

# Propeller Particulars and Scale Effect Analysis of ECO-Cap by CFD

Masafumi Okazaki, Taro Kajihama, Kenta Katayama, Yoshihisa Okada,  
Nakashima Propeller Co.,Ltd. Okayama/Japan, m-okazaki@nakashima.co.jp

## List of symbols

D	Propeller diameter	J	Advance coefficient	$J = \frac{V}{nD}$	$\Delta K_T$	$K_T$ ECO-Cap/ $K_T$ normal cap
V	Velocity of the flow	$K_T$	Thrust coefficient	$K_T = \frac{\text{Thrust}}{\rho n^2 D^4}$	$\Delta K_Q$	$K_Q$ Eco-Cap/ $K_Q$ normal cap
n	Propeller shaftspeed	$K_Q$	Torque coefficient	$K_Q = \frac{\text{Torque}}{\rho n^2 D^5}$	$\Delta \eta$	$\eta$ ECO-Cap/ $\eta$ normal cap
$\rho$	Density	$\eta$	Propeller efficiency	$\eta = \frac{J \cdot K_T}{2\pi K_Q}$	$K_T$	$K_T$ blade + $K_T$ boss + $K_T$ cap
$\nu$	Kinematic viscosity	$R_{n, Kempf}$	Reynolds number		$K_Q$	$K_Q$ blade + $K_Q$ boss + $K_Q$ cap
$l_{0.7R}$	Chord length at 0.7R	$R_{n, Kempf} = \frac{l_{0.7R} \sqrt{V^2 + (\pi n \cdot 0.7D)^2}}{\nu}$				
$C_{pn}$	Pressure Coefficient	$C_{pn} = \frac{\text{Pressure}}{\rho n^2 D^2}$				

## 1. Introduction

In recent years, Energy Saving Devices (ESD) for ships have gained attention. Among them are the propeller caps with fins. Their characteristics are easy to attached, so they are suitable for retrofitting. The most famous caps with fins are Propeller Boss Cap Fins (PBCF). The research and development of PBCF were originally carried out by Ouchi<sup>1)</sup> et al. and concluded that it can gain the propulsion efficiency about 2.1% on the model and about 4% on the actual ship. ITTC referred the results and mentioned that the full scale improvement rate of propulsion efficiency is 2 to 3 times greater than the model scale prediction in their guidance<sup>2)</sup>. But the effect of the difference of propeller particulars like as pitch, number of blades are not mentioned. Kawamura<sup>3)</sup> et al. researched PBCF by CFD and the scale effect was confirmed.

The authors also developed a new propeller cap with fins which was named ECO-Cap<sup>4)5)</sup>. Fig.1 shows the ECO-Cap attached to the actual ship. In our research, ECO-Cap gained the propulsion efficiency about 1.28% in the six blades propeller for the container vessel and about 0.69% in the five blades propeller for the bulk carrier on the model scale. And it reduced the fuel oil consumption about 2.8% in the four blades propeller for the twin-screw car ferry on the actual ship. It looks like same scale effect as PBCF. The purpose of this paper is to predict the effect of the difference of the propeller particulars and scale of ECO-Cap by CFD.



Fig.1 ECO-Cap attached to the actual ship

## 2. Analysis by CFD

### 2-1. Propeller particulars and analysis models

Analysis carried out using the six propellers which are designed for large container vessel. Table1 shows the propeller particulars and Fig.2 shows pitch distribution of propellers. Fig.3 shows the propeller particulars and profiles. The feature of ECO-Cap compared with normal cap is attaching the seven fins for recovering energy loss caused by generating hub vortex.

Table.1 Propeller particulars

	MPNo.1	MPNo.2	MPNo.3	MPNo.4
Number of blades	6			5
Diameter(mm)	250(model)/9500(actual)			
Exp. Area ratio	0.89			0.85
Pitch distribution	constant	tip loaded	tip unloaded	constant
Pitch ratio at 0.7r/R	0.994	1.007	0.981	1.039

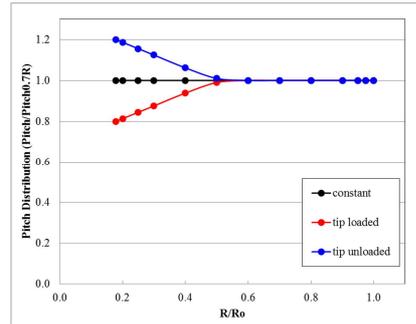


Fig.2 Pitch distribution

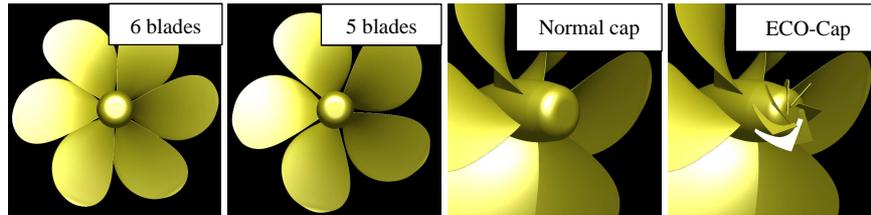


Fig.3 Propeller and cap profiles

RANS calculations are performed by SOFTWARE CRADLE SCRYU/Tetra Ver.10 which is a commercial CFD code based on a finite volume method with an unstructured grid. The k-kl- $\omega$  model is applied as turbulence model. The authors simulated the flow field around a propeller in uniform wake flow. The computational domain is composed of the inner rotational part including the propeller and the outer stationary part. The stationary part and the rotational part are connected discontinuously. Constant velocity and zero pressure are prescribed at the inlet and the outlet boundary, respectively. Fig.4 shows the computational domain. The numerical mesh is an unstructured grid, and basic cells are tetrahedral and prismatic cells are applied to near the blade surface for resolving the boundary layer. Table.2 shows conditions for the CFD model.

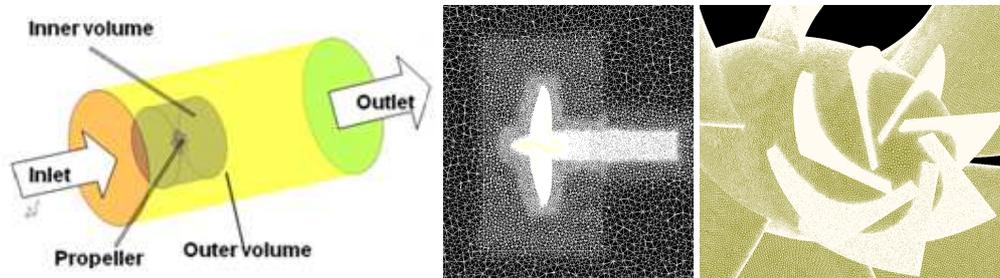


Fig.4 Numerical grids for CFD

Table.2 Conditions of CFD model

	Model scale		Full scale	
	Normal cap	ECO-Cap	Normal cap	ECO-Cap
$R_{nKempf}/10^5$	6.0		860.0	
$y^+$	1.0			
Total thickness(mm)	3.0			
Prism layer	18		32	
Growth ratio	1.40		1.41	
Number of cells/ $10^7$	2.2	2.9	3.6	4.8

## 2-2. Model scale analysis of difference of propeller pitch distribution

The authors calculated the MPNo.1-3 with normal cap in model scale. Fig.5 shows the distribution of pressure coefficient  $C_{pn}$  behind the normal cap at  $J=0.72$ . The blue part represents low pressure caused by the hub vortex. The low pressure was found for each propeller, but MPNo.2 is the smallest and MPNo.3 is biggest. Fig.6 shows pressure distribution behind the ECO-Cap at  $J=0.72$ . The recovery of pressure by ECO-Cap is found in each case. The tendency of extents of remaining blue part is same as the results of normal cap.

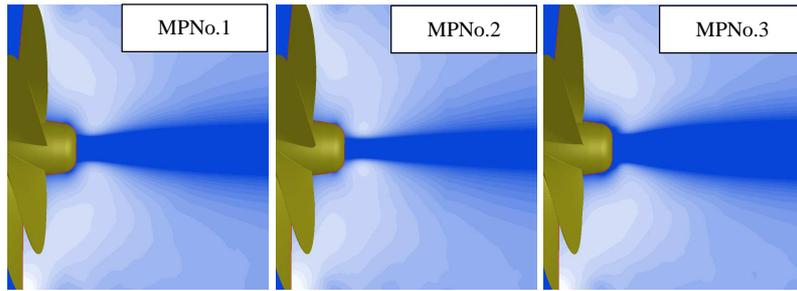


Fig.5  $C_{pn}$  distributions behind the normal cap

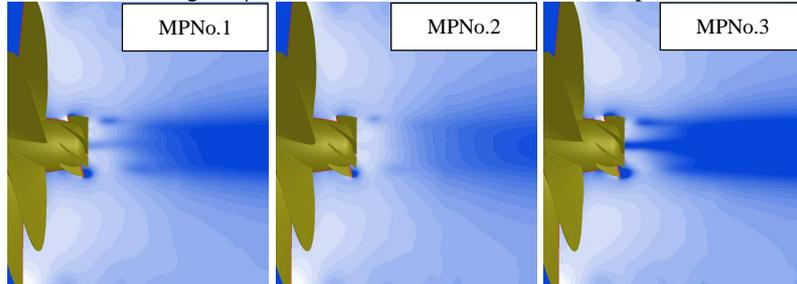


Fig.6  $C_{pn}$  distributions behind the ECO-Cap

Fig.7 shows the comparison of propeller characteristics of MPNo.1-3 equipped with the normal cap and ECO-Cap. Each propeller equipped with ECO-Cap improves propeller efficiency  $\Delta\eta_0$  by gaining  $\Delta K_T$  and reducing  $\Delta K_Q$ . Efficiency of MPNo.3 is improving most. The lower pressure behind the cap is, the more the propeller efficiency is improved by ECO-Cap.

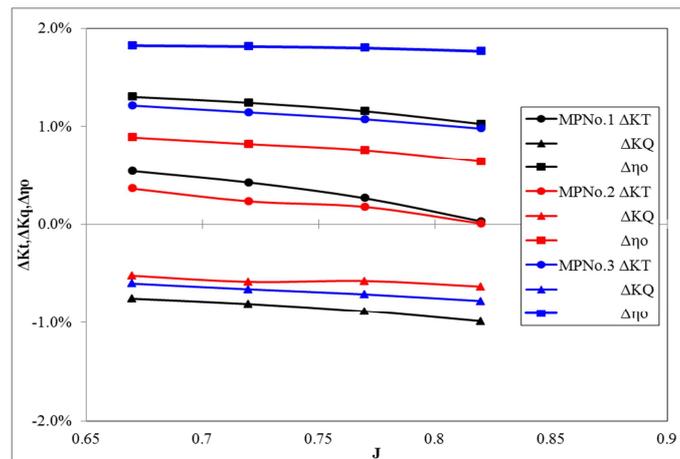


Fig.7 Comparison of propeller characteristics (with ECO-Cap/with normal cap)

### 2-3. Model scale analysis of difference of blade number

The authors calculated the normal cap and ECO-Cap about MPNo.4 which has five blades in the model scale. Fig.8 shows the streamline behind the normal cap at  $J=0.72$ . The colour of the streamline depends on  $C_{pn}$ . Each streamline swirls behind the cap and the direction is same as the propeller rotation. It looks like that the streamline of MPNo.1 is more swirly than that of MPNo.4. Fig. 9 shows the streamline behind the ECO-Cap at  $J=0.72$ . Each streamline was disturbed by fins and the pressure was recovered and the streamline direction was directed opposite direction of the propeller rotation by fins.

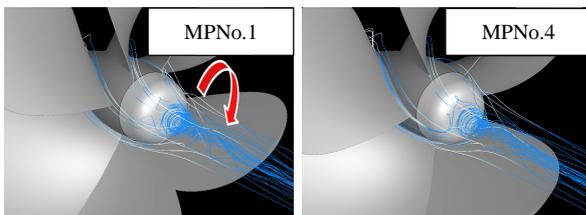


Fig.8 streamlines behind the normal cap

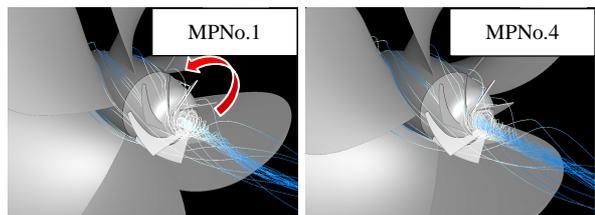


Fig.9 streamlines behind the ECO-Cap

Fig.10 shows the comparison of propeller characteristics of MPNo.1 and MPNo.4 equipped with the normal cap and ECO-Cap.  $\Delta\eta_0$  of MPNo.1 is higher than MPNo.4 because of the difference of  $\Delta K_T$  and the gap widens at the high J.

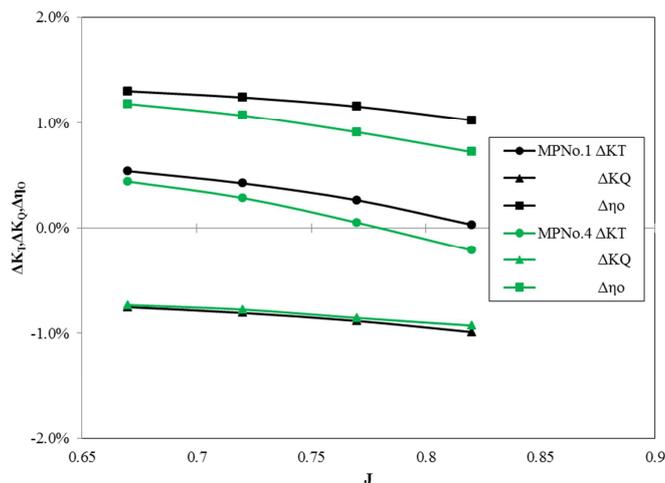


Fig.10 Comparison of propeller characteristics

#### 2-4. Analysis of scale effect

The authors calculated the normal cap and ECO-Cap in model scale and full scale. The Reynolds number  $R_{nKempf}$  is  $6.0 \times 10^5$  in model scale and  $860.0 \times 10^5$  in full scale. Fig.11 and Fig.12 show the  $C_{pn}$  distribution behind the normal cap and the ECO-Cap attached to MPNo.1. Each figure indicated that the  $C_{pn}$  distribution in model scale was different from that in full scale. Especially, low pressure remained behind the ECO-Cap in full scale against the result in model scale.

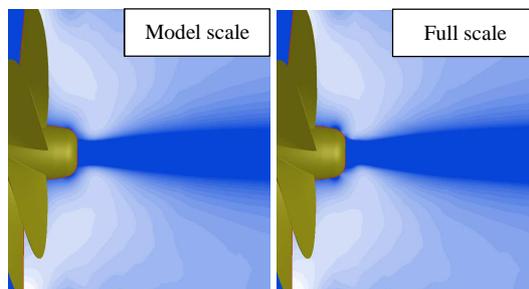


Fig.11  $C_{pn}$  distributions behind the normal cap attached to MPNo.1

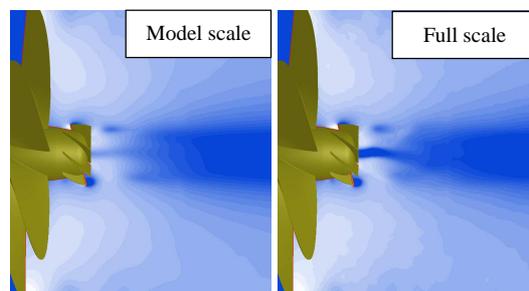


Fig.12  $C_{pn}$  distributions behind the ECO-Cap attached to MPNo.1

Fig.13 shows the comparison of propeller characteristics of MPNo.1 equipped with the normal cap and ECO-Cap in model scale and full scale. Propeller characteristic of full scale is improved compared with model scale. Table.3 is the comparison of  $\Delta\eta_0$  of model and full scale about MPNo.1-4 at design point. The full-scale improvement rate of propulsion efficiency is 1.5 to 3.2 times greater than the model scale.

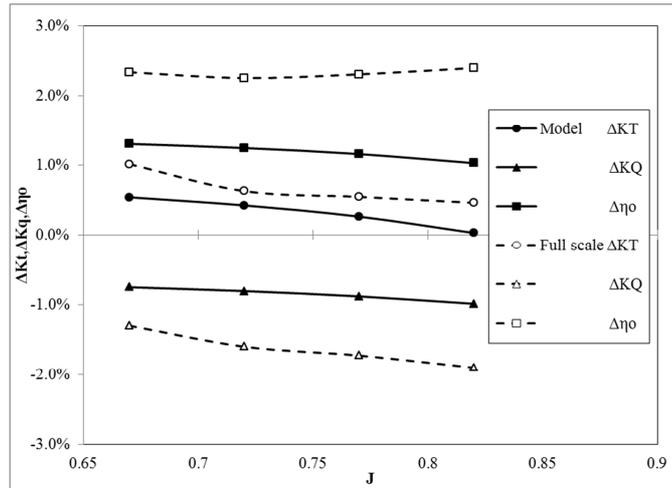


Fig.13 Comparison of propeller characteristics MPNo.1

Table.3 comparison of  $\Delta\eta_o$  of model and full scale

MPNo.	$\Delta\eta_o$		$\frac{\Delta\eta_o \text{ full}}{\Delta\eta_o \text{ model}}$
	model scale	full scale	
1	1.27%	2.27%	1.8
2	0.52%	1.68%	3.2
3	1.89%	2.76%	1.5
4	1.07%	1.88%	1.8

### 3. Conclusion

The authors confirmed the following by CFD analysis.

- 1) Propeller particulars such as pitch distribution and blade number affected pressure distributions behind the propeller cap. Reynolds number also affected pressure distributions behind the propeller cap.
- 2) The lower pressure behind the cap is, the more propeller efficiency is improved by ECO-Cap.
- 3) The full-scale improvement rate of propulsion efficiency is changed by propeller particulars, and it is 1.5 to 3.2 times greater than in model scale. It is nearly the same as ITTC's guidance.
- 4) The full-scale improvement rate of propulsion efficiency is expected because of the difference of pressure distribution that cannot reproduce in the model test.

### References

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