The Specialist Committee on Azimuthing Podded Propulsion Report and Recommendations

Noriyuki Sasaki, National Maritime Research Institute

$$\Delta R_{POD} = \Delta R_{BODY} + \Delta R_{STRUT} + \Delta R_{INT} + \Delta R_{LIFT}$$

$$R_{BODY} = (1 + k_{BODY}) \left( \frac{1}{2} C_F \rho V^2 S \right)$$


**Membership**

**Ir. Jaap H. Allema.**  Maritime Research Institute Netherlands (MARIN), Wageningen, The Netherlands.

**Professor Mehmet Atlar.**  (Former Chairman)  University of Newcastle, Newcastle-upon-Tyne, United Kingdom.

**Dr. Se-Eun Kim.**  Samsung Heavy Industries Co. Ltd., Daejeon, Korea.

**Dr. Valery Borusevich.**  Krylov Shipbuilding Research Institute (KSRI), St. Petersburg, Russia.

**Dr. Antonio Sanchez-Caja.**  VTT Industrial Systems, Espoo, Finland.

**Dr. Francesco Salvatore.**  Istituto Nazionale per Studied Esperienze di Architettura Navale (INSEAN), Roma,

**Professor Chen-Jun Yang (Secretary).**  Shanghai Jiao Tong University (SJTU), Shanghai, China.

**Dr. Noriyuki Sasaki (Chairman).**  National Maritime Research Institute (NMRI), Tokyo, Japan.
Outline

1. General
2. Questionnaires
3. Review and update Procedure 7.5-02-03-01.3
4. Cavitation behaviour of podded propulsors with steering angles
5. Hydrodynamics of POD propulsion for ice applications
6. Technical Conclusions
1. General
Meetings

(1) Tokyo, Japan, March 2006.
(2) Brest, France, October 2006, in conjunction with the 2nd T-Pod Conference
(3) St. Petersburg, Russia, June 2007
(4) Shanghai, China, March 2008.
Committee’s Tasks

1. Review and update Procedure 7.5-02-03-01.3 “Propulsion, Performance-Podded Propulsor Tests and Extrapolation”. Give special emphasis on how to scale housing drag and to the validation of full-scale propulsion prediction.

2. Continue the review of hydrodynamics of POD propulsion for special applications including fast ships, ice going ships (Liaise with the Ice committee) and special POD arrangements like Contra-rotating Propellers (CRP) and hybrids. Include the practical application of computational methods to prediction and scaling.

3. Review and analyse the cavitation behaviour of podded propulsors. Emphasize high pod angles and normal steering angles including dynamic behaviour. Include the practical application of computational methods to prediction and scaling.
## Task Distributions

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History of Podded Propulsion

- Uikku (1993) - ice breaker
- FANTASY (1991) - cruise ship
- HATAKAZE (1993) - war ship, ice breaker, cruise ship
- electric propulsion
- TRITON (1995) - ice breaker
- Queen Mary II (2002) - cruise ship
- TEMPERA (2002) - double acting tanker
- DAS (2005) - fast pod
- FAST POD
- HAMANASU

The hybrid system is composed of two steerable (wing) pod drives and two fixed (central) – booster – flush type water jets
Contra-rotating Pod Propellers

Super Eco Ship Project

Slender shaped pod

2 shafts – 2 electrical motors
Pure CRP Pods (Mechanical Drive) on the Shiga Maru

Shige Maru is one of the ships delivered as “Super Eco Ship”. The Super Eco Ship project was led by Ministry of Land, Infrastructure and Transport and National Maritime Research Institute from 2001.
A comprehensive numerical and experimental design study was conducted for 2 cruise liner type pod units (13MW) for a 45000 GRT cruise liner using 2D-3D RANS codes. Based upon this comparative study it was concluded that the propulsive performance of PJP was 14% higher than the conventional tractor pod mainly due to its superior open water efficiency.
2. Questionnaires
We sent following questionnaire to 40 organizations and received 20 replies.

25th ITTC Specialist Committee on Azimuthing Podded Propulsion
Questionnaire on Model Test Procedure, Powering Method and CFD Computation Method for Podded Propulsion System

Introduction

The task assigned by the 25th ITTC to this specialist committee is to develop and validate practical experimental and numerical prediction procedures for full scale performance of Azimuthing podded Propulsion System. As a first step toward accomplishing the task, the committee developed the following questionnaire to assess current practices in use by various organizations, including the ITTC member organizations. The analysis of the responses to the questionnaire will be presented to the 26th ITTC conference as part of the final report of this specialist committee.

The questionnaire consists of six parts: (A) Propeller Open Water Test, (B) Podded Propeller Open Water Test, (C) Resistance & Self Propulsion Test, (D) Powering, (E) CFD application (F) Special theme. You do not have to complete all the sections or questions of the questionnaire. If you are not in a position to answer the questionnaire at all, then a null response would be appreciated. If that is the case, please fill in the Respondent's Information only and return.

Please return the completed form preferably before 25th/Sept./2006, for the committee to evaluate the results in time. If you fail to meet the deadline please try to return anyway at your suitable time.

Respondent's Information (Example)

Name: Noriyuki Sasaki
Organization: National Maritime Research Institute
Position: Group Leader of Propulsors Research Group
Mailing Address: Shinkawa, Mitaka-shi, Tokyo 181-0004
Tel. No.: +81 422 41 3505
Fax No.: +81-422 41 3053
E-Mail Address: sasaki@nmri.go.jp
Website: http://www.nmri.go.jp/
**Questions A series : Propeller Open Water Test for Pod Propulsion**

**Experimental tank**

A-1 What kind of experimental tank do you use?
A. Towing Tank  
B. Circulation Water Channel (incl. Cavitation Tunnel)  
C. Both  
D. Others

A-7 What is the standard Reynolds Number (based on Dp) for the open water test?
A. We don’t have any standard for it  
B. We have a standard Reynolds Number  
C. We have two standards

**We have standard \( R_n = \text{*****} \)**
Questions A series: Propeller Open Water Test for Pod Propulsion

**Diameter**

A-3 What is the diameter of propeller?

**immersion**

A-11 How much is the propeller immersion, Im?
Questions B series : Pod Propeller Open Water Test

Survey Results of Gap Width

B-3 What is the propeller gap between boss and pod housing?
Questions B series : Pod Propeller Open Water Test

Survey Results on Propeller Immersion

B-11 How much is the propeller immersion, Im?
Questions C series: Pod Propeller Self Propulsion Test

Survey Results on Propulsion Analysis Methods for Pod Propulsion Ships

C-1 How do you analyze self-propulsion test?

A. Conventional way (regards pod housing as an appendage)
B. Unit base (regards pod unit as the propulsor)
C. Both

regards pod unit as a propulsor
Questions D series: Powering to full scale

Survey Results on Rn Correction Method

D-1 Do you assess the effect of Reynolds numbers on performance of Podded propulsor?
A. Yes  B. No

We assess the effect of Reynolds numbers
3. Review and update

Procedure 7.5-02-03-01.3
Flow diagram for full scale power prediction from model test results of a vessel equipped with podded propulsion.
Letter from ABB to ITTC (24th)

We have been performing model scale testing at all major European model test facilities doing commercial work. We have learned that each basin has different scaling method of housing drag and unit open water performance compared to others. First of all this is very confusing especially for the non-experienced personnel involved in some particular project. Especially for our co-operation partners (owners, shipyards, consultants etc.) these can be some times very confusing issues and we are afraid that this may influence negatively to reliability of the concept. For us this also means always extra careful consideration of scaling method and final power prediction of the vessel. Quite often we even have to make our own analysis and predictions in order to gain required confidence for full-scale performance prediction. We have experienced extremely difficult situations in our delivery projects due these problems during the model scale testing phase. In some extreme cases these problems can even lead to risk of delays in our production and this can create additional costs that we can not predict.

Figure 1: The comparison of scaling methods of two different basins with same model scale values
ABB Round Robin Tests

Tests scope same in all basins
- Unit open water test
- Propeller open water test
- Pod resistance test
- Every basin uses own analysing method
  - Two with one correction factor from model to full scale for unit.
  - Three with separated drag and scale corrections for unit.
- Basins involved: SSPA, Marin, HSVA, Marintek and VTT
- Same propeller tested in all basins
- Each basin manufactured own pod model
Problems to be solved

• Very few official data of full scale
• Each model basin developed their own procedure
• Pod maker complains about this chaotic condition
**Test Scheme**

- **ABB**
- **Pod Drawing**
- **Model Basin**
  - manufacture Pod Model
- **Pod Resistance Test**
- **Propeller Open Water Test**
- **Pod Unit Open Water Test**
- **Full Scale Prediction**
Propeller open water test.
Propeller open water test.

The procedure for open water tests of the propellers for a ship equipped with podded propulsors is basically the same as that of Procedure 7.5-02-03-02.1 "Propeller open water tests", (ITTC, 2002b) although some typical aspects for propellers with strongly tapered hubs are not considered and these aspects are given in this section where necessary.
Tapered Hub

Figure 1 Geometry of Model Fairings

Cylindrical Hub

Tapered Hub
Propeller Open Water Efficiency with the Same Model Propeller

Main reasons: Reynolds number, Shaft Immersion, Boss Correction?

mean (except top and bottom) = 0.653
Pod unit open water test.

Propeller open water test

Pod unit open water test

Self propulsion test

Pod housing drag correction

Powering In full scale

Resistance test

Covering Area of Guideline
**Typical pod unit open water test setup**

Principal dimensions of pod housing used in round robin testing programme,  
*Veikonheimo (2006)*

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<td><strong>Length of Pod Body</strong></td>
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<tr>
<td><strong>Diameter of Pod Body</strong></td>
<td>0.1135 m</td>
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<tr>
<td><strong>Height of Strut</strong></td>
<td>0.1372 m</td>
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<td><strong>Chord Length of Strut</strong></td>
<td>0.2672 m</td>
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<tr>
<td><strong>Total Wetted Surface Area of Pod</strong></td>
<td>0.2129 m²</td>
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Typical pod unit open water test setup

**ITTC Recommendation**

The propeller shaft must be immersed at a minimum depth of 1.5 propeller diameters (1.5D), preferably 2D. It must also be emphasized that the top of the strut should also be well submerged during the test.

Shaft housing: stream lined fairing  
End plate: to prevents vertical flow  
Strut gap: as small as possible  
Wedge: to prevent an uneven strut gap  
Propeller gap: 2-3 mm
Pod unit open water test results with the same model

\[ \eta_0 (\text{Pod Efficiency}) = 15\% \]

\( \text{mean (except top and bottom)} = 0.620 \)
Pod unit open water test results with the same model

NMRI (red) is very close to orange however, components are different.
Pod unit open water test results with the same model

Comparison between POWT and Pod Unit OWT

POD unit efficiency(Model) is lower than Propeller Open Water Efficiency
Pod Housing Drag Correction

Propeller open water test

Pod unit open water test

Self propulsion test

Resistance test

Covering Area of Guideline

High Rn

Pod housing drag correction

Powering /full scale
**Pod Housing Drag Correction**

*A summary of existing semi-empirical correction methods for pod housing drag (24th ITTC)*

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Pod Housing Drag Correction

- There is no unique method to match existing model basins
  (see the test results obtained by ABB round robin test)
- Total balance of system accuracy is most important
- The system should not be too complicated
- The system should be examined by several means incl. CFD

\[ \Delta R_{POD} = \Delta R_{BODY} + \Delta R_{STRUT} + \Delta R_{INT} + \Delta R_{LIFT} \]

Where, \( R_{BODY} \), \( R_{STRUT} \), \( R_{INT} \) and \( R_{LIFT} \) are components of the resistance associated with pod body (nacelle), strut, pod body-strut interference and lift effect due to swirling flow action of the propeller, respectively.
Pod Housing Drag Correction ($R_{BODY}$)

\[
R_{BODY} = \left(1 + k_{BODY}\right) \left(\frac{1}{2} C_F \rho V^2 S\right)
\]

\[
k_{BODY} = 1.5 \left(\frac{D}{L}\right)^3 + 7 \left(\frac{D}{L}\right)^3
\]

Where,

$S = \text{Wetted surface Area (m}^2\text{)}$
$L = \text{Pod length (m)}$
$D = \text{Pod diameter (m)}$
Pod Housing Drag Correction ($R_{STRUT}$)

$$R_{STRUT} = \left(1 + k_{STRUT}\right) \left(\frac{1}{2} C_F \rho V^2 S\right)$$

$$k_{STRUT} = 2 \delta_s + 60 (\delta_s)^4$$

Where, $\delta_s$ is the average thickness ratio of the strut and $S$ is wetted surface area of the strut.
Pod Housing Drag Correction \( (R_{INT}) \)

\[
R_{INT} = \frac{1}{2} \rho V^2 t^2 f \left( \frac{t_{\text{root}}}{C_{\text{root}}} \right)
\]

\[
f \left( \frac{t_{\text{root}}}{C_{\text{root}}} \right) = C_{\text{ROUND}} \left( 17 \left( \frac{t_{\text{root}}}{C_{\text{root}}} \right)^2 - 0.05 \right)
\]

Where, \( t_{\text{root}} \) is maximum thickness at strut root and \( C_{\text{root}} \) is chord length at the same section. \( C_{\text{ROUND}} \) is correction factor for various fairing and it varies from 0.6 to 1.0.
6.3.3 Effect of propeller slip stream

There are two expressions to predict the axial inflow velocity which is accelerated by a propeller given by Mewis (2001) and Holtrop (2001), respectively, as below:

\[ V_{INFLOW} = V_A (1 + C_T)^{0.5} \]

\[ V_{INFLOW} = a(nP) + (1 - a)V_A \]

Where, \( V_A \) and \( n \) are the advance speed of propeller and propeller shaft speed respectively, \( P \) is the average pitch of the propeller blades and \( C_T \) is thrust coefficient defined by:

\[ C_T = \frac{T}{0.5 \rho V_A^2 A_P} \]

Where,
\( T \) = Propeller thrust
\( A_P \) = Propeller disc area
Pod Resistance test
(additional)
Pod resistance tests

Investigate Reynolds Effect on Pod Resistance

Pod Resistance test ($V=6m/s$) at NMRI
Comparison of the pod housing drag from predictions and test results from seven different model basin. Veikonheimo (2006)
Comparison of pod resistance coefficients (CD) for the pod housing measured by seven model basins, Veikonheimo (2006).
Comparative analysis of pod housing drag predicted by the present and other methods

**MODEL SCALE**

- **V= 3.25 m/s**
- **R** <sup>pod</sup> (N)  |  R <sup>body</sup> (N)  |  R <sup>strut</sup> (N)  |  R <sup>btmfin</sup> (N)  |  R <sup>int_strut</sup> (N)  |  R <sup>int_bfin</sup> (N)
- **ITTC**  |  9.13  |  3.38  |  2.99  |  0.58  |  2.03  |  0.16
- **A**  |  8.18  |  3.34  |  2.99  |  0.60  |  1.14  |  0.11
- **B**  |  5.27  |  2.66  |  2.26  |  0.35  |  0.00  |  0.00
- **C**  |  6.45  |  2.37  |  1.64  |  0.27  |  2.03  |  0.16
- **EXPmin**  |  8.17  |  3.34  |  2.99  |  0.60  |  1.14  |  0.11
- **EXPmax**  |  13.38  |  2.66  |  2.26  |  0.35  |  0.00  |  0.00

**FULL SCALE**

- **V= 11.83 m/s**
- **R** <sup>pod</sup> (KN)  |  R <sup>body</sup> (KN)  |  R <sup>strut</sup> (KN)  |  R <sup>btmfin</sup> (KN)  |  R <sup>int_strut</sup> (KN)  |  R <sup>int_bfin</sup> (KN)
- **ITTC**  |  44.63  |  13.16  |  11.24  |  1.99  |  16.94  |  1.30
- **A**  |  46.76  |  13.01  |  11.25  |  2.06  |  18.60  |  1.84
- **B**  |  20.04  |  10.17  |  8.34  |  1.52  |  0.00  |  0.00
- **C**  |  34.97  |  14.14  |  11.24  |  1.99  |  7.06  |  0.54
- **EXPmin**  |  3.8%  |  1.1%  |  1.0%  |  0.2%  |  1.5%  |  0.1%
- **EXPmax**  |  4.0%  |  1.1%  |  1.0%  |  0.2%  |  1.6%  |  0.2%
- **B**  |  1.7%  |  0.9%  |  0.7%  |  0.1%  |  0.0%  |  0.0%
- **C**  |  3.0%  |  1.2%  |  1.0%  |  0.2%  |  0.6%  |  0.0%

**Percentage to Tunit**
Comparison of results from direct CFD and ITTC simplified method on pod housing drag calculations

<table>
<thead>
<tr>
<th>Component</th>
<th>Direct CFD</th>
<th>ITTC simplified procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blades</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Strut+ uppermost body</td>
<td>-4.6%</td>
<td>-2.7%</td>
</tr>
<tr>
<td>Pod body</td>
<td>-2.9%</td>
<td>-2.9%</td>
</tr>
<tr>
<td>Fin</td>
<td>-0.2%</td>
<td>-0.5%</td>
</tr>
<tr>
<td>TOTAL (unit thrust)</td>
<td>92.4%</td>
<td>93.9%</td>
</tr>
</tbody>
</table>

This means that Pod open water efficiency is less than propeller open water efficiency by 6-8% at model scale.
Comparison of results from direct CFD and ITTC simplified method on pod housing drag calculations (model scale)
Full Scale Prediction based on own procedure

Veikonheimo(2006)

Unit After All Corrections (Full Scale)
Effect of using different scaling method with their own test data on full scale power

Model scale >>>>>> Full scale
Effect of using different scaling method with their own test data on full scale power

Summary
Self Propulsion Test.

Covering Area of Guideline

- Propeller open water test
- Pod unit open water test
- Self propulsion test
- Resistance test
- High Rn
  - Pod housing drag correction
  - Powering In full scale
- Low Rn
Conclusions of pod housing drag correction method

• The most serious problem is a scatter of obtained model test data

• It seems that model basins have their own practical methods

• Present method can be used when tests are conducted according to ITTC recommended procedure or similar
4. Cavitation behaviour of podded propulsors with steering angles (incl. dynamic behaviour)
Review of the experimental investigations


Allenstrom, B. and Rosendhal, T., “Experience From Testing of Pod Units in SSPA’s Large Cavitation Tunnel”, 2nd T-POD Conference, Session 5, 3-5 October, University of Brest, France.
Islam, M.F., Veitch, B., Akinturk, A., Bose, N. and Liu, P., 2007b, “Performance characteristics of a Podded Propulsor During Dynamics Azimuthing”, 8th CMHSC, St John’s, Canada
Effect of steering angle on hull fluctuating pressures, *Johannsen & Koop (2006)*
Effect of steering angle on blade cavitation,

Bretschneider & Koop (2005)
FASTPOD Container ship Pod arrangement,

Allenstrom and Rosendhal (2006)

Effect of flap angle on the cavitation inception and unit thrust

Approx. cavitation inception

Efficiency loss

Port

Flap angle

Starboard
Comparison of propeller forces and moments at fixed (continuous line) and dynamically controlled pod angles (scattered points) Heinke (2004).
Sway force when pod undergoing a fast ramp change in azimuth angle from 0° to 60°, Stettler et al (2005)
Longitudinal thrust coefficient on pod unit in static and dynamic azimuthing conditions. Islam et al (2007b)
Comparison of predicted propeller thrust with experiments in steering conditions, *Sasaki (2005)*

\[
J_\delta = \frac{V \cos \delta}{nD} = J_0 \cos \delta \quad \text{.....apparent } J \\
J' = J_\delta + \Delta J \quad \text{...... displacement effect by pod housing} \\
\Delta J = C_1 J_0 |\delta| \quad (C_1=\text{const.} \ 0.3-0.5)
\]

![Graph comparison of predicted propeller thrust with experiments](image)
Review of the numerical investigations


Guo, C-Y,Yang, C-J and Ma, N., 2008, “CFD Simulation For a Puller Type Podded Propulsor Operating at Helm Angles”, Private Communications with the 25th ITTC Specialist Committee for Azimuthing Podded Propulsion.

Model pod unit, Guo et al (2008)
Comparison of computed and measured forces at helm angle of 45°

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_T$</td>
<td>0.94</td>
<td>1.18</td>
<td>2.33</td>
</tr>
<tr>
<td>$K_T/K_{T0}$</td>
<td>Exp.</td>
<td>KT 1.812</td>
<td>KT 1.765</td>
</tr>
<tr>
<td></td>
<td>CFD 1.761</td>
<td>1.761</td>
<td>1.761</td>
</tr>
<tr>
<td>$K_Q/K_{Q0}$</td>
<td>Exp.</td>
<td>KT 1.711</td>
<td>KT 1.665</td>
</tr>
<tr>
<td></td>
<td>CFD 1.465</td>
<td>1.465</td>
<td>1.465</td>
</tr>
<tr>
<td>$K_L/K_{T0}$</td>
<td>Exp.</td>
<td>KT 0.403</td>
<td>KT 0.366</td>
</tr>
<tr>
<td></td>
<td>CFD 0.567</td>
<td>0.567</td>
<td>0.567</td>
</tr>
</tbody>
</table>
Pressure distribution and propeller shaft forces in oblique flow, Funeno, 2004

Fig. 9: Contour of pressure coefficient: $C_{pm}$ on potted propulsion unit in oblique flow (rudder angle: $\delta=30^\circ$, $J=0.666$).

Fig. 10: Fluctuation forces of propeller in oblique flow (rudder angle: $\delta=30^\circ$, $J=0.666$).
Hydrodynamics of POD propulsion for ice applications

Double Acting Tanker
Full Astern 12kts
Loading comparison Sampson, et al. (2006b)

Figure 3: Cavitation during simulated ice milling using crushable foam

the effect of cavitation during propulsor ice interaction
MV Norilskiy Nickel has been designed to transport mining products from Dudinka (Yenisey River) to the market (Murmansk) independently without icebreaker support. The vessel is equipped with diesel electric propulsion with one 13MW podded azimuth thruster (Azipod).

The design of the vessel follows the principles of Aker Arctic’s Double Acting Ship Concept, where the vessel is designed to be run ahead and astern in somewhat different conditions. Norilskiy Nickel has been designed to operate in level ice and pack ice to run both ahead and astern. In heavy ridges the vessel is designed to operate mainly running astern.
5. Technical Conclusions
Technical Conclusions

(1) Procedure of pod tests and extrapolation are established however, full scale data to evaluate this method will be needed.

(2) A lot of complex system of pod propulsion such as CRP type and a hybrid type has appeared and they are not deeply studied so far because of lack of full scale data of such kinds of pod systems.

(3) A pod performance at off design condition or manoeuvring condition is so important to affect on not only cavitation and vibration but also fuel consumption. There are many papers mentioned above cavitation and vibrations at pod steering conditions however, it is also important to design the pod from propulsive performance view point taking an efficiency loss at smaller helm angle (less than 10deg.).

(4) CFD becomes very strong tool now to evaluate the scale effect of pod housing drag and extrapolation method.
Thank you for your attention
Propeller Cap and Aft Fairing

Table 1 Principal Dimension of tested Propeller Model supplied by ABB

<table>
<thead>
<tr>
<th>NMRI M.P. No.</th>
<th>631</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter Dp</td>
<td>[m] 0.2310</td>
</tr>
<tr>
<td>Boss Ratio xB</td>
<td>0.2975</td>
</tr>
<tr>
<td>Pitch Ratio p=H/Dp</td>
<td>1.166</td>
</tr>
<tr>
<td>Expanded Area Ratio aE</td>
<td>0.669</td>
</tr>
<tr>
<td>Number of Blade Z</td>
<td>5</td>
</tr>
<tr>
<td>Turning Direction</td>
<td>Right</td>
</tr>
</tbody>
</table>

Fig. 1 Tested Caps and Aft Fairings

(a) Smooth Aft Fairing  (b) Knuckled Aft Fairing  (c) ABB Cap
Questions B series : Pod Propeller Open Water Test

B-6 Where is the location of the dynamometer for thrust and torque measurements for propeller?
   A. Inside of the pod
   B. Outside of the pod
   C. Both cases

B-9 Do you develop strategies for prevention of air drawing?
   A. Yes
   B. No
Survey Results on CFD Application

E-1 What is the purpose of your CFD application to podded propulsor or to ships with podded propulsor?

A. Scaling
B. Propulsor design
C. Propulsor-hull optimization
D. Other

E-2 What kind of turbulence model do you introduce into your computational code?

A. Baldwin-Lomax
B. k-\(\varepsilon\) type or similar
C. Spalart-Allmaras or similar 1-eq.
D. LES (iso or aniso)
E. DNS
F. Potential Theory
G. Other
Shaft housing and end plate
Strut gap and wedge
Propeller gap during experiments
Problematic issues: *Propeller-pod housing gap effect*

- First reported by (Mewis 2001) and only influences propeller thrust
- Limited other studies reported in supporting (e.g. Holtrop & Rijsbergen 2004) and in conflicting nature (e.g. Ukon et al 2003)

![Graph showing open water characteristics of a puller-type pod based on thrust for different propeller gap widths](Holtrop & Rijsbergen 2004)
Podded propulsor in open water test setup
2.3.2 Test conditions

After a resistance test of ship without a pod unit (same as a conventional propeller case), it is recommended that for ships fitted with podded propulsors, self-propulsion tests should be conducted with both the ship speed and the propulsor load varied independently. In addition to Skin Friction Correction of the hull surface, load correction due to pod housing drag correction should be considered.

2.3.3 Test set up

The self-propulsion test should preferably be carried out in the following manner:

- The pod propellers are to be driven from the top of the unit by an electric motor, through a belt drive or a geared set of a horizontal and a vertical shafts.
- Thrust and torque of the propeller are to be measured close to the propeller. Alternatively the electrical motor could be located inside the pod for direct driving provided that the testing facility has such device available.
- The unit thrust \( \Delta K_{TV} \) is to be measured by means of an at least 2 component measuring frame at the intersection of the pod strut with the ship model, on which frame the motor is fitted.
Questions D series: Powering to full scale

Survey results on tested data of pod propulsor stored

D-2 Do you take account wake scaling effect into powering?
- A. Yes
- B. No

D-2(a) Number of data sampled.
- A. None
- B. below 5
- C. between 6 and 10
- D. above 11

None

5
14

5
1
1

7
Principal dimensions of pod housing used in co-operative testing programme, Veikonheimo (2006)

<table>
<thead>
<tr>
<th>Principal dimensions of Pod Propulsor</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Pod Body</td>
<td>0.4563 m</td>
</tr>
<tr>
<td>Diameter of Pod Body</td>
<td>0.1135 m</td>
</tr>
<tr>
<td>Height of Strut</td>
<td>0.1372 m</td>
</tr>
<tr>
<td>Chord Length of Strut</td>
<td>0.2672 m</td>
</tr>
<tr>
<td>Total Wetted Surface Area of Pod</td>
<td>0.2129 m²</td>
</tr>
</tbody>
</table>

a drawing supplied by ABB
Main data for the CFD study case

<table>
<thead>
<tr>
<th></th>
<th>Model scale</th>
<th>Full scale</th>
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</thead>
<tbody>
<tr>
<td>Propeller diameter</td>
<td>0.231</td>
<td>5.8</td>
</tr>
<tr>
<td>Propeller revolutions (rps)</td>
<td>16</td>
<td>2.33</td>
</tr>
<tr>
<td>Advance coefficient</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>Reynolds number (model)</td>
<td>1.29x-10^6</td>
<td>1.14x10^8</td>
</tr>
</tbody>
</table>
How to use ITTC recommended procedure for powering

Pod OWT based on ITTC procedure

Calculation by ITTC method

\[ R_{POD} = R_{BODY} + R_{STRUT} + R_{INT} \]

\[ K_{TU} = (K_{TU})_M + \Delta K_{TP} + \Delta K_{TU} \]

\[ \Delta K_{TU} = \frac{\Delta R_{POD}}{p n^2 D^4} \]

\[ \Delta R_{POD} = \Delta R_{BODY} + \Delta R_{STRUT} + \Delta R_{INT} \]
Comparison of computed and measured forces at helm angle of 15°

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<table>
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<tr>
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<tbody>
<tr>
<td></td>
<td>Exp.</td>
<td>CFD</td>
<td>Exp.</td>
<td>CFD</td>
<td>Exp.</td>
</tr>
<tr>
<td>$C_T$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K_T/K_{T0}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>1.084</td>
<td>1.079</td>
<td>1.050</td>
<td>1.029</td>
<td>1.012</td>
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<tr>
<td></td>
<td>1.109</td>
<td>1.079</td>
<td>1.055</td>
<td>1.038</td>
<td>1.022</td>
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<tr>
<td>$K_Q/K_{Q0}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.155</td>
<td>1.128</td>
<td>1.075</td>
<td>1.040</td>
<td>1.020</td>
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<tr>
<td></td>
<td>1.065</td>
<td>1.042</td>
<td>1.029</td>
<td>1.024</td>
<td>1.019</td>
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<tr>
<td>$K_L/K_{T0}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.115</td>
<td>0.074</td>
<td>0.062</td>
<td>0.050</td>
<td>0.020</td>
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<tr>
<td></td>
<td>0.180</td>
<td>0.122</td>
<td>0.078</td>
<td>0.061</td>
<td>0.045</td>
</tr>
</tbody>
</table>
Propeller Cap and Aft Fairing

Table 1 Principal Dimension of tested Propeller Model

<table>
<thead>
<tr>
<th>NMRI M.P. No.</th>
<th>Diameter $D_P$ [m]</th>
<th>631</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boss Ratio $x_B$</td>
<td>0.2975</td>
<td></td>
</tr>
<tr>
<td>Pitch Ratio $p=H/D_P$</td>
<td>1.166</td>
<td></td>
</tr>
<tr>
<td>Expanded Area Ratio $a_E$</td>
<td>0.669</td>
<td></td>
</tr>
<tr>
<td>Number of Blade $Z$</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Turning Direction</td>
<td>Right</td>
<td></td>
</tr>
</tbody>
</table>

supplied by ABB
Comparison of predicted propeller thrust with experiments in steering conditions, Sasaki (2005)

C1=0.35
Evaluation by CFD approach

<table>
<thead>
<tr>
<th></th>
<th>Tunit</th>
<th>Rpod</th>
<th>Ratio (Rpod/Tunit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model scale (present) N</td>
<td>139.6</td>
<td>11.4</td>
<td>8.1%</td>
</tr>
<tr>
<td>Full Scale (CFD) KN</td>
<td>1165.0</td>
<td>94.8</td>
<td>8.1%</td>
</tr>
<tr>
<td>Full Scale (present) KN</td>
<td>1165.0</td>
<td>75.8</td>
<td>6.5%</td>
</tr>
<tr>
<td>Ratio (present/CFD)</td>
<td></td>
<td></td>
<td>79.9%</td>
</tr>
</tbody>
</table>

Pressure distributions and streamlines on pod housing/strut surfaces at model and full scale Sanchez-Caja, et al. (2003)
How to use ITTC recommended procedure for powering

Pod Open Water Test

Self Propulsion Test

Pod Open Water Characteristics (Ship)

Self Propulsion Factors

Pod Open Water Characteristics (model)

Powering