ITTC Quality System Manual

Recommended Procedures and Guidelines

Guideline

Hybrid Contra-Rotating Shaft Pod Propulsors Model Test

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Propulsion Committee of the 28th ITTC	28th ITTC 2017
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Hybrid Contra-Rotating Shaft Pod Propulsor Model Test

1. PURPOSE OF GUIDELINE

The purpose of this guideline is to provide an aid to model basins in conducting tests related to the propulsive performance of ships with Hybrid Contra-Rotating Shaft Pod propulsors (HCRSP propulsors).

The guideline addresses conventional displacement vessels meaning Froude number less than 0.45 and/or vessels with values of the volumetric Froude number less than 1.18.

The guidelines required the use of existing ITTC procedures 7.5-02-03-01.1 “Propulsion/ Bollard pull Test”, 7.5-02-03-01.3 “Podded Propulsor Tests and Extrapolation”, 7.5-02-03-01.4 “1978 ITTC Performance Prediction Method” and 7.5-02-03-02.1 “Open Water Test”.

Because of the lack of full scale validation data, the guideline addresses model scale only and does not consider extrapolation and full scale prediction in detail.

1.1 Definition of Hybrid Propulsion

First of all, definition of hybrid propulsor must be clarified. Hybrid propulsor is defined as propulsion system which consists of more than two different types of propulsor. There exist many combinations of hybrid propulsors, however they can be classified into two major groups: low interaction group and high interaction group. The low interaction group consists of different propulsors arranged in parallel. On the other hand, different propulsors arranged in line with a short distance in between the propulsors are usually classified as high interaction group. Note that propulsors mounted in fore and aft end of a ship, such as double-ended ferry, are classified as the low interaction group.

For the low interaction case, model test can be conducted following the conventional Propulsion Test Procedure 7.5-02-03-01.1 or Podded Propulsor Test Procedure 7.5-02-03-01.3 or Waterjet Propulsion Performance Prediction – Propulsion Test and Extrapolation 7.5-02-05-03.1. However, load varying test should be conducted for each propulsor separately to determine the self-propulsion point.

Thus the high interaction case is addressed in this guideline. Still many combinations of propulsor (e.g. conventional propeller, podded propulsor, waterjet, Z-drive, CRP and so on) are possible, however high interaction case is usually adopted aiming at recovering the rotational energy of propeller and effective combination is limited.

The guideline focuses to the most major combination of conventional shaft propeller in front of a podded propulsor or Z-drive and called as Hybrid Contra-Rotating Shaft Pod propulsors (HCRSP propulsors).

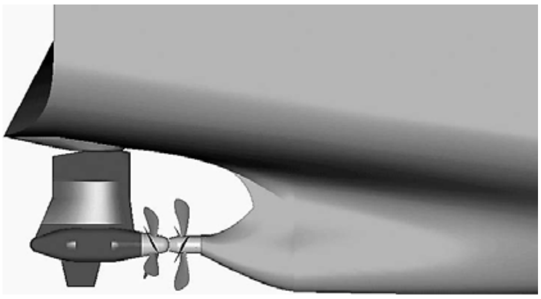

Figure 1: HCRSP propulsion system (Ueda 2004)

2. PARAMETERS

2.1 Non-dimensional Parameters

Advance Coefficient $J = \frac{V_A}{nD}$

Thrust Coefficient $K_T = \frac{T}{\rho n^2 D^4}$

Torque Coefficient $K_Q = \frac{Q}{\rho n^2 D^5}$

As the common basis, the advance coefficient is to be defined based on one propeller, usually the fore propeller.

2.2 Definition of Variables

D	(m)	Propeller diameter
n	(rps)	Rate of revolutions
Q	(Nm)	Propeller torque
R_U	(N)	Pod unit resistance
T	(N)	Propeller thrust
T_U	(N)	Pod unit thrust
F_D	(N)	Towing force
t	(-)	Thrust deduction factor
V_A	(m/s)	Advance speed
w_T	(-)	Thrust wake fraction
η_O	(-)	Open water efficiency
η_R	(-)	Relative rotative efficiency
ρ	(kg/m^3)	Mass density of water

Subscript $_{FP}$ presents the association with fore propeller

Subscript $_{AP}$ presents the association with aft propeller

Subscript $_{sys}$ presents the association with whole hybrid propulsion system.

3. DESCRIPTION OF GUIDELINE

Hybrid propulsor model tests consist of propulsor open water test, resistance test and self-propulsion test. The test procedure regards the whole propulsion system as one propulsor (e.g. Sasaki 2009, Chang 2011, Quereda 2012). The interaction between two propulsors appears in the open water characteristics. It should be noted that the method is not yet verified by full scale trials.

3.1 Propulsor Open Water Test

3.1.1 Model and Installation

In general, these tests should follow the existing procedures for propeller open water test (7.5-02-03-02.1) and propeller/Pod open water test (7.5-02-03-01.3).

Model propeller and Pod drive model are used in open water test. Usually the Pod drive model may have an internal dynamometer for propeller thrust and torque measurement as well as the dynamometer for the unit thrust measurement in the upper part of the pod drive.

Five open water tests and hence configurations are required as listed below and shown in Figure 2.

Fore conventional propeller open test in normal position (POT)

Fore conventional propeller open test in reversed position (rPOT)

Aft propeller (for pod) open test

Pod drive open test

HCRSP propulsor open test (system OT)

Tests A and C are the conventional propeller open water test and test D is the conventional podded propulsor open water test.

Although they might not be fully compulsory, test C and D can be conducted to evaluate the interaction between pod housing and propeller, to investigate the effect of single propeller and of contra-rotating propellers on the pod housing open water test characteristics.

Test B is required for taking into account the wake fraction of propeller open dynamometer on test E. In test B, propeller is located behind the propeller open dynamometer and appropriate boss cap should be fitted. By comparing the open test results in test A and test B, the wake fraction of propeller open boat can be determined.

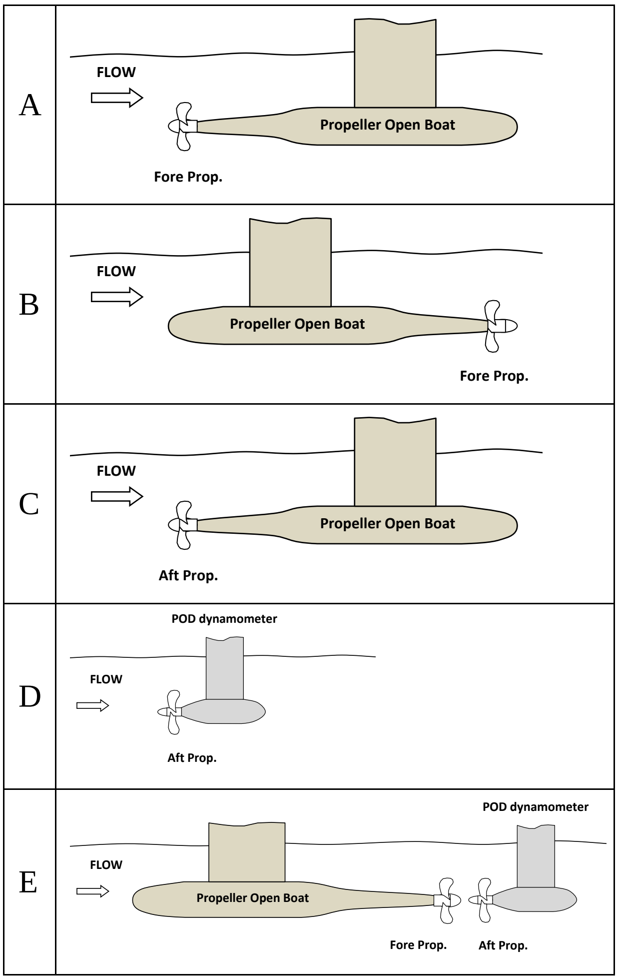

Figure 2: Open water test configurations used for HCRSP propulsor

In test E, propeller open water dynamometer and pod dynamometer must be located in line. The gap between two propellers must be the same as the configuration of the self-propulsion test.

Attention should be paid for the distance between the propeller and top end support plate which is to prevent the undesirable free surface effect. If the distance is too small, the flow becomes confined.

As a summary of open water test series of HCRSP, the configuration E is recommended and the configurations A and B are strongly recommended as the optional tests for the wake effect correction of the open boat. The configurations C and D are also optional that can be carried out for complementary manner, mainly for the propeller design.

3.1.2 Measurement Systems, Instrumentation and Calibration

For this purpose the reader can refer to the existing procedure 7.5-02-03-02.1 and 7.5-02-03-01.3 described in the following.

3.1.3 Test Procedure and Data Acquisition

As stated in 7.5-02-03-02.1 and 7.5-02-03-01.3, influence of boss cap or nose cap must be measured.

In test B and E, influence of propeller open boat dynamometer must be considered. The wake fraction of the propeller open boat at propeller position is to be evaluated because in some cases (depending on the geometry of open boat) the value of the wake fraction may not be negligible i.e. up to 5% ~10% (Ohmori 2013). Thus the wake fraction should be measured beforehand and advance coefficient should be corrected accordingly. The wake fraction can be obtained from the difference between the results of tests A and B. The procedure of the correction is:

i) By thrust identity method, advance coefficients which correspond to the same thrust coefficient are obtained.
ii) The ratio of the advance coefficient in normal to reverse configuration coincides with the wake fraction of the propeller open boat described as;

$$1\text{-}w = J_{normal} / J_{reverse}$$

where J_{normal} and $J_{reverse}$ are advance coefficient in normal and reversed configuration, respectively.

iii) Finally, the advance coefficient of the HCRSP propulsor in test E should be corrected by multiplying the advance speed by the wake fraction.

The schematic sketch of correction is shown in Figure 3.

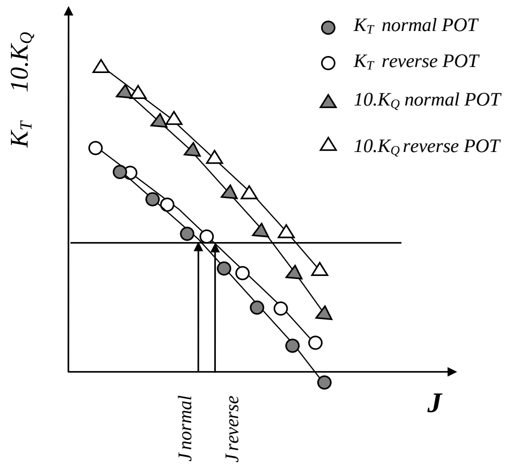

Figure 3: Schematic sketch of the wake correction

Instead of the thrust identification, wake fraction can also be obtained directly from wake measurement. However, it must be noted that nominal wake is obtained by simple wake measurement without rotating propeller.

As an alternative to the proposal in section 3.1.5 the advance coefficients can be taken from the torque curves.

Note that the wake fraction changes according to the carriage speed, so the wake correction should be conducted by appropriate data. It is strongly recommended to use wave restriction plate in the reverse or pod drive open test configurations.

The load distribution between fore propeller and aft podded propulsor is to be varied at each J in system OT (test E) , and the range of fore and aft propeller revolutions $\frac{n_{AP}}{n_{FP}}$ has to cover the whole combinations used in self-propulsion test, in order to analyse the self-propulsion test at precise condition.

Alternatively, pre-test in self-propulsion test setup, for determining the revolution ratio corresponding to the given power ratio can be done. Then the open water test (test E) can be carried out for the pre-designated revolution ratio. However this alternative method covers only one power ratio in self-propulsion point and in case the power ratio of full scale ship differs from the self-propulsion test, error in power calculation is inevitable.

As pointed out by Chang 2011, for a given towing speed, it is recommended, while changing the fore propeller revolution rate, to perform the Test E at different ratio of $\frac{n_{AP}}{n_{FP}}$ to be able to find the revolution ratio that would fit with the design Power ratio between shaft and Pod and with the lowest total Power.

3.1.4 Data Analysis and Presentation

For this purpose the reader can refer to the existing procedure 7.5-02-03-02.1 and 7.5-02-03-01.3 in general. Further detail as follows:

In case of system OT (test E), considering the difference of advance speed between fore and aft propeller is negligibly small, the following parameters are derived from the data acquired:

$$J_{sys} = \frac{(1-w)V_A}{n_{FP} D_{FP}}$$

$$T_U = T_{AP} - R_U$$

$$K_{T\_sys} = \frac{T_{FP} + T_U}{\rho n_{FP}^2 D_{FP}^4}$$

$$K_{Q\_sys} = \frac{n_{FP}Q_{FP} + n_{AP}Q_{AP}}{\rho n_{FP}^3 D_{FP}^5}$$

$$\eta_{o\_sys} = \frac{J_{sys}K_{T\_sys}}{2\pi K_{Q\_sys}}$$

3.1.5 Discussion

The influence of the propeller open boat can be obtained from the difference between the result of test A and B. However the boss cap resistance is still remaining. The boss cap resistance consists of the form drag and the hub vortex drag component. The form drag can be evaluated by the measurement with idle boss without the propeller. However the hub vortex resistance can be obtained only by diminishing the hub vortex. In order to obtain more accurate propeller open boat wake fraction, reverse propeller open boat with dummy shaft (or dummy propeller open boat) behind the propeller (test F) is useful as an additional test as shown in Figure 4. Hence the influence of the propeller open boat wake fraction and boss cap resistance can be derived by tests A, B and F.

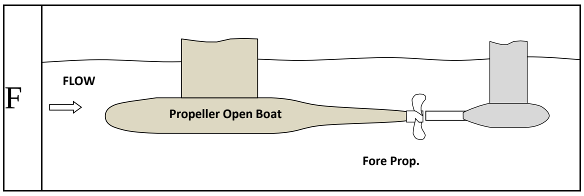

Figure 4: Additional test configuration

The HCRSP propulsor open water test is to be performed at different revolution rates of the fore shaft propeller n_{FP} and the aft pod propeller n_{AP}, in order to plot the open water test results of HCRSP propulsor for the different ratio of revolution rates $\frac{n_{AP}}{n_{FP}}$ as shown in Figure 5.

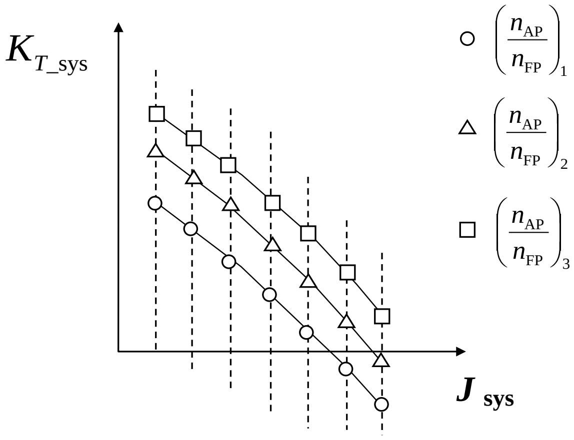

Figure 5: HCRSP propulsor open water test plot for different $\frac{n_{AP}}{n_{FP}}$

3.2 Resistance Test

For this purpose the reader can refer to the existing procedure 7.5-02-02-01 in general. Further detail as follows:

3.2.1 Model and Installation

The pod housing is regarded as a part of propulsor and not included in the resistance test.

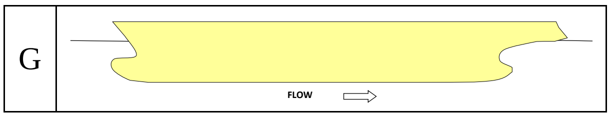

Figure 6: Resistance test configuration

3.2.2 Measurement Systems, Instrumentation and Calibration

For this purpose the reader can refer to the existing procedure 7.5-02-02-01.

3.2.3 Test Procedure and Data Acquisition

For this purpose the reader can follow the existing procedure 7.5-02-02-01.

3.2.4 Data Reduction and Analysis

For this purpose the reader can refer to the existing procedure 7.5-02-02-01.

3.3 Self-propulsion Test

For this purpose the reader can follow the existing procedure 7.5-02-03-01.1 and 7.5-02-03-01.3 in general. Further detail as follows:

3.3.1 Model and Installation

The pod dynamometer is to be equipped.

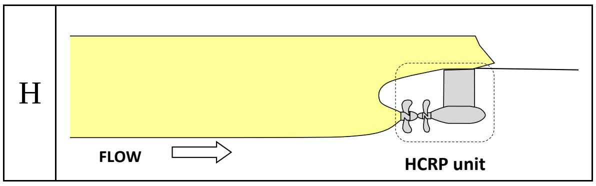

Figure 7: Self-propulsion test configuration

3.3.2 Measurement Systems, Instrumentation and Calibration

The unit thrust of the pod is to be measured by a suitable force balance system located at the intersection of the pod strut with the ship hull.

3.3.3 Test Procedure and Data Acquisition

As for the open water test, it is recommended to perform the self-propulsion test, for the designed ship speed, at different revolution rates of the fore shaft propeller n_{FP} and the aft pod propeller n_{AP}, in order to plot the open water test results of HCRSP propulsor for the different ratio of revolution rates $\frac{n_{AP}}{n_{FP}}$

Similar to the self-propulsion test of conventional propulsion system, skin friction correction between the model and full scale is applied as the towing force F_D.

In case of the HCRSP propulsor system, the unit thrust of the pod is significantly influenced by the Reynolds Number effect, since the pod housing drag significantly reduces the unit thrust. Therefore the additional towing force which is equivalent to the resistance correction of the pod housing is useful to apply to obtain accurate load ratio and loading condition for each propeller blade. That corresponds to the load correction due to the pod housing resistance correction (ΔT_U) in the recommended procedure for Podded propulsor test.

The self-propulsion test is performed at constant towing speed and varying rate of revolution of the propellers by keeping the same ratio of revolution rate between the fore and aft propeller and then changing to another ratio of revolution rate until the tested range covers around the expected self-propulsion point. These load varying tests and load ratio varying tests are to be conducted in order to obtain the self-propulsion factors at the target power balance between fore and aft propulsors. The test procedure is that the load variation of the aft propulsor is to be measured at each point of the load variation of fore propeller.

When predicting ship speed at full scale, power distribution difference between predicted load condition and design is inevitable. The main point of design in HCRSP propulsor system is the power distribution. That is the reason why different ratios of revolution rates between fore and aft propeller are performed.

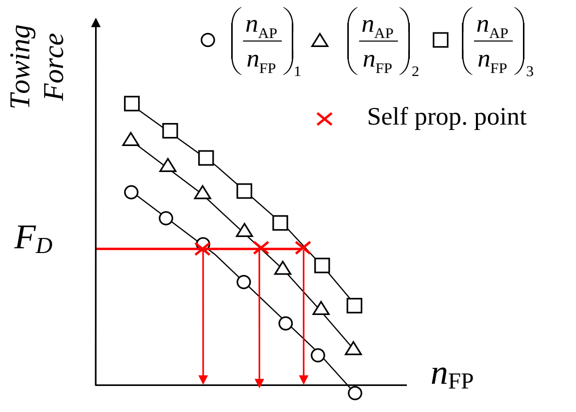

Figure 8: Schematic sketch of load ratio variation test

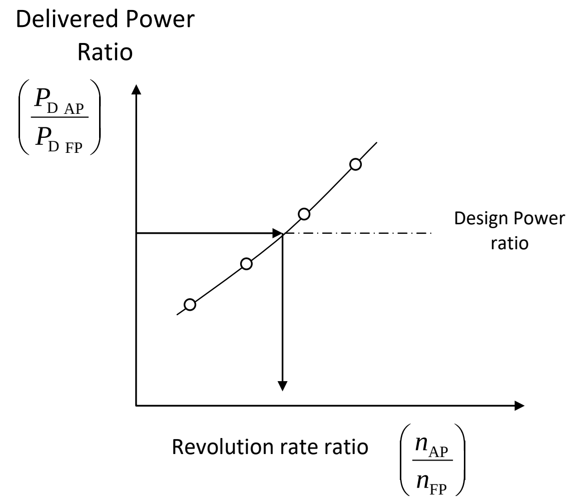

Figure 9: Schematic sketch of the determination of the self-propulsion point

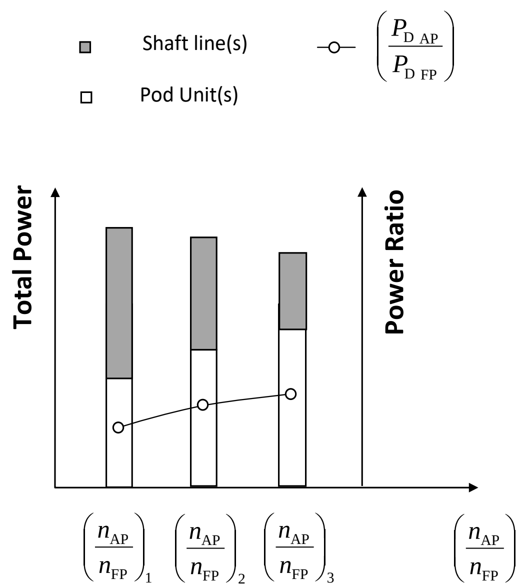

Figure 10: Schematic sketch of difference in total power and power ratio

3.3.4 Data Analysis and Presentation

The self-propulsion point of the HCRSP propulsor system is to be obtained at the point where the towing force equals to the skin friction correction (F_D) as shown in Figure 8. On the other hand the power ratio of fore and aft propeller is uniquely derived from the revolution ratio of the fore and aft propeller as shown in Figure 9.

Then the self-propulsion point which corresponds to the design point is derived from designed point of power ratio.

Moreover, the procedure is able to give information on the power share differences for different ratio of revolution rate on propellers so that the propulsor designer has more information on the interaction between the shaft propeller and the Pod unit, i.e. minimum total power and power share. Figure 10 is a sample summarization of the relationship between power share ratio and total power.

In the extrapolation, the pod unit thrust T_U is to be corrected according to the difference of Reynolds Number of the pod housing between the open water test and self-propulsion test data. Details are described in the procedure 7.5-02-03-01.3.

3.3.5 Discussion

In this method, the scaling of effective wake coefficient is simple, the same as that of conventional propulsion case. The potential wake component of the pod housing is included in the propulsor open characteristics and the scaling method should follow that of the pod propulsion case.

The resistance of the pod housing is also included in the propulsor open characteristics and the scale effect is to be considered. Details are described in the procedure 7.5-02-03-01.3 "Propulsion, Performance Podded Propulsion Tests and Extrapolation".

4. VALIDATION

4.1 Uncertainty Analysis

Uncertainty analysis should follow 'Guide to the Expression of Uncertainty in Experimental Hydrodynamics' 7.5-02-01-01 and related procedures. In addition to the above an example 'Uncertainty Analysis: Example for Propulsion Test' 7.5-02-03-01.2 is provided.

4.2 Benchmark Tests

Benchmark data of hybrid propulsors are not yet available.

5. REFERENCES

Chang, B. J. and Go, S., 2011, "Study on a procedure for propulsive performance prediction for CRP-POD systems", J. Marine Science and Technology, Vol. 16 No.1 pp.1-7.

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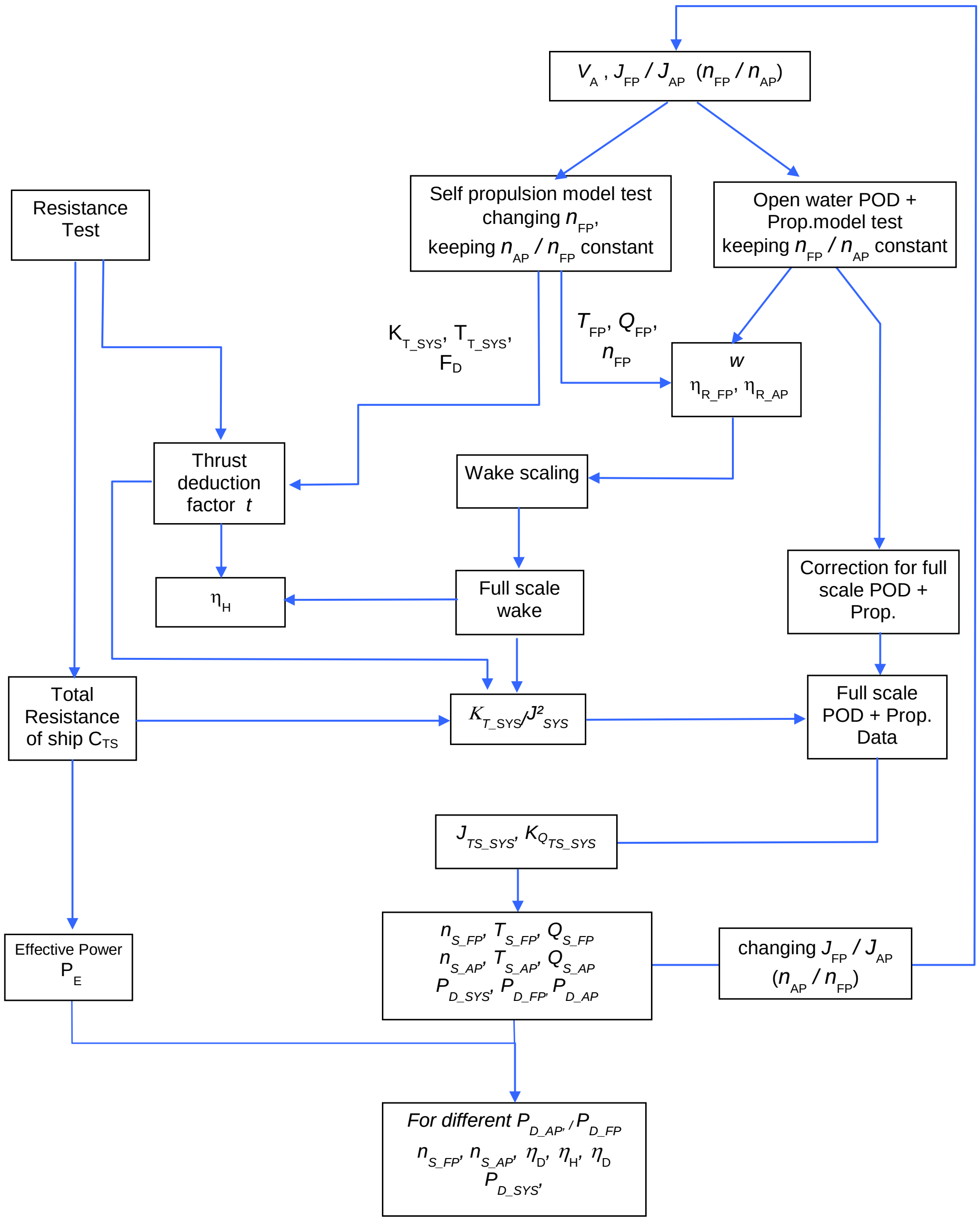
Sasaki, N., Kuroda, M., Fujisawa, J., Imoto, T. and Sato, M., 2009, "On the Model Tests and Design Method of Hybrid CRP Podded Propulsion System of a Feeder Container Ship", Proc. smp'09.

Ueda, N., Oshima, A., Unseki, T., Fujita, S., Takeda, S. and Kitamura, T., 2004, "The First Hybrid CRP-POD Driven Fast ROPAX Ferry in the World", http://www.mhi.co.jp/en/technology/review/pdf/e416/e416338.pdf, Mitsubishi Heavy Industries, Ltd. Technical Review Vol.41 No.6.

Appendix A.


V_A , J_FP / J_AP (n_FP / n_AP)
Resistance Test
Self propulsion model test changing n_FP, keeping n_AP / n_FP constant
Open water POD + Prop.model test keeping n_FP / n_AP constant
K_T_SYS, T_T_SYS, F_D
T_FP, Q_FP, n_FP
w
η_R_FP, η_R_AP
Thrust deduction factor t
Wake scaling
η_H
Full scale wake
Correction for full scale POD + Prop.
Total Resistance of ship C_TS
K_T_SYS/J²_SYS
Full scale POD + Prop. Data
J_TS_SYS, K_QTS_SYS
Effective Power P_E
n_S_FP, T_S_FP, Q_S_FP
n_S_AP, T_S_AP, Q_S_AP
P_D_SYS, P_D_FP, P_D_AP
changing J_FP / J_AP
(n_AP / n_FP)
For different P_D_AP / P_D_FP
n_S_FP, n_S_AP, η_D, η_H, η_D
P_D_SYS,