

Technical Committee on Resistance and Propulsion

2017-2021

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Virtual

- 18 June 2021

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- Development of a procedure for wave profile measurement and wave resistance analysis.
- Investigate feasibility of a procedure for verification and validation of the detailed flow field data.
- Cooperation with other committees:
 - Specialist Committee on Energy Saving Methods on subjects of common interest.
 - Specialist Committee on Ships in Operation at Sea
 - Specialist Committee on Combined CFD/EFD Methods
- Investigate and propose new roughness correction methods for both hull and propeller.
- Validate procedure 7.5-02-03-01.7, 1978 ITTC Performance Prediction Method for Unequally Loaded, Multiple Propeller Vessels.
- Continue with the monitoring of existing full scale data for podded propulsion.

- Monitor the use of and, if possible, develop guidelines for quasi-steady open water propeller and propulsion model tests.
- Conduct a survey of cavitation erosion modeling and prediction methods.
- Identify the need for a procedure concerning rim drive model testing and performance prediction.
- Identify the influence of the new F_D definition on power prediction.
- Investigate the need to change the standard criterion for Re in model tests of propulsors as well as in the aspect of CFD validation.
- Investigate the need of change of scaling methods with regard to propulsors (including pods).
- Investigate and describe a propulsor performance in waves, and discuss the scale effects on its modelling.





Review of state of the art

Update the state-of-the-art for predicting the performance of different ship concepts emphasizing developments since the 2017 ITTC Full Conference.





New experimental techniques and extrapolation methods

- Resistance
 - Ship model tests
 - Air-bubbling technique
 - Ship-wave-ice interaction
 - Measurement technologies (*PIV, LDV, OCT)
 - Flow over rough surface, compliant coating, etc.
 - Stern-wake measurement
 - Extrapolation methods
 - CFD at different scales vs extrapolation
 - Towing test vs similarity law scaling
 - Shallow water

*Particle Image Velocimetry (PIV), Laser Doppler Velocimetry (LDV), Optical Coherence Tomography (OCT)



Luo et al. (2018)'s experimental setup with paraffin model ices to investigate ship-wave-ice interaction



system to measure the flow in the stern wake of a ship model

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New experimental techniques and extrapolation methods

- Propulsion
 - New experimental techniques
 - Performance of a rim-driven tunnel thruster
 - Hydro-elastic response of flexible composite propellers
 - Combined CFD/EFD methods
 - Submarine hull, free surface and propeller interactions
 - Pressure-relieving holes for noise mitigation





Grasso et al. (2019)'s stereo camera setup to measure the propeller deflection





Aktas et al. (2019)'s propeller with pressure-relieving holes for cavitation/ noise reduction





Wave profile measurement procedure

Develop a new procedure for wave profile measurement and wave resistance analysis.





Wave profile measurement and analysis

- The purpose of observing, measuring or simulating the wave profile for a model ship at a given speed in a towing tank is mainly to evaluate the ship hull form, and to reduce the wave resistance by modifying the ship hull form.
- The quantitative measurement techniques of wave height around the model ship free surface field include intrusive and non-intrusive techniques. The resistive and capacitive type wave gauges are widely used as intrusive methods. Non-intrusive techniques include the optical sensors, acoustic sensors, radars, imaging methods, and combined laser-scanner and video hybrid system, etc.
- Although the quantitative wave profile measurement is mainly used for validation of CFD codes and improvement, there can still be a need to incorporate it to routine towing tank resistance test to estimate the wave resistance in a more rapid way.





Wave profile measurement and analysis

New procedure

- The widely used longitudinal wave cut method together with the Newman-Sharma analysis Method is recommended in the procedure.
- An example of wave pattern resistance calculation from wave profile measurement data is demonstrated in the appendix of the procedure.
- The new procedure is suggested to be numbered with 7.5-02-02-04, which is under the category of Resistance 7.5-02-02.

Recommendation for the next term

• Review the state-of-the-art of high Froude number surface ship wave breaking, which is multi-phase complex flow and is also a difficulty both for quantitative measurement and CFD simulation.





Investigate the need of change of standard hull and propeller roughness. Develop and propose new roughness correction methods for both hull and propeller.





Background



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"How might the roughness of coatings and biofouling be related to full-scale?"

Experiments to investigate roughness functions



Flat plate in smooth condition





Flat plate in rough condition



(a) ½-bow-rough condition



3.591 m/s

(b) ½-aft-rough condition





Similarity law scaling and CFD











- There is a need to adopt/develop new methods to predict the roughness effect of modern fouling-control coatings and marine biofouling on ship hydrodynamic performance. The similarity law scaling and CFD can be regarded as the most promising potential methods to predict such effects accurately. Both methods require the use of roughness functions of the surfaces in question.
- There is a need to generate a database of roughness functions of modern foulingcontrol coatings and surfaces representing heterogeneous biofouling accumulated on ship hulls and propellers.
- For this reason, it is recommended that standardized methods for roughness function determination should be adopted by researchers.
- It would, therefore, be useful to investigate the need for a guideline or procedure for the measurement of roughness functions for different surface finishes or conditions so that this information can be used for predicting the roughness corrections for both hull and propeller.





Quasi-steady propeller testing

Continue with monitoring the use of and, if possible, develop guidelines for quasi-steady open water propeller and propulsion model tests.





Quasi-steady open water propeller tests

- A quasi-steady (QS) method is a promising technique for time saving of POW test and propulsion test. MARIN has studied the method in the past and has shown a good correlation between QS tests and conventional ones. The last committee stated that validation by other than MARIN was a future issue.
- During this term, HSVA presented the effectiveness of the QS resistance tests for more than 18 different ships in several different setups and confirmed good agreement with the conventional tests.
- The reliability of the QS method has been confirmed by both MARIN and HSVA, and it appears to be a viable alternative to conventional testing.

- However, to develop the guidelines, limitation of the application, e.g. how much wave making and/or dynamic trim and sinkage are allowed, should be clarified.
- It is recommended in the next term to conduct benchmark tests and validate the method by more model basins.



Distribution of discrete deviations of the QS propulsion tests to the conventional tests





Identify the need of the elaboration of the procedure concerning the rim drives model testing and performance prediction.



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- Committee prepared a questionnaire on rim driven thruster testing
- Sent to 92 members of ITTC
- 13 completed responses received
- 6 organisations are actively involved in these type of devices

Is your company involved in activities related to rim thrusters? (Yes/No)



Yes No No response









Do you consider it advisable to develop a special ITTC procedure for model tests of rim thrusters and their performance prediction? (Yes/No).



■ Yes ■ No





- · Lack of full scale test data
- Model tests carried out in towing tank or cavitation tunnel but special mounting arrangements and drive units required
- Thrust measured on whole unit using load cells or 6-component balance
- Torque either measured using load cells, 6-component balance, or derived from power
 - Friction in the gap between inner and outer ring needs to be accounted for
 - Torque on nozzle may not be negligible so needs to be measured
- Performance prediction can use standard ITTC method but needs corrections for gap friction. CFD commonly used for scaling.
- In summary there is no consistent approach to measurement or performance prediction so recommend that next RPC work towards a procedure.





Investigate the need of changing the standard criterion for Re in model tests of propulsors as well as in the aspect of CFD validation.





- As described in the ITTC recommended procedures 7.5-02-03-02.1 Open Water Test and 7.5-02-03-01.4 1978 ITTC Performance Prediction Method, the minimum Re number must not be lower than 2×10⁵.
- There are some concerns about unstable propeller open water test data and about the applicability of corrections for low blade area ratio propellers or other unconventional propulsors, when below the critical Re number.
- The 28th ITTC Propulsion Committee suggested that it might be necessary to increase the minimum Re to at least 3×10⁵ to have enough margin to obtain reliable data. An additional literature review for the minimum Re is conducted during 29th ITTC term.





- From Kim et al. (1985), the difference of K_T and K_Q in Reynolds number are unstable at Re<5×10⁵ for a propeller model KP088 (D=0.25m, P/D=1.635, Ae/A0=0.779) in the towing tank open water test. And there is no difference in terms of the thrust and torque of the propeller due to three wing section profiles (NACA 66, MAU and NSMB series). The measured values are stabilized when Re≥3×10⁵.
- Sheng et al. (1979) investigated the scale effect by using five propeller models of same MAU 4-60 (P/D=0.788) in towing tank open water test condition at Reynolds number ranging from 1.2×10⁵ to 8.1×10⁵. The recommended critical Re was 3.0×10⁵. If the Re < 2.5×10⁵, the scale effect was still existing after ITTC 1978 scale effect correction.



Five propeller models of same MAU 4-60



Open water efficiency variation against Re number from Sheng (1979). The dotted lines represented the efficiency after scale effects correction using ITTC1978 method and solid lines represented the model test results.





- Hasuike et al (2017) presented the extensive oil flow visualization and numerical calculation for the scale effect of a series of propellers (27 in total) for a chemical tanker. Flow patterns in SPT condition at Re=2.7×10⁵ were similar (laminar and include laminar flow separation) to that in POT condition at Re= 3×10⁵ which was typical Reynolds number in SPT condition.
- Baltazar et al (2019) presented the numerical prediction for an open water propeller (P_{0.7R} /D=0.757 and Ae/A0=0.464) at different Reynolds numbers ranging from 10⁴ to 10⁷. From the flow pattern numerical results at Re=1×10⁵ and 5×10⁵ and K_T K_Q trend with Re ranging from 10⁴ to 10⁷, it seems that 5×10⁵ might be the minimum Re.
- Yao (2019) presented the CFD investigation on the flow pattern of a PPTC propeller model (D=0.25m, P/D=1.635, Ae/A0=0.779) using commercial codes STAR-CCM+. The critical Re for such case is estimated to be around 3.48×10⁵.
- Heinke et al (2019) investigated the Reynolds number influence on open water characteristics using four short chord length model propellers. For propeller A (D=0.239m, Ae/A0=0.418) and propeller B (D=0.239m, Ae/A0=0.444), the thrust coefficients are nearly constant, while the torque coefficient decreases linearly with rising Reynolds number if Re is above 5×10⁵. The ITTC 1978 correction method is applicable for consistent full scale propeller open water characteristics when the Re is above 5×10⁵.





- The minimum Reynolds number (2×10⁵) in the present ITTC procedure is probably not sufficient for obtaining stable open water test data. This minimum Reynolds number generally ranges from 3×10⁵ to 5×10⁵ for different propeller types. This range might not be suitable for other propeller type, like CLT propeller and ducted propeller etc., which should be treated separately.
- One specific minimum Reynolds number which is applicable for all propeller type may not be possible. Each model
 basin is suggested to analyze the specific propeller case and choose the proper minimum Reynolds number
 especially for propulsion factors evaluation purpose.
- Careful attention should be paid for propeller open water RPM selection to achieve the similar transition or turbulent flow, not fully laminar flow pattern on the propeller model surface, and also for the proper propeller dynamometer range to reach the sufficient measurement resolution. A series of Reynolds number variation open water test or CFD simulation covering self propulsion propeller Reynolds number range is recommended for investigating the Reynolds number dependency.
- The ITTC procedures 7.5-02-03-01.4 1978 ITTC Performance Prediction Method and 7.5-02-03-02.1 Open water test procedures are recommended to be revised during 30th ITTC term.





Cooperation with other committees

Cooperate and exchange information with the Specialist Committee on Ships in Operation at Sea regarding consequences of EEDI and with the Specialist Committee on Energy Saving Methods.





Cooperation with the SC on Ships in Operation at Sea

- Recommended Procedure 7.5-02-03-01.4 "1978 ITTC Performance Prediction Method" was reviewed.
- The SOS committee found the inconsistency on a load variation test (LVT) in the current procedure. The figures, which are used for obtaining ξ_{V} in LVT, are derived from different data sets.
- The committee and the SOS calculated load variation factors for SSPA benchmark data. The load variation coefficients, ξ_P , ξ_N , ξ_V , derived from the same data set are almost same among all facilities.
- The committee has replaced Figure 4 and 5 in the current procedure with the new ones derived from the same dataset.
- For reference, the calculation detail for deriving the coefficients has been added as an appendix of the procedure.



Comparison of load variation factors among SSPA, the SOS and the RPC

	SSPA	The SOS	The RPC
ξ _P	-0.19	-0.19	-0.19
ξn	0.25	0.25	0.25
ξ _v	0.33	0.34	0.32





Validation of 7.5-02-03-01.7

Conduct the validation of the procedure 7.5-02-03-01.7, 1978 ITTC Performance Prediction Method for Unequally Loaded, Multiple Propeller Vessels.





Validation of the procedure 7.5-02-03-01.7

- For the validation of this procedure, the detailed sea trial data for each shaft is required to be compared with model test prediction, but R&P committee cannot find any sea trial data in public domain or from contact with shipping company
- Leaving this task as future work, R&P committee refined this procedure with sample data/graph/explanation to make this guide more comprehensive and practical
- Procedure title changed: "Performance Prediction Method for Triple Shaft Vessels" → "Performance Prediction Method for Unequally Loaded, Multiple Propeller Vessels"; This means more general description and definition are requested in the guide
- Key point in the data analysis of ships having different loading of propeller due to different design and position is how the interaction effect between propeller and hull is evaluated. This is presented as "thrust deduction factor" of each propeller





Validation of the procedure 7.5-02-03-01.7

- Thrust deduction factor is the ratio of the resistance and the (corresponding) thrust
- The question is how much (what portion of) resistance is burdened or distributed in each propeller and in other words "which propeller interacts more strongly with the hull?"
- Procedure 7.5-02-03-01.7 presents three steps to get the thrust deduction factor

$$1 - t_i = \gamma_i \frac{R_{TM} - F_D}{T_i} \text{ (thrust deduction factor)}$$

$$\gamma_i = \frac{T_i(1 - \tau_i)}{\sum_{j=1}^3 T_j(1 - \tau_j)} \text{ (load fraction)}$$

$$1 - \tau_i = -\left(\frac{\Delta F}{\Delta T}\right)_i \text{ (resistance fraction)}$$

- The ratio of resistance fraction of each propeller (not the absolute value) determines the thrust deduction factor by definition
- Three kind of load variation tests are requested: LVT1 for all propeller, LVT2 for center propeller and LVT3 for side propeller



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Validation of the procedure 7.5-02-03-01.7

Sample calculation

 Model test data is provided for 1,500 passenger/1,600 lane meters RoPax ferry and it has one center propeller and two wing-side propeller



Load variation test for resistance fraction and the result of $\left(\frac{\Delta F}{\Delta T}\right)_i$

• Model test prediction of each propeller: in this case, the center propeller has a higher value of thrust deduction factor and this means a stronger interaction of center propeller with hull

Item	1-τί	γi	t	wts	KT/J2	JTS	etaH	EtaO	EtaD	EHP	DHP	DHP_total
	[-]	[-]	[-]	-	-	-	-	-	-	[kW]	[kW]	[kW]
Center	0.92	67.1%	0.173	0.191	0.355	0.782	1.023	0.669	0.678	6178	9106	14546
Side	0.99	16.5%	0.110	0.045	0.131	1.101	0.932	0.591	0.558	3035	5440	



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Influence of F_D definition

Identify the influence of the new F_D definition on power prediction.





Influence of the new F_D definition

- ITTC 28th general conference accepted to adopt the new FD definition to enhance the accuracy of powering performance prediction adding CA in the formula, but did not provide any basis on whether it actually improved the accuracy
- From the year of 2008, the existing (old) △CF was divided into new △CF and CA (i.e, CTS includes new △CF and CA, but only (new) △CF was only included in FD calculation). This separation had been proposed from 19th ITTC because the existing △CF had been criticized for not properly reflecting the roughness effect of the hull and finally adopted at 25th ITTC (2008)
- From the year of 2017, the new FD definition includes the CA and R&P committee is requested to identify the impact on the powering prediction

~ ITTC 24 th (2005)	$F_D = 1/2 ho_M V_M^2 S_M [C_{FM} - (C_{FS} + \Delta C_F)]$
	$\Delta C_F = [105 (rac{k_S}{\mathcal{L}_{WL}})^{1/3} - 0.64] imes 10^{-3}$
ITTC 25 th (2008)~27 th	$F_D = 1/2\rho_M V_M^2 S_M [C_{FM} - (C_{FS} + \Delta C_F)]$
(2014)	$\Delta C_F = 0.044 [(rac{k_S}{\mathcal{I}_{WL}})^{1/3} - 10 Re^{-1/3}] + 0.000125$
ITTC 28 th (2017)	$F_D = 1/2\rho_M V_M^2 S_M [C_{FM} - (C_{FS} + \Delta C_F + C_A)]$
	$\Delta C_F = 0.044 [(rac{k_S}{L_{WL}})^{1/3} - 10 Re^{-1/3}] + 0.000125$
	$C_A = (5.68 - 0.6 log Re) imes 10^{-3}$



Influence of the new F_D definition

• The actual value of F_D in propulsion test with normal size of model ship is calculated. If we take the change from 27th to 28th, the typical value of change is as below;

Ship Type	Value	ITTC 28 th (2017)	ITTC 25 th (2008)~27 th (2014)	ITTC ~24 th (2005)
VLCC	$F_D(N)$	14.47	15.33	14.85
	∆C _F *1000	0.118	0.118	0.169
(14.5K(5)	C _A *1000	0.092		
	Fd(N)	13.70	15.33	14.03
Aframax (1/15kts)	$ riangle C_F^*1000$	0.117	0.117	0.251
(14.5Kts)	C _A *1000	0.167		
Cuerren	Fd(N)	19.46	21.41	19.93
(15kts)	$ riangle C_F^{*1000}$	0.122	0.122	0.224
	C _A *1000	0.135		
94k LDGC	Fd(N)	12.64	14.03	12.72
84K LPGC	$ riangle C_F^{*1000}$	0.137	0.137	0.279
(17KG)	C _A *1000	0.151		
174k Twin	Fd(N)	25.44	26.27	25.36
LNGC	$ riangle C_F^{*1000}$	0.152	0.152	0.199
(19.5kts)	C _A *1000	0.043		
15 41 66	Fd(N)	36.95	36.02	36.31
(22ktc)	$ riangle C_F^{*1000}$	0.162	0.162	0.152
(22KIS)	C _A *1000	-0.033		

VLCC	-5.6%
Aframax	-10.7%
Suezmax	-9.1%
VLGC	-9.9%
174k LNGC	-3.2%
15.1k CC	2.6%

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Influence of the new F_D definition

- A total of 31 cases from committee members were collected, covering a wide variety of ship types and speed.
- The influence of F_D for large and high speed vessels is relatively limited.
- For small and slow vessels, the impact of F_D definition change over power prediction is considerable and the propulsion efficiency change (EtaD) is about 1~2%.
- For the revolution of propeller, the impact of F_D definition change is very limited around 0.2%.
- The new F_D definition appears to make a very small difference to the powering prediction compared to previous definition.







Cavitation erosion modelling

Conduct a survey of cavitation erosion modeling and predicting methods.



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Cavitation erosion occurs when impulsive pressure from shock waves and/or microjets generated by bubble collapse exceeds some material threshold, such as its yield stress.





Model based on the energy balance

Model based on the microjet formation





Cavitation erosion modelling

It is difficult to simulate the erosion numerically because a wide range of scales in time and space should be treated in the calculation. Instead of direct simulations, erosion indicators derived from the macroscopic flow solved using CFD calculation are usually used.



Illustration of time and length scales

Most indicators relate to pressure p, cavity volume V, void fraction α and their time derivatives.



Cavitation erosion modelling



Hasuike et al. (2009)



Usta et al. (2017)



Melissaris et al. (2019)

- To assess the cavitation erosion risk practically, various erosion indicators have been proposed. These indicators are helpful for propeller designers to predict potential erosion areas and locations.
- However, it is unclear whether they always give reasonable predictions against various kinds of cavitation pattern. To evaluate the cavitation aggressiveness, some threshold for the indicator is required. Although they influence much on the erosion prediction, how to determine it is also unclear.
- Cavitation erosion modelling is a rapidly developing topic, and further developments should continue to be monitored, and updates to procedures should be considered in future.





Propeller performance in waves

Investigate and describe a propulsor performance in waves, and discuss the scale effects on its modelling.





Propeller Performance in Waves

- A literature study was undertaken to investigate and identify the influences of operating propellers in waves.
- The influences on the propeller inflow are broken down into two categories; wave dynamics, and induced flows from ship motions in waves.
- Influences were identified as added resistance, temporal and spatial variation of inflow wakes, ventilation, shaft speed variation affecting thrust, torque, efficiency, cavitation, and pressure pulses.





Calm water and wave agreement considering propeller inflow speed from McCarthy et al (1961)





Propeller Performance in Waves

 Fluctuations in the open water thrust and torque in waves are in good agreement with the calm-water uniform-flow performance curves for the propeller (McCarthy, 1961 and Taskar et al, 2016).

=> Efficiency is primarily affected by the average change in wake fraction and not much by wake distribution.

- For the low frequencies of encounter of a propeller and waves, unsteady effects may be neglected.
- Tokgoz et al (2017) investigated depth of propeller immersion in waves. Due to wave orbital velocities, the minimum thrust is achieved when the wave crest is at the propeller plane.
- Ventilation was shown to significantly affect the trend of thrust fluctuations where the maximum value of thrust occurs in the wave crest while the minimum values of thrust occur in the wave trough when ventilation occurs.



Calm water and wave agreement considering propeller inflow speed from Taskar et al (2016)



Correlation of Kt from waves and calm water and influence of ventilation for KVLCC2 propeller at J=0.5 from Tokgoz et al (2017)





Propeller Performance in Waves

- Tokgoz et al (2017) computed the KVLCC2 in waves and showed that when surge is
 essentially zero, the mean values of the EFD and CFD results are comparable. When the
 ship surges forward the thrust is not comparable.
- Taskar et al (2017) show that the mean wake fluctuations due to the wave orbital velocities are relatively constant and greater than that due to surge regardless of the wavelengths. The mean change in wake is more significant at low ship speeds.
- Hsin, Ching-Yeh et al (2016) concluded that the unsteady flow effects due to the ship wake is more important than that due to the ship motions.
- Taskar et al (2015) showed that cavitation and pressure pulses are directly related to wake distribution, and they depend less on average wake fluctuations. The relative stern motion was only shown to affect the range of Cpmin and not the angle of attack.
- Taskar et al (2016) additionally revealed that the blade root circulation in short waves was always greater than calm water and generally higher for all other wave conditions.
- Taskar et al (2017) found that contrary to the expectation of less hull wake influences for a twin-screw ship, both the cavitation and pressure pulses increased remarkably due to the effect of waves, as did the cavitation volumes.



Surging influence on thrust in waves from Tokgoz (2017) Region A negative surge, Region B relatively zero surge



Wake and relative stern motion influence on angle of attack and Cp_{min} from Taskar et al (2015)





Recommendations



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Recommendations

- Adopt the updated procedures:
 - 7.5-02-02-01
 - 7.5-02-02-02
 - 7.5-02-02-02.1
 - 7.5-02-02-02.2
 - 7.5-02-03-01.1
 - 7.5-02-03-01.3
 - 7.5-02-03-01.4
 - 7.5-02-03-01.7
 - 7.5-02-03-02.1
 - 7.5-03-01-01
 - 7.5-03-01-02
 - 7.5-03-02-02
 - 7.5-03-02-04

 Adopt the new procedure on "Wave profile measurement and wave pattern resistance analysis"



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Recommendations

- Develop new methods to predict the roughness effect of modern fouling-control coatings and marine biofouling on ship hydrodynamic performance.
- Develop a guideline or procedure for the measurement of roughness functions for different surface finishes.
- Continue attempting to obtain full scale data on multiple propeller vessels
- Continue trying to obtain full scale data on podded propulsors
- Develop a guideline/procedure on quasi-steady propulsion testing
- Develop a guideline/procedure for rim driven thruster testing and performance prediction
- The ITTC procedures 7.5-02-03-01.4 and 7.5-02-03-02.1 are recommended to be revised during 30th ITTC term to update the minimum Reynolds number for propulsion testing.

- Continue monitoring developments in cavitation erosion prediction
- Carry out a benchmark study on propeller performance scaling using CFD
- The procedures on CFD verification and validation should be reviewed and updated to reflect current best practice
- The requirements for testing and numerical evaluation of high speed vessels should be investigated
- The use of CFD to predict full scale ship performance and the need for validation at full scale evaluated
- The measurement and prediction of breaking waves should be further investigated
- Continue to monitor developments in hull and propeller model manufacturing
- Develop guidelines for model testing of low skin friction coatings and air lubrication systems.

