# Numerical Analysis of the Propeller with Economical Cap by CFD

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## 1.Introduction

In recent years, the ship speed and the propeller load increase more and more. Especially, the tendency is remarkable at container ship. When the horsepower per unit area is 700-800 kW/m$^2$ or more and the ship speed is 22-23 knots or more, Mikael Grekula et al.[1)] pointed out that the rudder erosion should be occurred. Juergen Friesch[2)] described the causes of rudder erosion were propeller tip-vortex cavitation, propeller hub-vortex cavitation and etc. and he introduced a new twisted rudder TW05 to reduce the risk of cavitation erosion in his paper. However, it is considered that the cavitation of the propeller should be disappeared in front of the rudder.

Yamasaki et al.[3)] developed Non-Hub vortex(NHV) propeller. The features of this NHV propeller is confirmed an increase in efficiency due to the decrease of the hub vortex. Special propeller caps with similar characteristics are known, for example PBCF developed by Ouchi[4)] et al. Kawamura et al.[5)] investigated the characteristics of PBCF on model and full scale Reynolds number by CFD. Recently, there are special caps by some manufacturers, however there are no published paper for design of these special caps by CFD.

This paper describes that the development of economical propeller cap for prevention of rudder erosion. The authors carried out the optimaization of economical propeller cap by CFD, and the performance of the propeller with economical cap was confirmed by model test.

***Keywords*** CFD・Propeller・Economical Cap・Diffusion effect・Hub vortex・Rudder erosion

### *List of symbols*

| | | | | | |
|---|---|---|---|---|---|
| $D$ | Propeller diameter | $J$ | Advance coefficient $J=\frac{V}{nD}$ | ⊿$K_T$ | $K_T$ economical cap／$K_T$ contraction type |
| $V$ | Velocity of the flow | $K_T$ | Thrust coefficient $K_T=\frac{Thrust}{\rho n^2 D^4}$ | ⊿$K_Q$ | $K_Q$ economical cap／$K_Q$ contraction type |
| $n$ | Propeller shaft speed | $K_Q$ | Torque coefficient $K_Q=\frac{Torque}{\rho n^2 D^5}$ | ⊿$\eta$ | $\eta$ economical cap／$\eta$ contraction type |
| $\rho$ | 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 | $R_{nD}$ | Reynolds number $R_{nD}=\frac{nD^2}{\nu}$ | $K_Q$ | $K_Q$ blade + $K_Q$ boss + $K_Q$ cap |

## 2.Analysis by CFD

### 2-1.Propeller Particulars and Analysis Models

MPNo.1&2 are analyzed by CFD, MPNo.1, has 6 blades, is for large container vessel and MPNo.2, has 5 blades, is for bulk carrier. Table1 and Fig.1 show the propeller particulars and profile. MPNo.1 has the large blade area and large skew angle and MPNo.2 has the small blade area and medium skew angle. These propellers are designed to confirm the difference regarding the performance of the propeller with cap by the difference of propeller profile.

Table 1. Propeller Particulars

| | | MPNo.1 | MPNo.2 |
|---|---|---|---|
| Number of blades | | 6 | 5 |
| Diameter (Model/Actual) | mm | 240 / 9500 | 265 / 6700 |
| Pitch ratio at 0.7r/R | | 1.043 | 0.833 |
| Exp. Area ratio | | 0.81 | 0.44 |


Fig.1 Propeller Profile

RANS calculations are performed by SOFTWARE CRADLE SCRYU/Tetra Ver.10 which is a commercial CFD code and is based on a finite volume method with an unstructured grid. The Shear Stress k-ω model is applied to the turbulence model of the present simulations. The authors simulated the flow field around a propeller in non-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.2 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. The first layer thickness of the prism layer was set to a non-dimensional wall distance for a wall-bounded flow ($y^+$ in short) =1. The total number of elements was about 32 million.

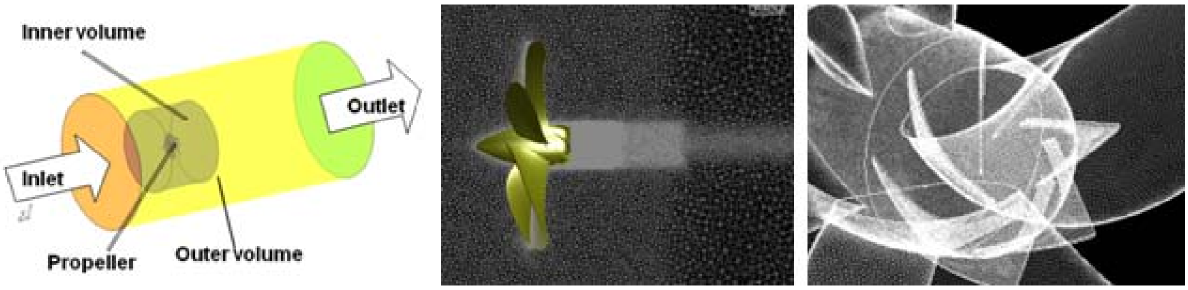


Fig2. Analysis Model for CFD

**2-2.Analysis of General Propeller Caps**

Firstly, the performance of the general propeller caps was analyzed by CFD. Fig.3 shows the profile of the general propeller caps. The contraction type is typically used in many propeller manufacturers. Straight type and diffusion type has sometimes adopted as countermeasure against hub vortex cavitation. In this analysis, Reynolds number is abt.$2\times10^6$ considering calculation cost and scale effect


Fig.3 Profile of General Propeller caps

Fig.4 shows the pressure distribution behind the propeller caps by CFD result. The blue part represents the low pressure which is the cause of the hub vortex cavitation. In MPNo.1, contraction type generates the low pressure part behind the propeller cap. The low pressure part generated by straight type is smaller than contraction type and the part by diffusion type is still smaller. Compared with MPNo.1, the low pressure part in MPNo. 2 is smaller. Namely, it is estimated that the hub vortex generated by 5blades propeller is weaker than the vortex by 6 blades propeller. As well as MPNo.1, it is shown by Fig.4 that the reduction of the low pressure part by straight cap in MPNo.2. From above results, it can diffuse the hub vortex when the propeller cap is straight or diffusion type. However, these propeller caps still generate large low pressure part.

Next, it was visualized how hub vortex is generated by CFD for design of economical cap.

Fig.5 shows the isosurface which represents the flow of tangential direction of a certain velocity. The flow generated at trailing edge was concentrated at the center of propeller cap rear. If the concentration of tangential flows is prevented, it is expected that the hub vortex is weakened. It is named “diffusion effect” in this paper. In addition, it was confirmed that the low pressure part decreases on straight type or diffusion type due to diffusion effect.

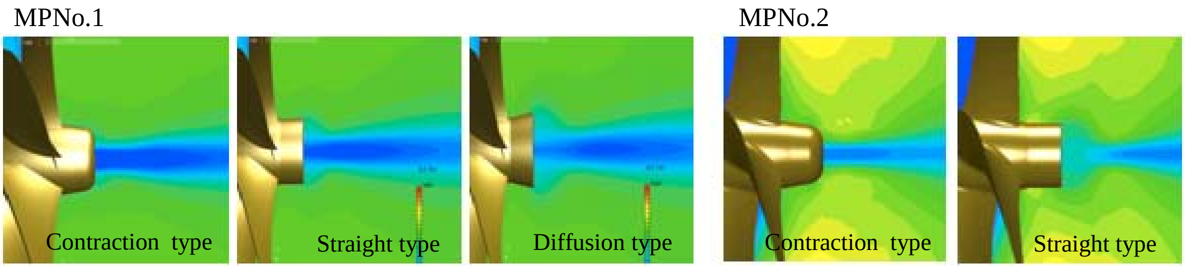


Fig.4 Pressure distribution behind the Propeller caps (MPNo.1&2)

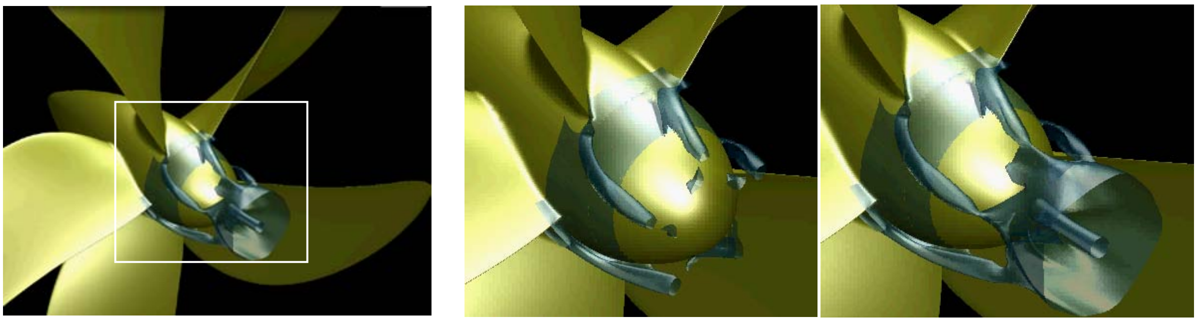

Fig.5 Visualization of Hub Vortex generation for MPNo.2

The authors confirmed the following items by numerical analysis of CFD.

1) The low pressure part on MPNO.1 has 6 blades is larger than on MPNo.2 has 5blades.
2) The cap of straight type or diffusion type can reduce low pressure part than contraction type by diffusion effect.
3) Hub vortex is occurred by concentration of several tangential flows generated from propeller blade root.

## 2-3.Design of Economical Cap

It is important to prevent the concentration of the tangential flow at the center of the propeller cap rear for a reduction of the hub vortex. Therefore, the design concept of an economical cap is prevention of the concentration of tangential flows, and the authors designed three economical caps as follows. Fig.6 shows the profile of the designed the economical caps.

Case-1 : Straight fins, and the end of fins is concentrated at the center of propeller cap rear.
Case-2 : Straight fins same as Case-1, and the end of fins is separated at the center of propeller cap rear.
Case-3 : Taper fins, and the end of fins is separated at the center of propeller cap rear.


Fig.6 Profile of Economical Propeller caps for MPNo.2

Fig.7 shows the isosurface of tangential flow visualized by same way of Fig.5 on the economical caps. In all of them, the diffusion effect is confirmed. In Case-1, weak hub vortex is occurred at the center of propeller cap rear, and the tangential flows are induced to the part of concentration of the fins at cap rear. Therefore, the authors judged the edge of fins should be separated at the center of propeller cap for prevention of hub vortex. Fig.8 shows the pressure distribution of each economical cap, and the low pressure part (blue area) of each economical cap is reduced than the general caps. The effect of reducing the low pressure part of the CASE-3 is higher than Case-1 and Case-2. Therefore the authors designed the economical cap for MPNo.1&2 based on Case-3, and made a comparison between the economical cap and the contraction type about the propeller characteristics with those cap.

Fig.9 & 10 shows the comparison of the propeller characteristics with the economical cap and the contraction type, and the components of $K_T$ & $K_Q$ of the propeller characteristics for MPNo.1&2. $K_T$ of propeller with economical cap is larger than with contraction type. Moreover, $K_Q$ is smaller. As the results, the propeller efficiency became to increase. From the figure of the components of $K_T$ and $K_Q$, the authors confirmed that $K_T$ of propeller cap increased and $K_Q$ of propeller cap decreased. In MPNo.1, $K_Q$ of the boss is decreased in a range of high J. Regarding the propeller efficiency, MPNo.1 is increased max.1.23% and MPNo.2 is increased max.0.61 % by economical cap.

Fig.11 shows the pressure distribution of the propeller cap. The contraction type has the large low pressure part (blue area) at the propeller cap rear. In the economical cap, the high pressure part (yellow and red area) on the cap is increased by fins, and the low pressure part of the boss also reduced by economical cap.

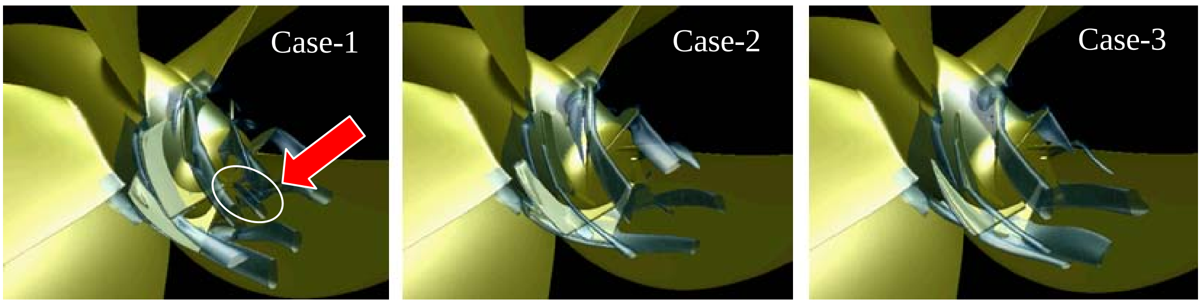

Fig.7 Tangential Flow of Economical caps for MPNo.2

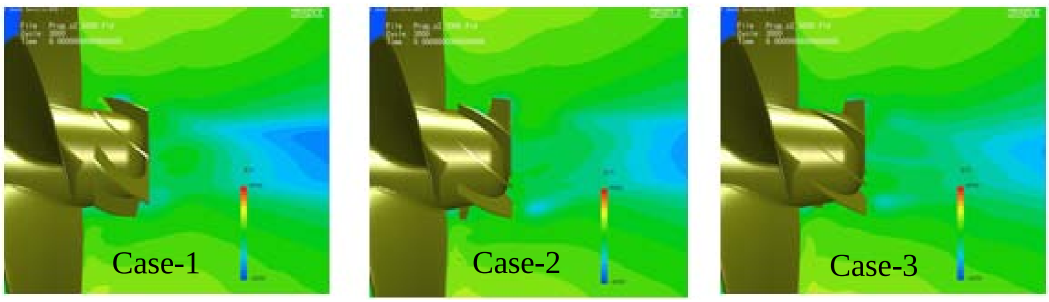

Fig.8 Pressure distribution behind Economical caps for MPNo.2

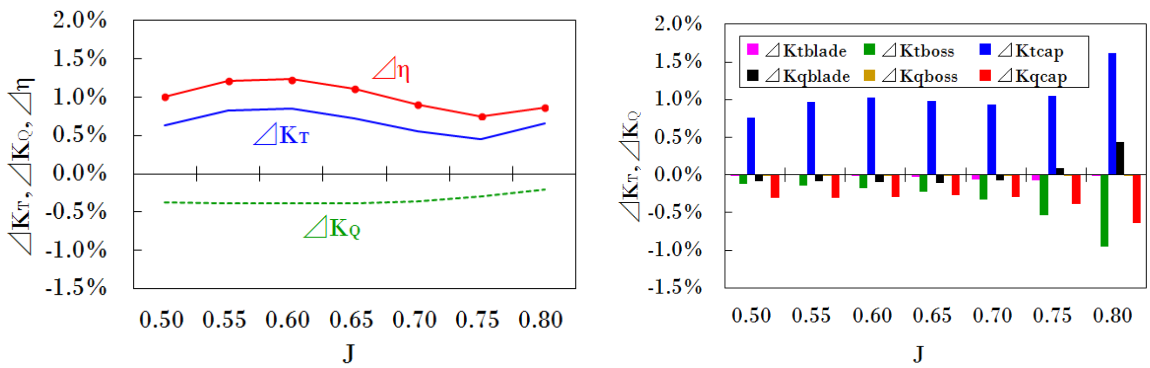

Fig.9 Comparison of Propeller Characteristics for MPNo.1 (Economical/Contraction)

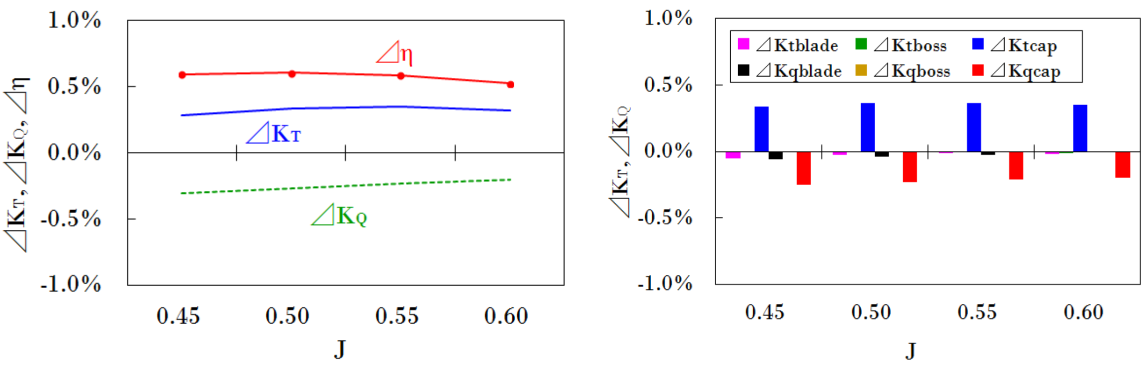

Fig.10 Comparison of Propeller Characteristics for MPNo.2 (Economical/Contraction)

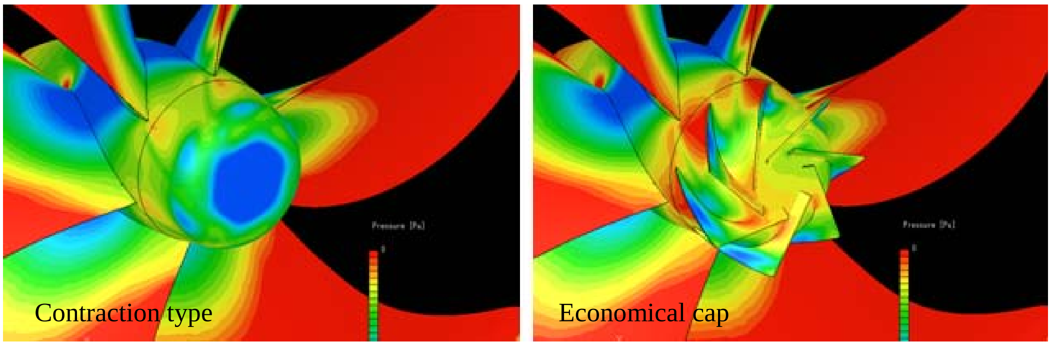

Fig.11 Comparison of Pressure distribution of Contraction type and Economical Cap for MPNo.1

## 3. Confirmation by Model Test

### 3-1. Procedure of Model Test

Fig.12 shows the measurement equipment for economical cap. Model test was carried out by circulating water channel in West Japan Fluid Engineering Laboratory Co., Ltd.. This model test was carried out at Reynolds number of abt.$4\times10^5$, and was adopted reverse POT for measurement of the characteristics of the propeller with cap.

Fig.12 Measurement Equipments for the Propeller Characteristics by Reverse POT

### 3-2. Model Test Results

Fig.13 shows the comparison of the propeller characteristics by model test results. In MPNo.1, the propeller efficiency is increased max. 1.28% because Kt of economical cap is increased and KQ is almost decreased. In MPNo.2, the propeller efficiency is increased max.0.69% because KT is increased and KQ is slightly increased.
For the increase in propeller efficiency by model test, was almost the same as numerical analysis by CFD. However, on MPNo.2, the difference tendency between model test and CFD regarding KQ was observed.

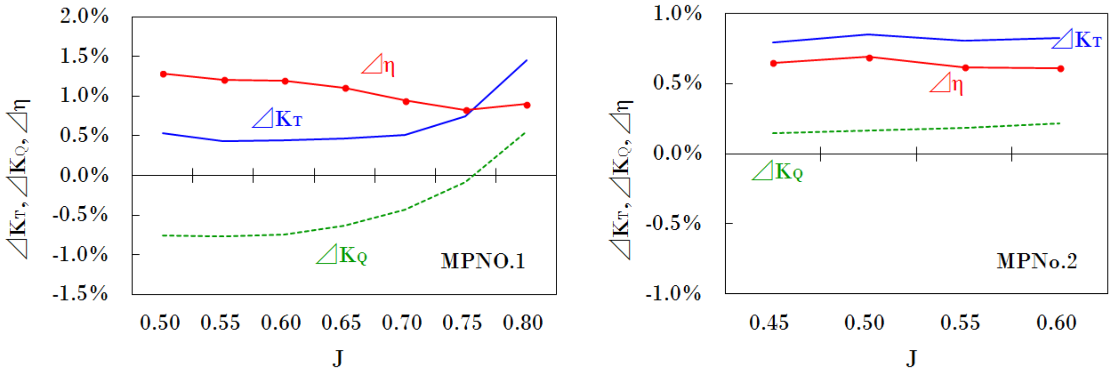


Fig.13 Comparison of Propeller Characteristics by Model Test (Economical/Contraction)

Fig.14 shows the photograph of flow visualization of the hub vortex. The flow visualization test by air injection method was conducted to confirm the strength of the hub vortex. In comparison with the contraction types, MPNo.1 generated strong hub vortex compared with MPNo.2. In the results of both propellers, the hub vortex was disappeared on the economical cap.

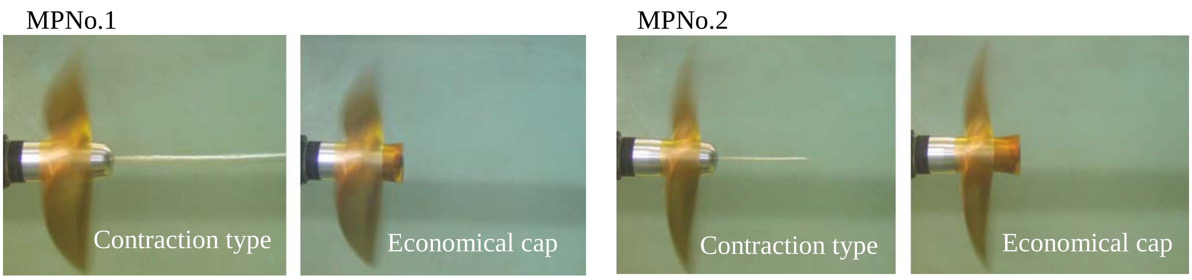


Fig.14 Flow Visualisation Test for the Hub Vortex

## 4. Conclusions

In numerical analysis by CFD and the motel test, the authors were confirmed that the following.

1) Diffusion effect of the hub vortex by economical cap was confirmed by CFD and the model test.
2) The increase of total efficiency by the economical cap was confirmed by CFD and the model test. According to CFD result, the effect of an improvement of the efficiency was by the fins on the economical cap.
3) About the increase of efficiency by economical cap in model test, MPNo.1 was max.1.28% and MPNo.2 was max.0.69%. In addition, almost the same results could be confirmed by CFD analysis.
4) Therefore, it is expected that prevention of rudder erosion and improvement of efficiency by economical cap.

After this, the authors will try the numerical analysis of economical cap including hull by CFD, and confirmation the efficiency in actual operation.

## 5. References

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