The Seakeeping Committee

Committee Chairman: Mr. Terence R. Applebee
Session Chairman: Ir. Arne H. Hubregtse

1. DISCUSSIONS

1.1 Discussion to the 25th ITTC Seakeeping Committee by Joe Longo, Claus Simonsen, Fred Stern, IIHR-Hydroscience & Engineering, Force Technology, USA

The purpose of this discussion is to bring to the attention of the 25th ITTC Seakeeping Committee the recent research at IIHR-Hydroscience & Engineering (Irvine et al., 2008) and Force/DMI (Simonsen et al., 2008) on (1) uncertainty assessment (UA) for towing tank pitch and heave tests in regular head waves and (2) derivation and validation of simple equations for estimating Fr for maximum pitch and heave response.

Uncertainty Analysis for pitch and heave tests

Uncertainty Analysis methods and procedures in ITTC QM Procedure 7.5-02-02-02 are applied in both studies. In Irvine et al. (2008), measurements include model ballasting, ship motions, incident head wave, and carriage speed for an L_{pp} = 3.048 m naval combatant (model 5512) undergoing pitch and heave motions in a towing tank. Uncertainty Analysis for the ballasting tests is not described in this discussion. The test campaign includes a range of Froude number Fr = 0, 0.19, 0.28, 0.34, 0.41, wavelengths λ / L_{pp} = 0.5 – 3.2, and wave steepness Ak = 0.025, 0.05, 0.075 where A and k are the wave amplitude and wave number $k = 2\pi / \lambda$, respectively. Data-reduction equations (DRE's) are written for encounter frequency f_e, Fourier reconstruction of incident head wave, pitch, heave (ζ_I, x_5, x_3), and pitch and heave transfer function (TF_{x5}, TF_{x3}), and phase (γ_{x5}, γ_{x3}).

$$f_e = \sqrt{\frac{g}{2\pi\lambda}} + \frac{U_c}{\lambda} \qquad (1)$$

$$\zeta_I(t) = \zeta_{I0} + \zeta_{I1} cos(2\pi f_e t + \gamma_{\zeta_{I_1}}) + \zeta_{I2} cos(4\pi f_e t + \gamma_{\zeta_{I_2}}) + \zeta_{I3} cos(6\pi f_e t + \gamma_{\zeta_{I_3}}) \qquad (2)$$

$$x_5(t) = x_{50} + x_{51} cos(2\pi f_e t + \gamma_{x5_1}) + x_{52} cos(4\pi f_e t + \gamma_{x5_2}) + x_{53} cos(6\pi f_e t + \gamma_{x5_3}) \qquad (3)$$

$$x_3(t) = x_{30} + x_{31} cos(2\pi f_e t + \gamma_{x3I_1}) + x_{32} cos(4\pi f_e t + \gamma_{x3_2}) + x_{33} cos(6\pi f_e t + \gamma_{x3_3}) \qquad (4)$$

$$TF_{x5} = \frac{x_{5_1}}{k\zeta_{I_1}} \quad (5)$$

$$TF_{x3} = \frac{x_{3_1}}{\zeta_{I_1}} \quad (6)$$

$$\gamma_{LCG} = \gamma_{\zeta I_1} - 2\pi\frac{D}{\lambda} \quad (7)$$

$$\gamma_{x_5} = \gamma_{x_{5_1}} + \gamma_{LCG} \quad (8)$$

$$\gamma_{x_3} = \gamma_{x_{3_1}} + \gamma_{LCG} \quad (9)$$

Where $\gamma_{\zeta I1}$ is the 1st-harmonic phase of the regular head wave at the servo wave gage, D is the distance between the wave gage and the model LCG, and λ is the regular head wave wavelength. Elemental bias errors are estimated for all variables in the DRE's either with manufacturer's specifications or independent tests. Error propagation equations are derived for the DRE's to establish the bias limit equations. Sensitivity coefficients are mostly evaluated analytically except for the FS harmonics and phases which are evaluated numerically.

Results indicate that the bias error in the wavelength B_λ contributes 85-100% to the uncertainty in all variables above. Bias error in the incident wave elevation and carriage speed measurement contributes 5-10% and 5% to the uncertainty in the transfer function and phase values, respectively. Precision limits are determined with an end-to-end, multiple-test method. Ten repeat tests at the same conditions are obtained for Fr = 0.28, Ak = 0.025. The datasets are spaced evenly in time through the course of the experiments (14 days) to account for factors that influence variability of the measurements such as ambient motions in the tank water and amplitude and wavelength differences in the regular head waves. The precision limits are computed with the standard multiple-test equation $P(M) = KSDev/\sqrt{M}$ where K = 2 is the coverage factor for 95% confidence level, and $SDev$ is the standard deviation of a sample of M = 10 realizations.

The UA results are listed in Table 1 including variable dynamic range D_X, bias and precision limits (B_X, P_X) and their contribution to total uncertainty, and total uncertainty U_X. Most variable uncertainties are composed of 95-100% bias error except for ζ_I which is only 2% bias and 98% precision. U_X for incident wave elevation is comparable to the reported value in Longo et al., (2007) for forward speed diffraction tests. U_X's for the transfer functions are low (~1%) but comparable to reported values of sinkage and trim U_X's in Longo and Stern (2005) for the same model and facility. O'Dea et al., (1992) present bias and precision uncertainties for linear- and nonlinear-regime measurements of pitch and heave motions for a 3.5 m containership model ITTC S-175. Although final uncertainties are not presented, the authors mention that seakeeping experiments and correlations with predictions are typically considered to have a precision of no better than 10-20%. U_X's for the transfer function phases are about 5% which is mostly due to uncertainty of the incident wavelength measurement.

In Simonsen et al. (2008), measurements include carriage speed, ship motions, resistance, thrust, torque, propeller rpm, and wave elevation (stationary and encounter) for a L_{pp} = 4.3671 m KCS container ship geometry undergoing pitch and heave motions in the deep water facility at Force Technology. The test campaign includes three Fr = 0.26, 0.33, 0.4, wavelengths λ / L_{pp} = 0.5 – 2.0, and wave steepness H / λ = 30-120 where H = 2A. DRE's are the same as Irvine et al., (2008) for Fourier reconstructions, transfer functions, and phase of pitch and heave and also include a resistance DRE written equation(10)

$$X' = \frac{F_{Xmeasured} + M\cos\theta(\dot{u} + qw - X_G q^2 + Z_G \dot{q})}{0.5\rho U_c^2 S} - \frac{M\sin\theta(\dot{w} - qu - Z_G q^2 - X_G \dot{q})}{0.5\rho U_c^2 S} \quad (10)$$

where $F_{Xmeasured}$ is the total X-force measured in the global coordinate system, M is the total mass of the model, ρ is the water density, S is the wetted surface area, u and w are the surge and sway velocities, and q is the pitch rate. Dots above the velocity quantities indicate accelerations.

Elemental bias errors, error propagation equations, sensitivity coefficients, precision limits, and total uncertainties are established similarly as in Irvine et al. (2008). Bias error in the incident wave elevation contributes 90% to the bias limit of the resistance and self propulsion measurements. The UA results are listed in Table 2. Bias and precision limits contribute 85% and 15%, respectively, to total uncertainties of resistance (9.84%) and self-propulsion (15.04%). U_X's are higher than calm-water resistance tests reported in Longo and Stern (2005).

Simple equations for estimating maximum response

Simple equations for estimating Fr for maximum pitch and heave response are derived by evaluating the encounter frequency equation $f_e = g/2\pi\lambda + U_c/\lambda$ with $f_e = f_n$ and $L_{pp} / \lambda = 0.75$. This produces an equation for $Fr_{mx,res}$ which is written

$$Fr_{mx,res} = 1.33\left(\sqrt{\frac{L_{pp}}{g}}\, f_n - \sqrt{\frac{3}{8\pi}}\right) \quad (11)$$

Equation (11) can be applied to either pitch or heave by substituting the appropriate expression for pitch $f_5 = \sqrt{C_{55}/I_{55} + A_{55}}\ / 2\pi$ or heave $f_3 = \sqrt{C_{33}/m + A_{33}}\ / 2\pi$ natural frequency

and simplifying assumptions from Lloyd, (1989), i.e., $A_{55} \sim I_{55}$ and $A_{33} \sim m$. The following two equations express $Fr_{mx,res}$ for pitch and heave, respectively, in terms of vessel geometrical coefficients and constants.

$$Fr_{mx,res} = 1.33\left(\sqrt{\frac{C_{IT}}{96\pi^2 \hat{I}_{55}} \frac{1}{\left(L_{pp}/B\right)^3}} - \sqrt{\frac{3}{8\pi}}\right) \quad (12)$$

$$Fr_{mx,res} = 1.33\left(\sqrt{\frac{C_{WP}}{8\pi^2 C_B} \frac{1}{\left(T/L_{pp}\right)}} - \sqrt{\frac{3}{8\pi}}\right) \quad (13)$$

Irvine et al (2008) were not able to validate the equations since testing at Fr higher than maximum response Fr were not included in the test program. Subsequently, the KCS test program of Simonsen et al. (2008) was designed specifically to cover the maximum response conditions, i.e., Fr = 0.26, 0.33, 0.4 where the equations predict $Fr_{mx,res}$ = 0.33 produces maximum pitch and heave response when $f_e \sim f_n$ = 0.9 Hz and $L_{pp} / \lambda = 0.75$.

EFD heave results from Simonsen et al. (2008) are consistent with Irvine et al. (2008) since they show that heave response is maximum when $f_e \sim f_n$, and for $L_{pp} / \lambda = 0.75$ (Fig. 1a), maximum heave is observed for Fr = 0.33. The pitch results are inconsistent with Irvine et al. (2008) since the maximum response occurs for $f_e < f_n$ and $L_{pp} / \lambda <$ 0.75 (Fig. 1b). Interestingly, peak values for added resistance are observed at $L_{pp} / \lambda \sim 0.75$and $f_e \sim f_n$ which is evident in Fig. 1c.

References

Irvine, M., Longo, J., and Stern, F., (2008), "Pitch and Heave Tests and Uncertainty Assessment for a Surface Combatant in Regular Head Waves," *Journal of Ship Research*, Vol. 52, No. 2, pp. 146-163.

Lloyd, A.R.J.M., (1989), *Seakeeping: Ship Behaviour in Rough Water*, Chichester, UK.

Longo, J., and Stern, F., (2005), "Uncertainty Assessment for Towing Tank Tests With Example for Surface Combatant DTMB Model 5415," *Journal of Ship Research*, Vol. 49, pp. 55-68.

Longo, J., Shao, J., Irvine, M., and Stern, F., (2007), "Phase-Averaged Nominal Wake for Surface Ship in Regular Headwaves," *Journal of Fluids Engineering*, Vol. 129, pp.524-540.

O'Dea, J., Powers, E., and Zselecsky, J., (1992), "Experimental Determination of Non-linearities in Vertical Plane Ship Motions," *Proceedings*, 19th ONR Symposium on Naval Hydrodynamics, Seoul, Korea.

Simonsen, C., Otzen, J., and Stern, F., (2008), "EFD and CFD for KCS heaving an pitching in regular head waves," *Proceedings*, 27th ONR Symposium on Naval Hydrodynamics, Seoul, Korea.

Table 1 Coupled pitch and heave test uncertainty assessment results at Fr = 0.28 (Irvine et al., 2008).

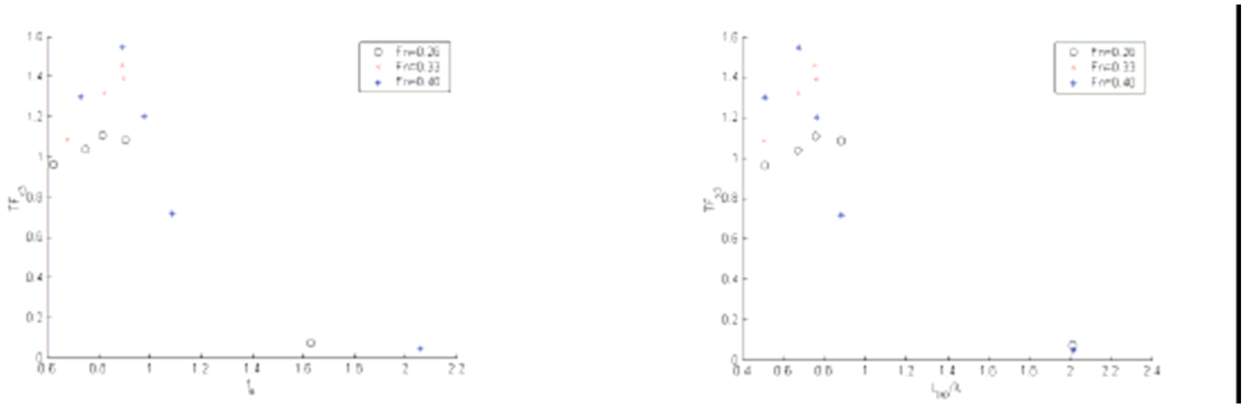
Term	D_X †	B_X [10^{-2}]	B_X^2/U_X^2 (%)	P_X [10^{-2}]	P_X^2/U_X^2 (%)	U_X [10^{-2}]	U_X/D_X (%)
f	0.584 (Hz)	0.3448	97.3	0.0571	2.7	0.3495	***0.6***
f_e	0.92 (Hz)	0.3537	96.0	0.0719	4.0	0.3609	***0.4***
ζ_{I1}	8.58 (mm)	0.7236	2.1	4.901	97.9	4.955	***0.6***
$\gamma_{\zeta I1}$	2π	20.58	100	0	0	20.58	***3.3***
TF_{x5}	1.0	1.225	97.9	0.1800	2.1	1.238	***1.2***
TF_{x3}	1.0	0.9629	94.5	0.2322	5.5	0.9905	***1.0***
γ_{x5}	2π	29.19	100	0.6854	0	29.19	***4.6***
γ_{x3}	2π	29.18	100	0.6337	0	29.19	***4.6***

†: D_X is the range of X

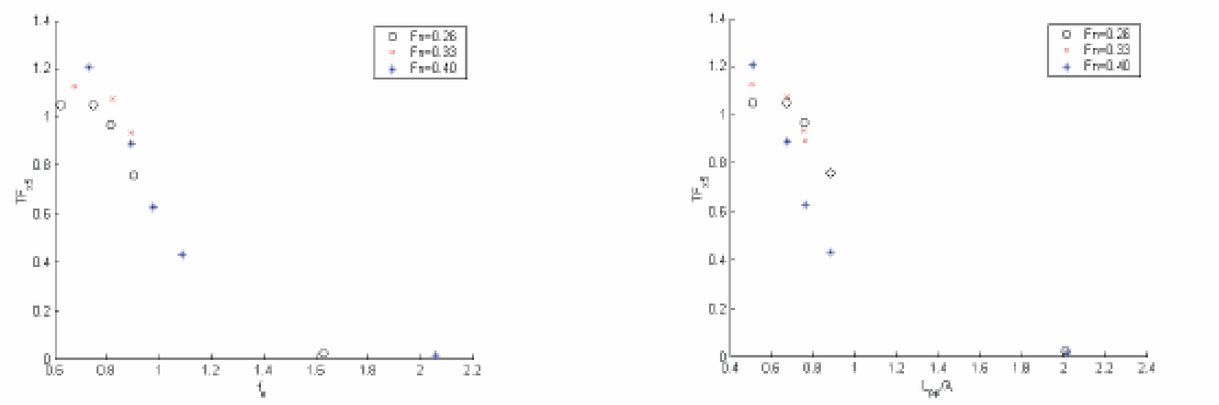
Table 2 Coupled pitch and heave test uncertainty assessment results at Fr = 0.26 (Simonsen et al., 2008).

Term	D_X †	B_X [10^{-2}]	B_X^2/U_X^2 (%)	P_X [10^{-2}]	P_X^2/U_X^2 (%)	U_X [10^{-2}]	U_X/D_X (%)
Resistance	0.03082	0.2806	85.6	0.1151	14.4	0.3033	***9.84***
Self propulsion	0.02910	0.4009	83.9	0.1756	16.1	0.4377	***15.04***

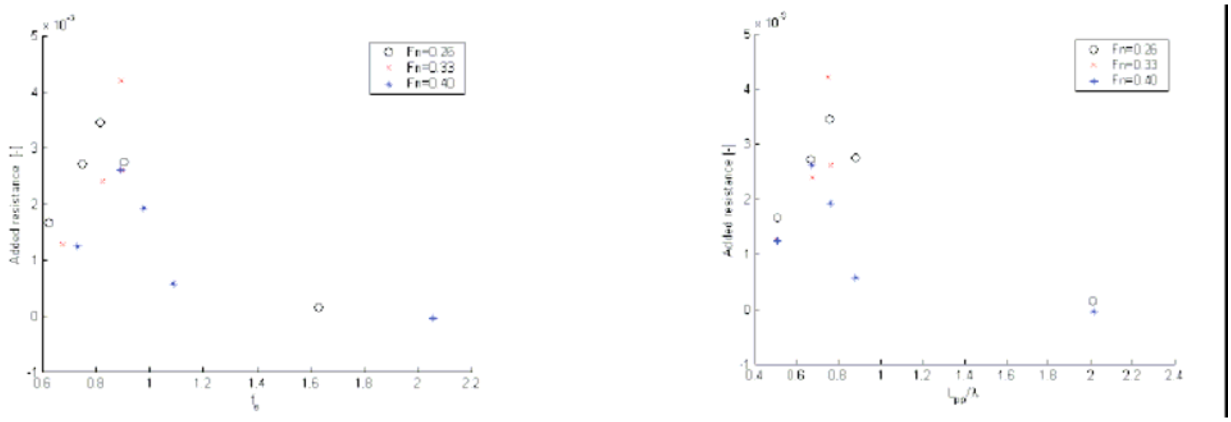
†: D_X is the range of X



(a) KCS heave results



(b) KCS pitch results



(c) KCS added resistance results

Figure 1 Heave and pitch transfer functions and added resistance versus f_e (left) and L_{pp} / λ (right) for an L_{pp} = 4.3671 m KCS container at three Fr.

1.2 Discussion to the 25th ITTC Seakeeping Committee by Ahmed Derradji, Canada

What are the uncertainties in wave length and in wave amplitude?

As indicated by D.Murdy this morning that there are significant uncertainties in wave height and length . Can the seakeeping committee suggest or investigate ways for how to minimize these 2 main sources of uncertainties?

1.3 Discussion to the 25th ITTC Seakeeping Committee by Anton Minchev, Force Technology, Denmark

Thank you for the comprehensive report and clear presentation.

The accurate prediction of added resistance / power in a seaway is getting more and more important in view of improving sea trial predictions, vessel route planning and optimization. In this respect I would like to refer to the section of added resistance/power in waves.

My question is how the towing force necessary to meet the “ship” self-propulsion point is applied in your recommended procedure for added power determination, more specifically in the torque and revolution method (QNM)?

1.4 Discussion to the 25th ITTC Seakeeping Committee by David C. Murdy, NRC – IOT, Canada

I applaud the initiative of the committee in making contact with the ISSC Loads Committee and holding a joint meeting.

Did the discussion during the joint meeting lead to any direct benefits such as need to spend less time on something because the ISSC committee was working on it?

1.5 Discussion to the 25th ITTC Seakeeping Committee by Giles Thomas, Australian Maritime College, Australia

In line with the previous discussions I would like to thank the committee for their very comprehensive and valuable report.

In particular I congratulate the committee on their work on establishing a set of parameters for benchmark data.
It will be a terrific resource for potential publishers of seakeeping experimental results.

I have two questions:

1. Did the committee give thought to approaching previous publishers of high-speed vessel data in oblique seas to ascertain if full information would be available? Since presumably all of the required parameters would have been recorded during testing, although they might not have been published.

2. The method used to ascertain the gyradii of models can significantly influence the resulting motions. This has been our experience when attempting to replicate experiments, concerning catamaran motions, conducted previously at another institution. Could the committee add to their list of required parameters for benchmark data the method used to measure the model radii of gyration?

1.6 Discussion to the 25th ITTC Seakeeping Committee by Mehmet Atlar, University of Newcastle, UK

Thank you for committee’s contributions in many areas including “resistance increase in waves” that is becoming more and more important from the point of view of its accurate prediction.

I would like to ask committee's opinion if there would be any benefit to import the estimation of this resistance component by measuring the motions on board (on-line) of a ship and hence – at least make a better prediction of the contribution due to the vessel motions. Of course the contribution due to the diffraction still needs to be estimated using numerical tool.

1.7 Discussion to the 25th ITTC Seakeeping Committee by Neil Bose, AMC University of Tasmania, Australia

1. In the data presented in figure 15, no comparison is given to model experiments, yet the conclusion is that the 3 methods which agree are better than the DPM, which should be discontinued. Did the committee compare these methods with experimental data and could they publish this comparison?

2. Several reports refer to previous versions of procedures. Does the ITTC provide access to previous versions of the Quality Manual?

1.8 Discussion to the 25th ITTC Seakeeping Committee by Stephen R. Turnock, University of Southampton, UK

I would be grateful if the committee could clarify some apparent contradictions in their report.

Firstly, could you explain on page 241 why if particle methods (SPH etc.) are still of limited practical use why they are considered a significant tend, especially as my understanding is that not only is pressure different to extract but there is even more uncertainty associated with the inclusion of viscous turbulent behaviour important for damping coefficients for sloshing and slamming.

This also links to a second point on page 242, where CFD tools are not generally useful for slamming and then previously on page 227 results are presented by three authors with at least one quoted as "validated" and no critical comments included which would support the statement on page 242.

I would like to bring to the attention of the committee recent work of Goddedge et al. who have done detailed validation studies of sloshing calculations which has shown that for violent events air and water compressibility effects need to be included as well as viscous unsteady boundary layers.

In conclusion, I would like to thank the committee for an excellent report and presentation.

Goddeidge, B., Tan, M., Earl, C., Turnock., S., 2007, Boundary layer resolution for modelling of a sloshing liquid, Proc of ISOPE.

2. COMMITTEE REPLIES

2.1 Reply of the 25th ITTC Seakeeping Committee to Joe LONGO, Claus Simonsen, Fred Stern

We thank the authors for providing the well-documented uncertainty analysis and the methodology for estimating the Froude number for maximum heave & pitch response. The committee will pass on these results to the 26th ITTC Seakeeping Committee for consideration.

2.2 Reply of the 25th ITTC Seakeeping Committee to Ahmed Derradji

We thank Dr. Derradji for his comments.

I refer Dr. Derradji to the report of the Specialist Committee on Uncertainty Analysis (Chapter 5) and the example illustrated for wave height (pp. 441-442).

Uncertainties in parameters such as wave height and wavelength are a function not only of the instrument used to measure waves, but also in the mechanism that creates them.

Thus, as shown in the example, a wave height gage calibration is estimated to be within ±4.1 mm. The measurement of a single wave train from a single gage provided roughly the same uncertainty.

Repeat measurements indicated an uncertainty of ±11 mm and multiple gage measurements produced uncertainty of ±29 mm.

The conclusion in this example is that the wavemaker and its control system exhibit a greater uncertainty in producing consistent waves than the uncertainty of the measurement of the wave height gage. Thus, the case is made for repeatability as the method for determining uncertainty for wave height measurement, and this should extend to wavelength as well.

2.3 Reply of the 25th ITTC Seakeeping Committee to Anton Minchev

Thank you for your written discussion. We also think prediction of resistance and/or power at sea will be very important from the economical and ecological viewpoints for shipping all over the world.

In the self-propulsion tests in waves, the model ship is towed with the load of skin friction correction (SFC) obtained from the self-propulsion tests in still water normally by using a pulley and weight system. But other systems or procedures seem to be proposed. For the 26th ITTC, these model test procedures should be reviewed in the seakeeping committee.

2.4 Reply of the 25th ITTC Seakeeping Committee to David C. Murdy

Our meeting and discussions with the ISSC I.2 Loads Committee did not identify any specific areas where duplication of effort could be avoided at this time. The intent of this first meeting was to establish communication, to investigate ways to share information, resources & expertise, and to identify joint collaboration opportunities. However, building on this foundation, it is expected that future meetings and exchanges will uncover areas of similarity and/or overlap that can be streamlined. The sharing of studies, reports, procedures, benchmark data, and committee members were proposed as methods for improving communication.

2.5 Reply of the 25th ITTC Seakeeping Committee to Giles Thomas

We thank Dr. Thomas for his comments and for reinforcing the importance of guidance for producing good quality benchmark data. In response to his two questions:

The committee did consider approaching previous publishers of high-speed vessel data but in their experience such data are usually commercially sensitive which will not be released in the public domain. In the wider context, the criteria for benchmark data represent minimum requirements, primarily for those facilities generating new data. However, legacy data should not be automatically precluded if they do not meet these requirements.

The committee can not comment on whether the measurement of model radii of gyration is dependent upon the measurement method. However, the committee agrees that, in the context of good experimental practice, it is appropriate to describe the methods employed to determine the radii of gyration.

2.6 Reply of the 25th ITTC Seakeeping Committee to Mehmet Atlar

We thank Mr. Atlar for an intriguing proposition. While real-time motion measurements might provide an indication of the power increase necessary based on experimental results, the question is to what end would this information be utilized? The work of the Committee to find the best method for predicting the power increase in realistic seas from regular wave experiments was somewhat confined to the model testing regime. Certainly, the correlation of motion measurements with actual power data in irregular waves provides an avenue for verification of the techniques described. How the contemporaneous ship motion information might be used otherwise is unknown.

2.7 Reply of the 25th ITTC Seakeeping Committee to Neil Bose

Thank you for your written discussion.

In Figure 15, the predicted results of power increase in irregular waves based on four kinds of procedures are compared, which are obtained from the model test results in still water and in regular waves.

Preferably, they are to be compared with the model test results in irregular waves, even though their accuracy is less precise in comparison with those in regular waves.

Thus far, appropriate sets of model test data in still water, in regular waves and in irregular waves have not been obtained.

The Seakeeping Committee of the 26th ITTC will continue to collect such data and evaluate them.

Reply (1) to discussion 2. From Secretary: Archive versions of the QM are available on the web site.

Reply (2) to discussion 2. Regarding availability of older version of procedures, the ITTC website contains an archive of older version of technical procedures as well as those presently valid (Latest approved versions).

Website address: http://ittc.sname.org/

2.8 Reply of the Seakeeping Committee to Stephen R. Turnock

We thank Dr.Turnock for his questions and comment.

Particle methods are currently of great interest, and a lot of work has been done during last several years. In particular, interest has been focused on the SPH method. SPH was originally developed for the movement of planets in space, and later extended to simulating violent free surface flows. Because the method was originally based on the assumption of weakly compressible fluid flows, the resultant pressure has exhibited very spiky behaviour, particularly for the problems with hydrodynamic impact.

One of the strong advantages of SPH and other particle methods is its capability of simulating very violent flows. Therefore, this method seems very useful to simulate strongly nonlinear flows, such as bow-wave breaking, dam breaking, violent sloshing flows, green water, and so on.

However, this method has a weakness in predicting hydrodynamic pressure. In this sense, SPH presently has a limited, practical use. The particle methods have great potential to be developed and extended further for the accurate prediction of pressure and loads as well as for more complicated flow problems.

For instance, some recent research (e.g., by the group of Nantes University led by Ferrant) showed significant improvement of pressure prediction. As pointed by Dr. Turnock, however, there are some technical issues for its application.

Due to strong nonlinearity and difficulty in predicting accurate impulsive pressure, CFD tools are still not in a mature enough status yet for slamming analysis. For practical use, the generalized von Karman and Wagner methods seem to be the most popular scheme at this moment. However, the application of CFD tools is increasing, and some papers have introduced systematic and careful validations for the accuracy and practicality of CFD methods.

As Dr. Turnock pointed, without including all the supporting details, the report appears to be somewhat inconsistent. However, it should be also understood that all the details cannot be introduced in the report, and we refer the reader to the specific reference.

Finally, we thank Dr. Turnock for contributing another good technical reference. Our committee surveys papers from a wide variety of journals and conferences, including ISOPE.

Among these, we select meaningful, representative papers for the report.

Thus, not all papers are included and, unfortunately, some good papers are inadvertently overlooked. Our apologies.