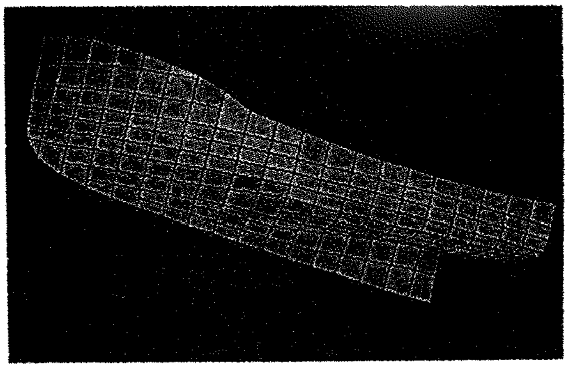

Fig. 5 Panelized Hull up to Bulwark

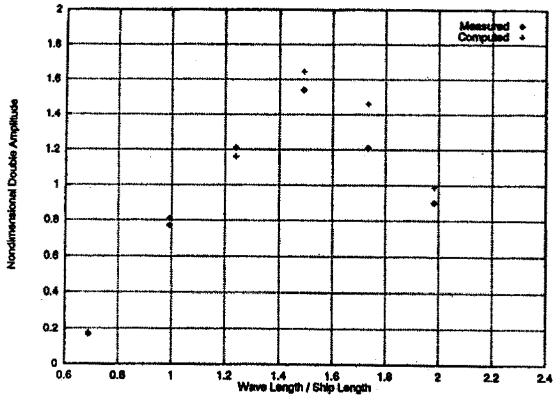

Fig. 6 Heave Acceleration in Head Seas

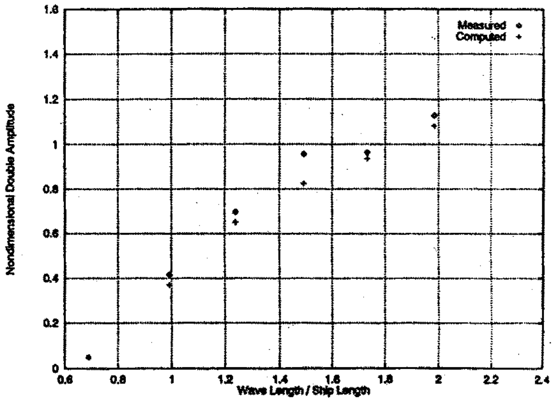

Fig. 7 Pitch Motion in Head Seas

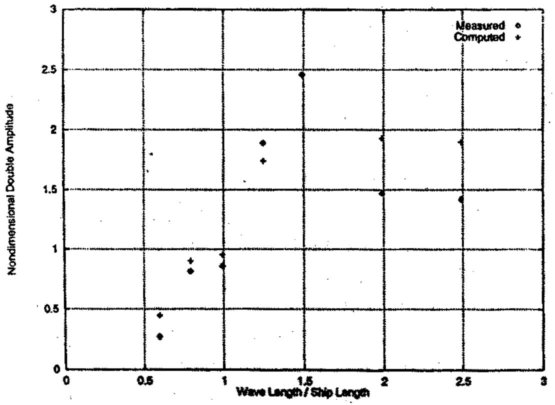

Fig. 8 Nondimensional Roll Motion in Beam Seas

Computations were also carried out in irregular beam seas of significant wave height 1.5 m and 2.5 m. The Ochi-Hubble six parameter wave spectrum was used in the computation. The numerical results are shown in Fig. 9 for $H_s = 1.5$ m and Fig. 10 for $H_s = 2.5$ m. The results shown are expressed in the full scale of the ship. It can be seen that the second peak spectral value occurs at the frequency which is close to two times the resonant frequency.

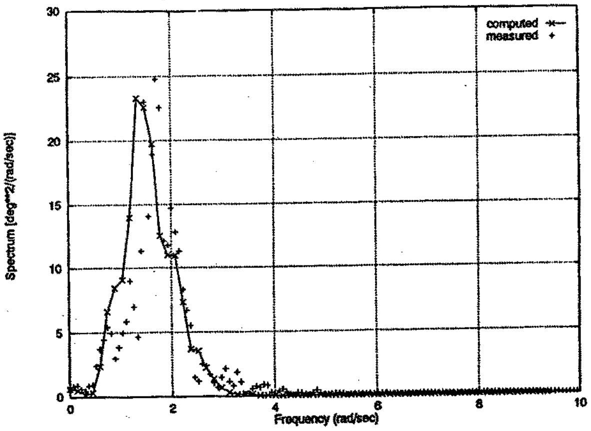

Fig. 9 Roll Spectrum in Beam Seas, H_s=1.5m

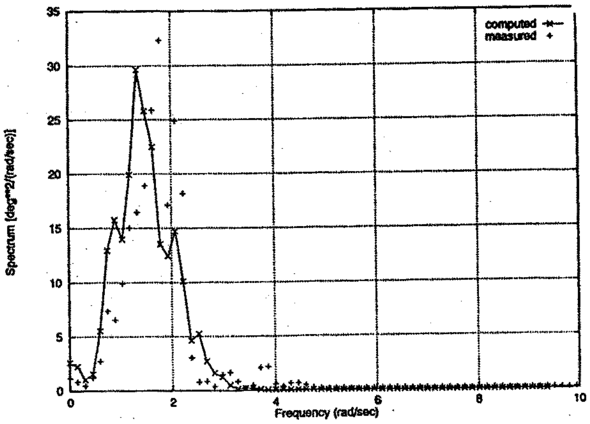

Fig. 10 Roll Spectrum in Beam Seas, H_s = 2.5m

4. Concluding Remarks

Equations of nonlinear ship motions are solved in the time domain for shallow-draft fishing vessels. The computed results show a good agreement with model test results for heave, roll and pitch, whereas noticable discrepancy exists for roll motion in long waves. Further studies are needed on seakeeping characteristics of shallow-draft, low length-to-beam-ratio vessels.

Acknoledgements

The authors are grateful for the supports from Transport Canada, and Natural Sciences and Engineering Research Council of Canada.

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On Extreme Ship Motions in Waves.

Comments by Dr. J.O. de Kat, MARIN:

I would like to thank the Seakeeping Committee for their efforts in reviewing recent experimental and analytical research. The following comments are meant to complement the Seakeeping Report in the area of extreme ship motions.

1) As regards Section 5.1. - Deck Wetness, it is worth pointing out the ongoing efforts in conjunction with the revision of the 1966 International Convention on Load Lines for the International Maritime Organization (SLF- Sub-Committee). The aim is to update the rules and methodology for assigning freeboard and bow height, and water on deck plays a major role in this process.

As part of this work an international study has focused on comparing numerical predictions of relative motions for different ship types, where freeboard exceedance is assumed to imply shipping water on deck. The results obtained for relative motions suggests that there is rather good agreement between various linear ship motion programs used worldwide, so long as the relative motion analysis is based on the undisturbed incoming wave and no dynamic swell-up is taken into account. Differences between predicted values increase when accounting for wave disturbance effects. As an example of fair agreement between computational methods, Fig. 1 shows the computed RAOs for relative motion at the bow in head seas for a fast container ship.
In this case, al methods denoted by countries are based on linear strip theory, except for Germany where a linear 3-D diffraction code was used, and wave disturbance effects are neglected. Details of this study have been reported at SLF 40 in London, September 2 - 6, 1996.

2. As regards the last paragraph of Section 6.1 - Nonlinear Rolling Dynamics and Capsizing, I would like to add a few specific observations from the ongoing CRNav Dynamic Stability Project. An interesting issue that showed up in the development of new design guidelines is the apparent relationship between calm water stability (GZ) characteristics and capsize dynamics: there is a clear dependency of the propensity to capsizing in waves on the angle of vanishing stability in calm water (i.e., range of positive stability and total area underneath the righting arm curve). This parameter is not included un current navy or IMO stability standards.

An illustration of the influence of hull form is the following. For a ship with a wide aft body and transom stern it was found that a larger range of positive stability is required than for a ship with a narrow aft body, when both ships are to have the same "capsize index" (a derived measure of capsize risk). This conclusion is relevant for many modern hull forms and is the result of extensive time domain simulations; it has been corroborated by model test results.

3. As regards the subject of safe ship operation mentioned in Section 6.2. - Phenomena in Following Seas, several types of diagram for on-board use haven been developed, where we can distinguish generic and ship-specific diagrams. An international effort through IMO has resulted in the creation of "Guidelines to

the Master for the Safe Operation of Ships in Heavy Weather" and includes generic diagrams indicating dangerous zones related to surfriding and broaching, as well as to loss of stability in following and stern quartering waves. Specific information on loading condition, KG, GM, etc. is not required for this guidance. This work is based on the analysis of model tests involving a range of small and large ships, and on numerical simulation results. The following IMO document contains the operator guidance: SLF/39/18/Corr.1.

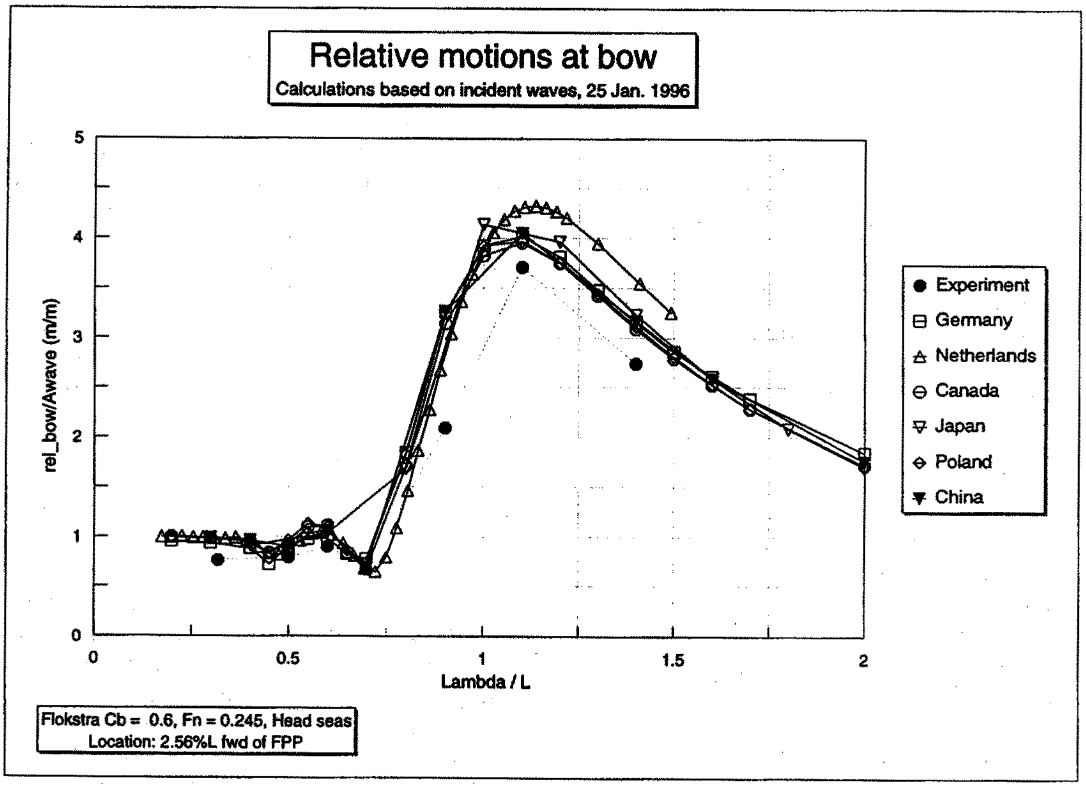

Fig. 1

A methodology for deriving ship-specific diagrams has been developed also as a part of the CRNav Dynamic Stability Project. For a given ship and loading condition, polar plots can be generated showing critical and non-critical combinations of speed, heading angle and sea state related to a number of extreme phenomena, including rolling, surfriding and broaching.

I would like to draw the attention to the paper by De Kat (1994), which addresses several issues related to stern sea phenomena. Broaching and capsizing in irregular waves are discussed, where an important observation is that the time-dependent *spatial* wave characteristics play a major role in the occurrence of such extreme events. It is asserted that when a ship meets a wave of critical spatial steepness and length at a certain heading and speed, it will capsize or broach regardless of the sea state and preceding time history of the encountered wave system. Based on the analysis of the spatial wave profiles leading to a broach, several modes of broach-induced capsizing are distinguished.

Basin measurements and wave group envelope considerations of spatial wave profiles show that in a random seaway a wave can retain its spatial characteristics during an extended period of time: when a ship travels with the seaway at its mean group speed, there is a strong temporal correlation between successively encountered (irregular) spatial wave profiles at the encounter period during the encountered wave group duration. The paper addresses furthermore the analysis of random waves using joint probability density functions applied to both temporal (at one location) and spatial measurements; comparisons are made between model tests and numerical simulations using the linear Gaussian model for the sea surface. Knowing the joint pdf of e.g. wave length and steepness in a given sea state, and having derived the critical waves that can lead to capsizing for a given speed and heading angle from time domain simulations, it is possible to predict the risk of capsizing for those conditions.

Reference

De Kat, J.O., 1994, "Irregular Waves and Their Influence on Extreme Ship Motions". Proceedings 20th Naval Hydrodynamics Symposium, Santa Barbara, pp. 39-58.

An Improved Method to Calculate Generation Signal of Multi-Directional Irregular Waves

by Masami Matsuura and Naoji Toki,
Ship & Ocean Engineering Laboratory
Nagasaki R&D Center
Mitsubishi Heavy Industries, Ltd.

Ship & Ocean Engineering Laboratory of Nagasaki R&D Center, Mitsubishi Heavy Industries, Ltd. completed the installation of its new wave maker on the shorter side of the seakeeping and manoeuvring basin [1]. The wave maker has the width of 30 m in total, and is composed of 75 units of 0.4 m width. As is reported by the Seakeeping Committee of 21st ITTC, importance of model testing in Multi-Directional Irregular Waves is on the increase. It is indispensable to simulate real sea condition in the laboratory.

However, calculation of generation signal of Multi-Directional Irregular Waves is troublesome work, even for today's computer, with the evaluation of many trigonometric functions and additions. Because even a highest level computer, which can be used in the laboratory, cannot complete the calculation within a time-step of irregular wave generation, wave generation signals for all wave-maker units usually have to be calculated beforehand.

This means;

(1) Long stand-by time is necessary after the wave condition of next experiment is decided, because the preparation calculation of irregular wave generation needs much longer time than the duration of actual wave generation.

(2) Expected maximum measurement time of model experiment must be decided before the start of preparation calculation, because the duration of actual wave generation cannot be longer than the prepared length of generation signal. Thus, the length of prepared wave generation signal, and therefore stand-by time before each experiment, tends to be longer.

These are quite troublesome for the actual execution of model test in multi-directional irregular waves. To eliminate these, we formulated and employed new calculus to execute the calculation for the generation of multi-directional irregular waves in real time (Japanese patent is applied). Summary of the calculus is explained here.

For the multi-directional irregular wave generation, it is necessary to evaluate the following $\eta_i(t)$ $(i = 1,2,\dots\dots L)$, L = number of component flaps;

$$\eta_i(t) = \sum_{n=1}^{N}\sum_{m=1}^{M}\frac{a_{mn}}{F_n}\sin(2\pi f_n t - ik_n b\cos\Theta_m + \epsilon_{nm}) \qquad (1)$$

where, t : time, f_n : wave frequency of n-th component wave, b : width of wave maker, N : number of component wave frequency, Θ_m : direction of m-th component wave, M : number of component wave direction, ϵ_{nm} : random phase lag defined from 0 to 2π, a_{nm} : amplitude of n, m-th component wave, F_n : transfer function of wave maker for n-th frequency, k_n : wave number of n-th component wave.

Direct evaluation of this formula is too time consuming, containing nxm times of evaluation of sine functions, and therefore is not suitable to execute within a time step of irregular wave generation.

To reduce the calculation time, the formula (1) is expanded by use of addition formula of sine function [1].[2]. As the final results,

$$\eta_i(t) = \eta_i(j\Delta t) = \sum_{n=1}^{N}\varphi_{ni,j} \qquad (2)$$

$$\begin{aligned}\varphi_{ni,j} &= \alpha_n\varphi_{ni,j-1} + \beta_n\phi_{ni,j-1}\\ \varphi_{ni,j} &= \alpha_n\phi_{ni,j-1} - \beta_n\varphi_{ni,j-1}\end{aligned} \qquad (3)$$

$$\alpha_n = \cos(2n\pi\Delta t),\ \beta_n = \sin(2n\pi\Delta t) \qquad (4)$$

$$\left.\begin{aligned}\varphi_{ni,0} &= \sum_{m=1}^{M} \frac{a_{nm}}{F_n}\sin(-ik_n b\cos\theta_m + \epsilon_{nm})\\ \phi_{ni,0} &= \sum_{m=1}^{M} \frac{a_{nm}}{F_n}\cos(-ik_n b\cos\theta_m + \epsilon_{nm})\end{aligned}\right\} \quad (5)$$

are obtained. By use of these formulae, all the calculations which should be finished within the time-step are the evaluation of formulae (2) to (4), if $\varphi_{ni,0}$ and $\phi_{ni,0}$ are evaluated at the preparation stage. Thus, real-time control of multi-directional wave maker becomes practically possible and this method is used for the new wave maker of Ship & Ocean Engineering Laboratory of Nagasaki R&D Center, Mitsubishi Heavy Industries, Ltd.

References

[1] B.T. Nohara, I. Yamamoto and M. Matsuura: "Multi-Directional Wave Maker and its Real Time Wave Control System Applied to a Seakeeping Model Basin", Wave Generation '95 Symposium, Yokohama, Japan (Sept. 1995).

[2] B.T. Nohara, I. Yamamoto and M. Matsuura: "The Organized Motion Control of Multi-Directional Wave Maker" Proceedings of AMC'96-MIE

Discussion of ITTC Seakeeping Committee Final Report and Recommendations to the 21st ITTC

by Dr. A.F. Molland
University of Southampton, UK

I should like to make a comment on the report of the Seakeeping Committee relating to the testing of high speed craft. In particular, I refer to the short paragraph in Section 7.2 relating to catamaran studies which states that 'the testing of high speed models in a bay or lake could be an interesting alternative to tests in a wave basin when longer run time or very high speed is desired'.

I would suggest that this statement has far more profound implications than the simple words 'interesting alternative' might imply. In fact it would seem that self-propelled model tests in open seas may become of necessity in many cases if reasonable run times at high speeds in oblique seas are to be investigated. Due to the resulting model size to carry the propulsor and instrumentation in self-propelled tests, run speeds are high and there can be significant limitations on oblique sea tests, even if the wave basin is large.

I mention this because we have been investigating this problem at Southampton. We have already carried out head sea tests in a test tank on three catamaran models with different length-displacement ratios, each at two hull spacings and at three Froude Numbers, 0.3, 0.5 and 0.8, Ref. A. The programme of research has now moved on to oblique sea performance of catamarans, where part of the tests will be carried out in the DRA Haslar basin under controlled conditions using 5 m models, but more extensive tests using the same models will be carried out in open seas in a bay.

Whilst the position and hence speed of a model in open seas can now be tracked with sufficient accuracy using DGPS, it is apparent that a major problem with open sea tests is the difficulty in quantifying the test environment and the properties of the short crested waves. We are examining this problem in some detail using the resources and expertise of the Southampton Oceanography Centre, and have been liaising with Dr. Fryer of DRA Haslar, some of whose work in this area is referenced in the Seakeeping Committee report.

I would add that this research forms part of the UK Marine Technology Directorate Fast Craft Programme, a UK government and industry sponsored initiative covering aspects of hydrodynamics, propulsion and structures with funding amounting to over a million pounds.

Ref. A. Wellicome, J.F. Temarel, P., Molland A.F. and Couser P.R, "Experimental Measurements of the Seakeeping Characteristics of Fast Displacement Catamarans in Long-Crested Head-Seas." 65 pgs, University of Southampton, Ship Science Report No. 89, 1995.

Contribution on Seakeeping Assessment to the Seakeeping Comm.

by Luca Sebastiani
Cetena, Italy

First of all I would like to thank the Seakeeping Committee for the excellent work done.

My contribution to the Committee Report concerns the problem of seakeeping assessment and is addressed to highlight the increasing importance for shipowners, and consequently for shipyards and ship design offices, of seakeeping assessment of vessels either conventional or advanced.

Just to give an example of this fact we briefly report the conclusions of a study devoted to the Operability Analysis of a ferry. The study was carried out by means of an in-house developed software package based on the Seakeeping Operability Envelope (SOE) concept.

The following calculations conditions were used:

- 4 speeds
- 13 headings
- 10 x 7 sea states (North Sea) were considered.

The following Seakeeping Performance Criteria were selected:

- Effective power
- Vertical/lateral accelerations
- Roll angle
- Slamming probability
- Deck-wetness probability
- Motion Induced Interventions
- Subjective Motion Magnitude

A sample of representative figures is attached:

- Fig. 1 presents the exceedance probability of H_s for the Geographical Area considered;
- Fig. 2 presents a sample SPD for vertical acceleration;
- Fig. 3 presents the Operativity Index versus H_s as regards effective power;
- Fig. 4 presents the sustained speed versus H_s as regards slamming probability;
- Fig. 5 presents the Operativity Index versus H_s with and without inclusion of effective power constraint.

Based on our experience and the results of the present study we are of the opinion that it should be encouraged through ITTC effort on the following items:

- development of seakeeping criteria related to human performance and passenger comfort;
- standardisation of SPC and associated limits for a variety of ship typologies and missions;
- integration of seakeeping assessment into ship design.

We further point out the importance of including the constraint on effective power due to added resistance when considering the problem of seakeeping assessment.

II REPLIES

Reply from ITTC Seakeeping Committee to

Dr. de Kat comments on "Extreme Ship Motions"

The Committee would like to thank Dr. de Kat for having brought to the attention of ITTC the results of IMO work on deck wetness and safe ship operations. IMO documents indeed have very limited circulation and have been rarely included in the Committee Report. We hope that this problems will be handled by the Specialist Committee on Stability.

As regards water on deck, Dr. de Kat reports the results of a cooperative work on relative bow motion computations. All results presented in the figure were obtained by means of linear theories. Unfortunately, there is no indication of the wave height used in the experiments, so that it is difficult to comment on the validity of the linear approach itself. It is the opinion of this Committee that good reliability in the predictions in extreme waves can only come out from 3-D **and** non-linear approaches as outlined in Section 4 of the report.

As regards nonlinear rolling dynamics and capsizing, Dr. de Kat comments on the importance of the total range of positive stability in calm water and the total area underneath the righting arm curve as the relevant parameters in stability assessment. We should clarifiy that it was not in the mandate of this Committee to discuss and establish stability rules. However, we think that the reported results are of interest. We are of the opinion that some more screening would be needed to avoid including too many parameters describing stability curve in calm water in the stability rules.

As regards the subject of safe ship operation, this was touched only incidentally in the Committee Report, while it is a relevant item in IMO activity.

Finally, Dr. de Kat draws attention on the dependence of broaching and capsizing phenomena in irregular waves on the time dependent spatial wave characteristics. This is a very important point and should be verified through fully non-linear time domain approaches as outlined in Section 4.4 of the Report. The Committee welcomes further development in this field.

Reply from ITTC Seakeeping Committee to Dr. Molland

We like to thank Dr. Molland for his contribution and find it interesting that the technique of testing models in wind generated waves in a lake or a bay is still being developed.

In a tank you have limited area which means limitations on:

- time and running length of the tests
- also the size of the model and speed to be tested is limited

These shortcomings can be overcome when testing in a lake or a bay. When testing high-speed vessels this is very valuable and free running tests are frequently used when testing the manoeuvrability of high-speed craft models in calm water.

The drawback when testing in wind generated waves is the lack of control over the wave environment. In the past a number of seakeeping tests in wind generated waves have been reported where the conclusions were unclear because of lack of adequate information about or lack of possibilities to control the wave climate.

The committee realise that the development of electronics and computer technique together with better theoretical wave models provide better possibilities to analyse seakeeping tests in wind generated waves. Maybe now is the time to look at this technique in a more scientific way than has been done in the past.

Reply from ITTC Seakeeping Committee to

Prof. Grant E. Hearn
Professor of Hydrodynamics
University of Newcastle upon Tyne, UK

We could only be grateful to prof. Hearn about this additional confirmation of our conclusions on the effectiveness of GPS instrumentation in full scale measurements. We hope that this problem will be further considered in more extent by the newly formed Specialist Committee on Trials and Monitoring.

The Committee would like to reconfirm Professor Hearn's statement saying the weight distribution and hence the dynamics should be conserved as we go from model scale to full scale and vice versa. These aspects need to be considered for the uncertainty analysis of both seakeeping model tests and full scale experiments. Under the same content, the committee agrees to replace the phrase “Seakeeping model experiments” in item 1 of “Recommendation to the Conference” to “Model and Full Scale Experiments”. But the points we have to mention at this time are that the uncertainty analysis for seakeeping model test is still in its preliminary stage and, as mentioned in the Committee Report, that the uncertainty analysis for prototype vessel requires a lot of more efforts and time than that of modelship.

In his discussion Professor Hearn has provided a useful link from predictions and hull form optimization to full scale results. The Committee agrees that criteria are very important in the hull form optimization procedure. At the same time, identification of the criteria which are appropriate for a particular mission is very difficult. In the 19th ITTC Seakeeping report criteria which are commonly used were summarized. The difficulty in identifying criteria has led to criteria-free optimizations, in many cases.

Reply from ITTC Seakeeping Committee to Prof. Hsiung's Discussion

The Committee thinks that this discussion is a very valuable contribution in the field of seakeeping analysis of shallow draft vessels with low length-to beam ratio, and the original paper has been referred to in the committee's report in the Section of Time Domain Method.

In general, validation is defined as a study undertaken to verify the consistency and accuracy of a numerical method by systematically varying parameters which dominantly influence the results. Therefore, this discussion will be a very valuable comparison study and will hopefully be the beginning of a systematic validation study.

Because many different sources of external forces from both linear and non-linear and from frequency and time domain are used in the formulation, it is very hard to precisely evaluate the comparison of results during the present ITTC. Anyway, the Committee recommends that the discusser make enough comparison with widely used and well verified methods as well as with model experiments in order to evaluate the accuracy and applicability of the present method.

Concerning coordinate systems, similar new treatment was reported by Prof. Hamamoto of Osaka University and this is quoted in the references prepared by the Manoeuvrability Committee, page 385, and a description can be found on p. 360. Prof. Hamamoto called this new coordinate system a horizontal body axis, including effects of both large rolling and manoeuvrability in waves. This will also be attractive.

Concerning Fig. 9 and Fig. 10 in the free running experiments, there will occur yawing motion, even in beam sea conditions, because of the strong asymmetric fore and afterbody profile. So, we think that in the experiments, an autopilot or other rudder system was adopted. In this case, in Fig. 9 and Fig. 10, the rudder effect on rolling is included in the free running experimental results.

The important point of this discussion is that they included manoeuvring effect for nonlinear rolling or capsizing. And this treatment will become more and more important for estimating more realistic ship motion in rough weather.

Reply from ITTC Seakeeping Committee to M. Matsuura & N. Toki (Mitsubishi Heavy Industries)

The Seakeeping Committee appreciates this contribution because the necessity of techniques about directional wave generation, measurement and application are stressed in the Committee Report.

Dr. Matsuura and Dr. Toki report on a quick method to calculate the surface elevation of multi-directional irregular waves. This method will be also applicable for the quick simulation of particle velocity, pressure etc. We would recommend Dr. Matsuura and Dr. Toki to publish their method in more details.

Reply from ITTC Seakeeping Committee to Dr. Yang

The Seakeeping Committee would like to thank Dr. Yang for presenting this interesting discussion written by his colleagues at KRISO. The addition of measured results for a high speed catamaran are welcome. Their discussion supports several issues of interest to this committee.

As noted in the Seakeeping Committee report, there is an increase in the use of onboard systems for measurement of motions. This is done for many purposes such as routing and motion control. Beyond this there is interest in using such results to validate and improve prediction techniques. Needless to say, this is particularly important since it is our goal to accurately predict motions and performance of ships at sea.

There has been an increase in the measurement of wave elevation due to advances in instrumentation. In work referenced in the Seakeeping report, Sandison et al. showed the accuracy of over-the-bow sensors through comparisons made with buoy measurements.

Such measurements were used in the effort reported here. These results demonstrate the importance of detailed knowledge of the seaway - that is, identification of the wave period as well as significant wave height. Measured heave is compared with predictions for the actual wave period as well as another period. All too often seaways are identified by sea state only as if there is only one wave spectrum corresponding to a sea state. The results in this discussion from KRISO demonstrate that invalid conclusions about performance and prediction capabilities can result from using inappropriate wave spectra since the magnitude of a ship's responses to seaways varies with variations in the seaway's energy distribution.

Seakeeping Committee response to Luca Sebastiani's discussion

The Seakeeping Committee would like to thank Dr. Sebastiani for his discussion. We support his suggestion that seakeeping assessment should be integrated into ship design; we need to convince other delegates at this conference of the importance of seakeeping in the design process. Traditionally, resistance and powering considerations drive designs. An integrated approach which includes a variety of performance characteristics would result in designs with better performance. Dr. Sebastiani's results on the reduction in effective power with increase in sea state due to added resistance support this approach.

As is clear from a review of the references in the Seakeeping Committee's report, investigators from around the world are implementing methods for improving motion characteristics in the design stage. These approaches include those with and without criteria. There are advantages and disadvantages to each approach. Of course, the difficulty with utilizing criteria is that appropriate criteria must be identified for various missions. The 19th ITTC Seakeeping Committee report summarized criteria in common use for conventional ships. There has been little reported change in the intervening years. A report on an American-British-Canadian collaboration on Human Performance at Sea is referenced in this report, and a NATO working group is currently carrying out a related study. Perhaps their report can serve as the basis for an effort by a future ITTC committee which can deal with this complex topic.