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The development of "Ultimate Rudder" for EEDI

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Abstract. EEDI (Energy Efficiency Design Index) came into effect mandatory in Jan. 2013, and the ship owners definitely required a higher efficiency propulsion system than ever before. Hence, the shipyards have been conducting an optimization of ESD (Energy Saving Device) system in self-propulsion test for each project. As the results, the shipyards have installed a rudder bulb as an effective ESD.

The rudder bulb is a popular ESD system from a long time ago. Mewis1) described that the rudder bulb was developed by Costa in 1952 and the efficiency improve by the rudder bulb for a container vessel was 1% on average. Fujii et al.2) developed "MIPB (Mitsui Integrated Propeller Boss)" as an advanced rudder bulb. The feature of MIPB was a streamlined profile from propeller cap to rudder. According to their paper, the efficiency improve by installing MIPB was 2-4%.

Recently, NAKASHIMA PROPELLER Co., Ltd. developed ECO-Cap (economical propeller cap)3) as a new ESD with FRP (Fiber Reinforced Plastics). The strength of FRP is higher than that of NAB (Nickel Aluminium Bronze), therefore ECO-Cap was able to adopt thin fins on propeller caps for low resistance. Although the material used for the energy-saving propeller cap was generally NAB, the research results on FRP showed that FRP could be used as ESD due to their properties such as lightweight and flexibility.

As explained above, the authors thought that there was a possibility to evolve the rudder bulb profile using the easily moldable FRP compared with NAB. This paper described about the development of "Ultimate Rudder" of new design concept by FRP. The authors optimized the profile of "Ultimate Rudder" by CFD and confirmed the efficiency increase from 4.9 to 5.4% in self-propulsion test.

1 INTRODUCTION

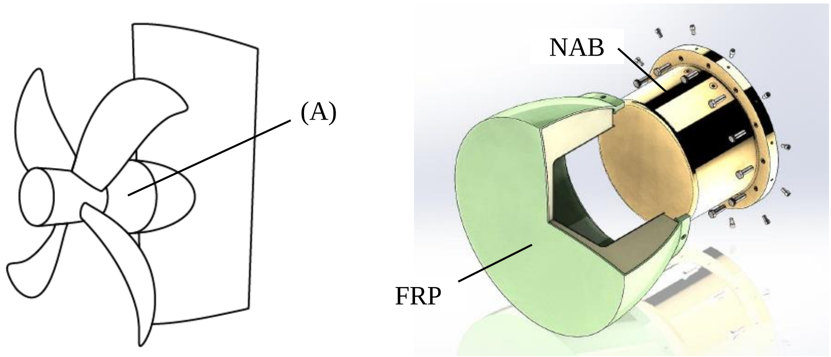
The rudder bulb is adopted as the ESD due to the rudder for improving the efficiency. The mainly effects of hydrodynamics by the rudder bulb were known to the following items.

a) Decrease of contraction flow behind a propeller
b) Elimination of a propeller hub vortex
c) Homogenize of wake distribution and improvement of the hull efficiency by wake gain

To attain the above items effectively, the bulb mounting position is thought to be as close to the propeller plane as possible. In the case of MIPB, the bulb position was closer than past rudder bulb by installation of the divergent propeller cap and the efficiency was improved.

Thereafter, some ESD manufactures installed the divergent propeller cap for their own rudder bulb. However, it was difficult to make rounded cap profile like a conventional rudder bulb by the NAB casting, the divergent propeller cap usually has straight outline. If the propeller cap has the rounded profile like a rudder bulb, the efficiency will improve due to wake gain.

In this study, FRP material was used to Ultimate Rudder, and the propeller cap, which was adopted the rounded profile shown in Fig.1 to compensate the drawback of NBA casting. The Ultimate Rudder with FRP were developed by CFD analysis, furthermore the model test was conducted for a confirmation of an effect on the efficiency of Ultimate Rudder.



Picture of Ultimate rudder Structure of rounded cap(A)

Figure 1 Profile of Ultimate rudder

2 ANALYSIS MODEL BY CFD

NP208BC was bulk carrier that used for CFD analysis of the Ultimate Rudder, and four-blade propeller was installed. Figs.2 & 3 show hull & propeller profile, and Table 1 shows hull dimension and propeller particulars.

Figure 2 Hull profile of NP208BC

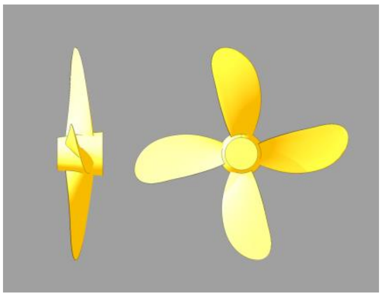


Figure 3 Propeller profile

Table 1 Hull dimension and propeller particulars

Hull dimension		Propeller particulars	
	Actual / Model	Number of blades	4
Lpp (m)	295 / 6.54	Dia. (m) Actual/Model	8.8 / 0.195
B (m)	50 / 1.1085	Pitch ratio	0.75
d (m)	16.1 / 0.3569	Boss ratio	0.18
Cb (-)	0.839	Exp. area ratio	0.4

A normal rudder, a conventional rudder bulb and two kinds of Ultimate Rudder were analyzed by CFD and Fig.4 shows each rudder profile. Two different profiles of Ultimate Rudder were designed as bulb diameter series. Ultimate Rudder1 (UR1) with small diameter and Ultimate Rudder2 (UR2) with large diameter.

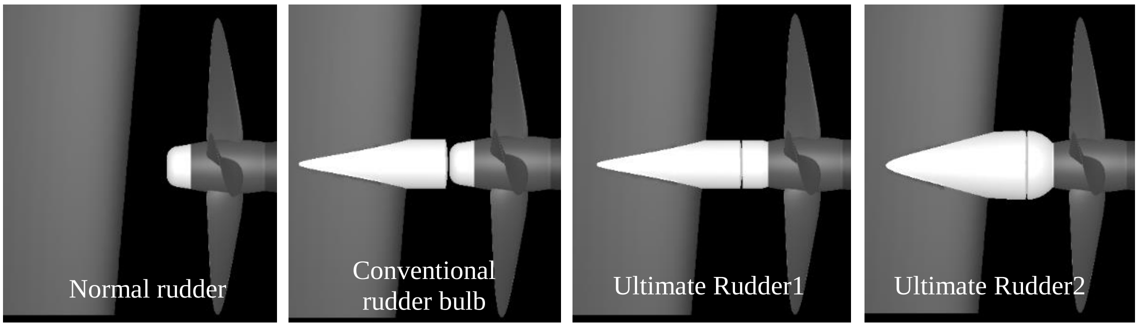


Figure 4 Rudder profile for CFD analysis

The RANS analysis was performed by SOFTWARE CRADLE SCRYU/Tetra Ver.10, which was a commercial CFD code and was based on a finite volume method with unstructured grids. The Shear Stress Transport k-ω model is applied to the turbulence model of present simulations. A full hull body submerged under the design load water line is modeled. The rotational region is introduced to simulate the propeller rotational condition. Fig.5 shows the present computational domain and the surface mesh around the hull with a propeller and rudder. Constant velocity and zero pressure are prescribed at the inlet and the outlet boundary respectively. The numerical mesh is an unstructured grid, and basic cells are tetrahedral and prismatic cells are applied to near the 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+ =1. The total number of meshes is about 45 million.

A symmetry condition (double-body model) at a still-water surface is implemented in the present analysis. The wave resistance coefficient cannot be calculated and is given by the results of the resistance test. RANS simulations of the resistance test, self-propulsion test and propeller open water test are performed to analyze the self-propulsive performance at the thrust identity condition as used in the self-propulsion test. At the self-propulsion point, the total resistance of the ship including an additional towing force (ex. Skin friction correction) is balanced by the delivered thrust from the propeller. The required propeller thrust is obtained by interpolating the results of three rotational rates of the propeller. The Froude number 0.271 is equivalent to 13.5kt at full scale.

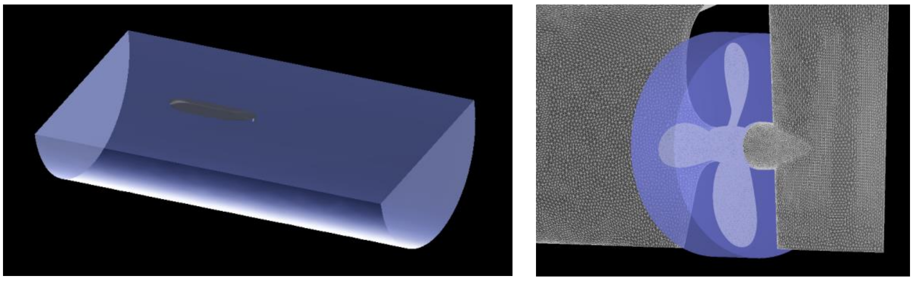
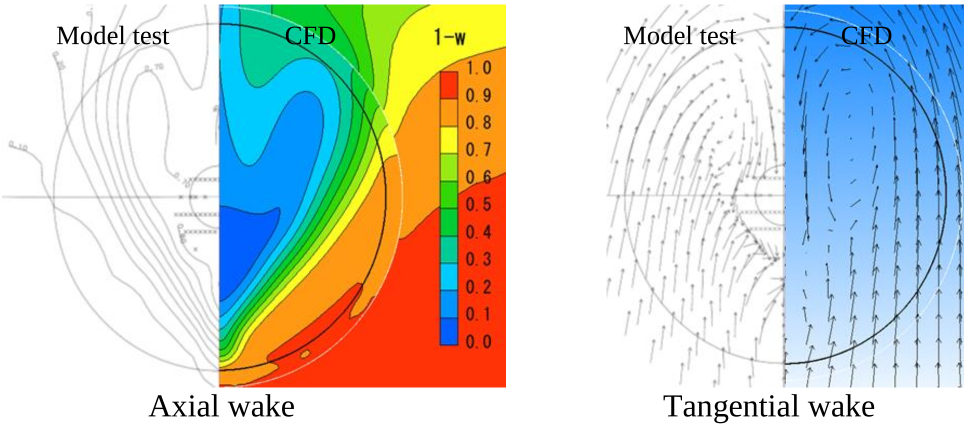


Figure 5 Analysis model of CFD

3 ANALYSIS RESULTS BY CFD

Fig.6 shows the comparison of the wake distribution of towed condition. The calculation results of axial and tangential wake by CFD were almost similar distribution compared with measurement results of model test. This model and condition of CFD analysis was good-enough accuracy for the development of the rudder bulb.



Axial wake

Tangential wake

Figure 6 Wake distribution (model test/CFD)

3.1 Survey of Ultimate rudder profile

The CFD analyses for survey of Ultimate Rudder profile were carried out.

Fig.7 shows the vortex behavior by the iso-surface of Q-function, which means the second invariants of the velocity gradient tensor. The normal rudder was confirmed the strong vortex behavior from the rear of the propeller cap to the rudder plane. On the other hand, the conventional rudder bulb, UR1 and UR2 were reduced the vortex behaviors by the rudder bulbs.

The self-propulsion factors of each rudder bulb are shows in Fig.8. These values of each rudder bulb are divided by those of the normal rudder. In this graph, the direction for increase of the efficiency was presented to positive value about self-propulsion factors.

1-t, 1-w and ηr of both Ultimate Rudder were better than those of the normal rudder and the conventional rudder bulb. Especially, 1-t and 1-w of Ultimate Rudder was remarkable. 1-w was improved by the displacement effect of Ultimate Rudder. Wake gain of UR2 was increased compared with UR1. This indicated that the rounded cap of large diameter was effective than that of small diameter.

In comparison with the normal rudder, the improvement of ηh･ηr was 3.5% at UR1 and was 4.1% at UR2 respectively. In this way, the effect of Ultimate Rudder installed rounded cap was confirmed by CFD analysis. As the results, UR2 was selected as the most effective rudder bulb for NP208BC.

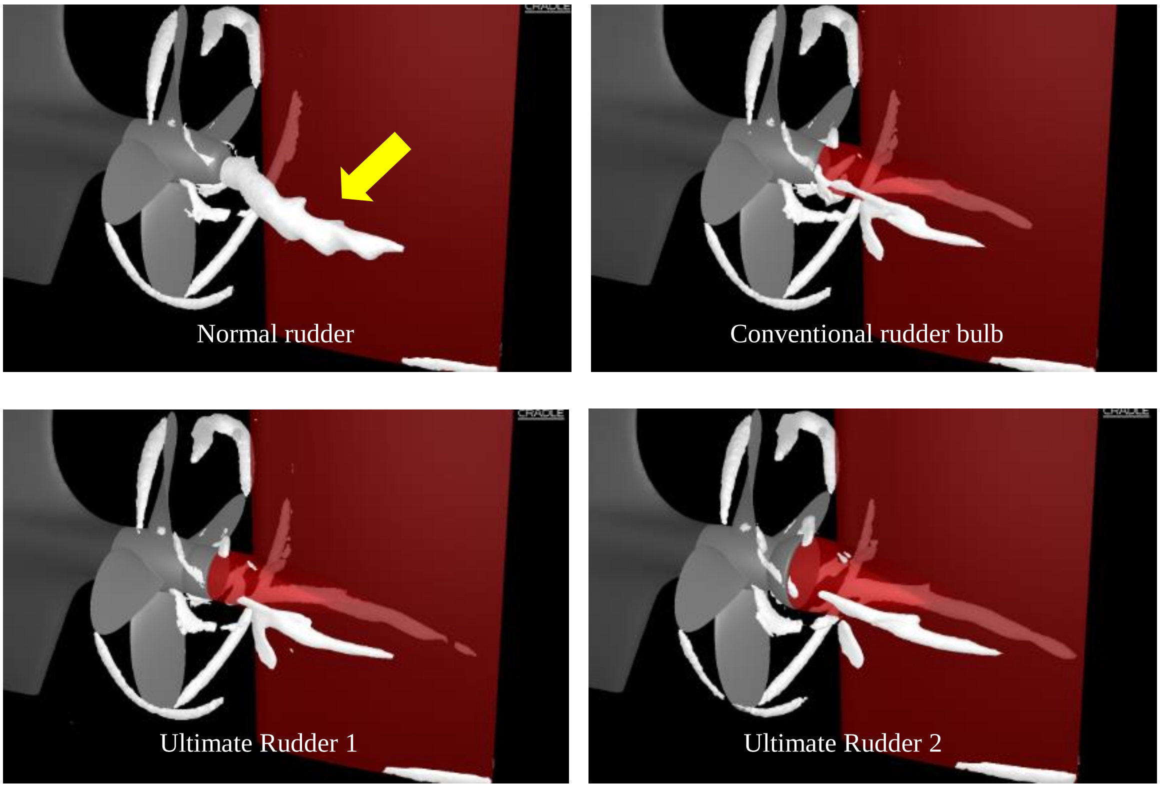


Figure 7 Vortex behavior by the iso-surface of Q-function.

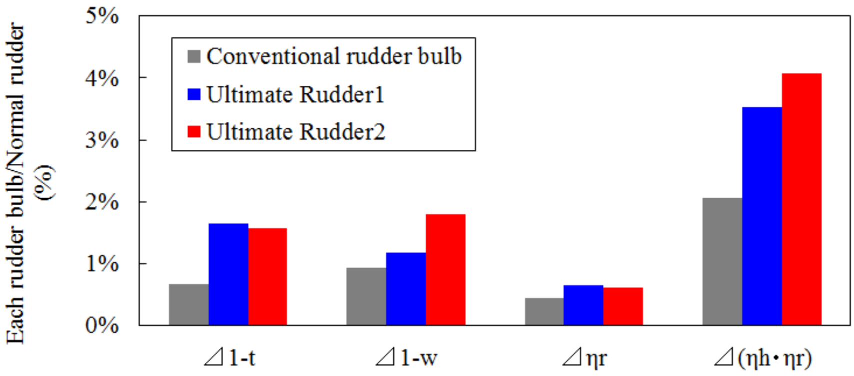


Figure 8 Self-propulsion factor at Fn=0.134

3.2 Comparison of normal rudder and UR2

The detail results of UR2 were compared with the normal rudder.

The turbulent energy of normal rudder and UR2 were visualized in Fig.9. The stream line of UR2 was smoothly and the turbulent energy of UR2 was smaller than the normal rudder. Therefore, UR2 was confirmed the elimination of the propeller hub vortex.

Fig.10 shows the pressure distribution of the normal rudder and UR2. The negative pressure generated at the propeller cap rear in the normal rudder, and this pressure induced the thrust of aft direction. The leading edge of rudder of UR2 was increased negative pressure and this pressure induced the thrust of fore direction. Therefore, total thrust of UR2 was increased.

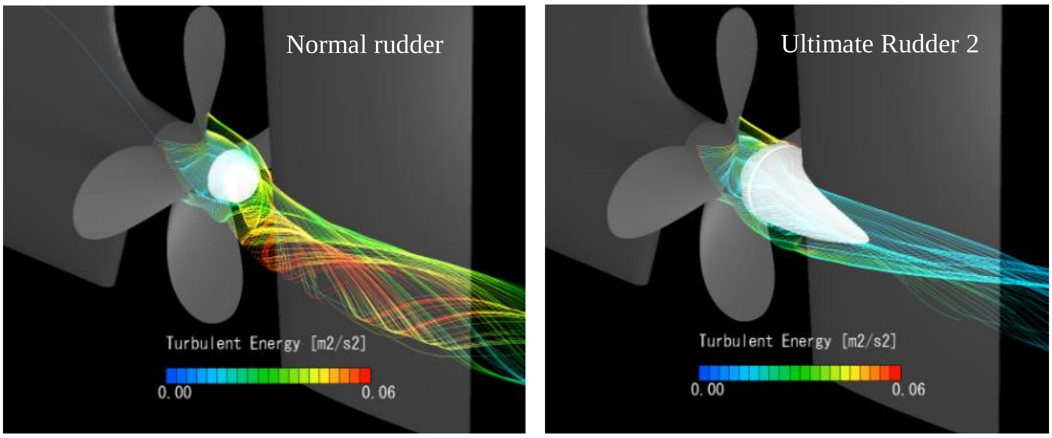


Figure 9 Turbulent energy of normal rudder and UR2

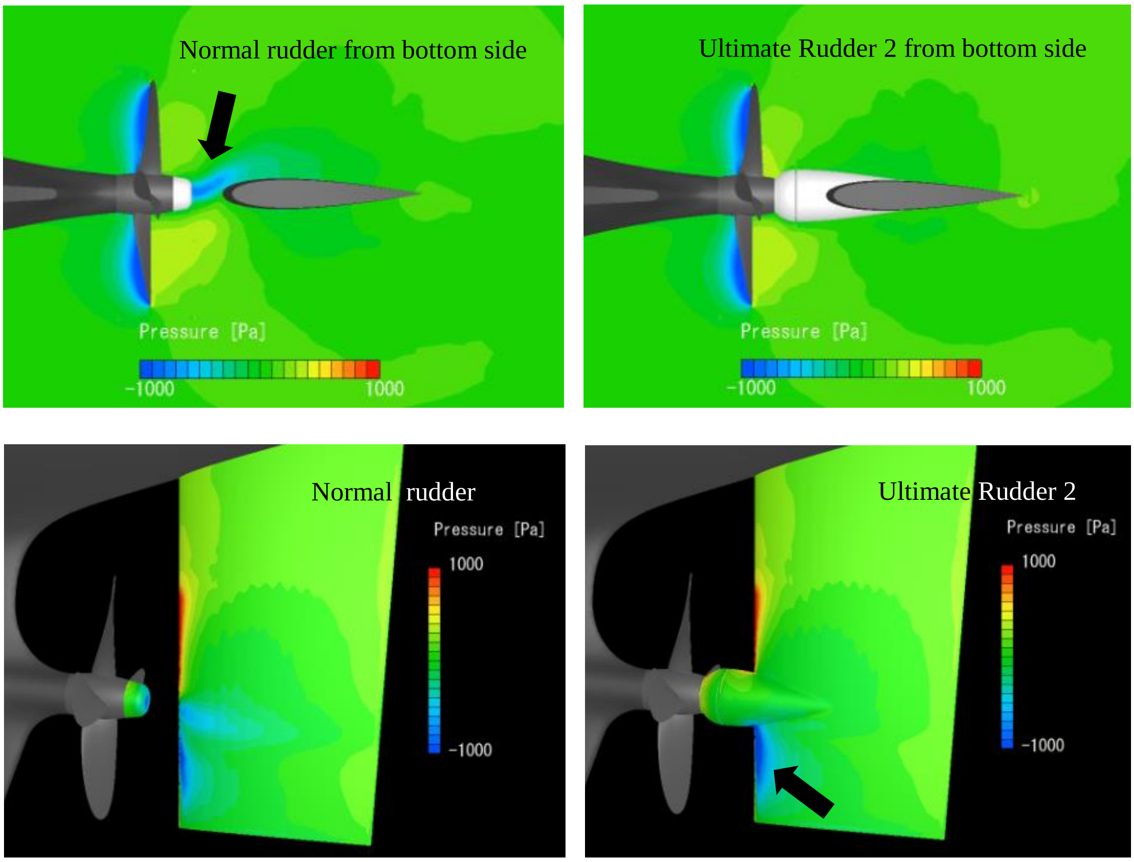


Figure 10 Pressure distribution of normal rudder and UR2

4 MODEL TEST RESULTS

Self-propulsion test was carried out for confirmation of propulsion efficiency in SRC(Shipbuilding Research Centre of Japan). The hull dimension and propeller profile in model test were used the same as CFD analysis.

The comparison of model test and CFD was shown in Fig.11. Each values of self-propulsion factor for UR2 were divided by the normal rudder. The improvement of self-propulsion factor was confirmed by model test results. The $\eta h \cdot \eta r$ of UR2 at each Fn were increased from 4.9 to 5.4%.

In comparison of model test and CFD, the improvement rate of 1-w and ηr in model test was almost same as CFD analysis. However, the improvement rate of 1-t in model test was about 1.3-1.7% higher than CFD analysis.

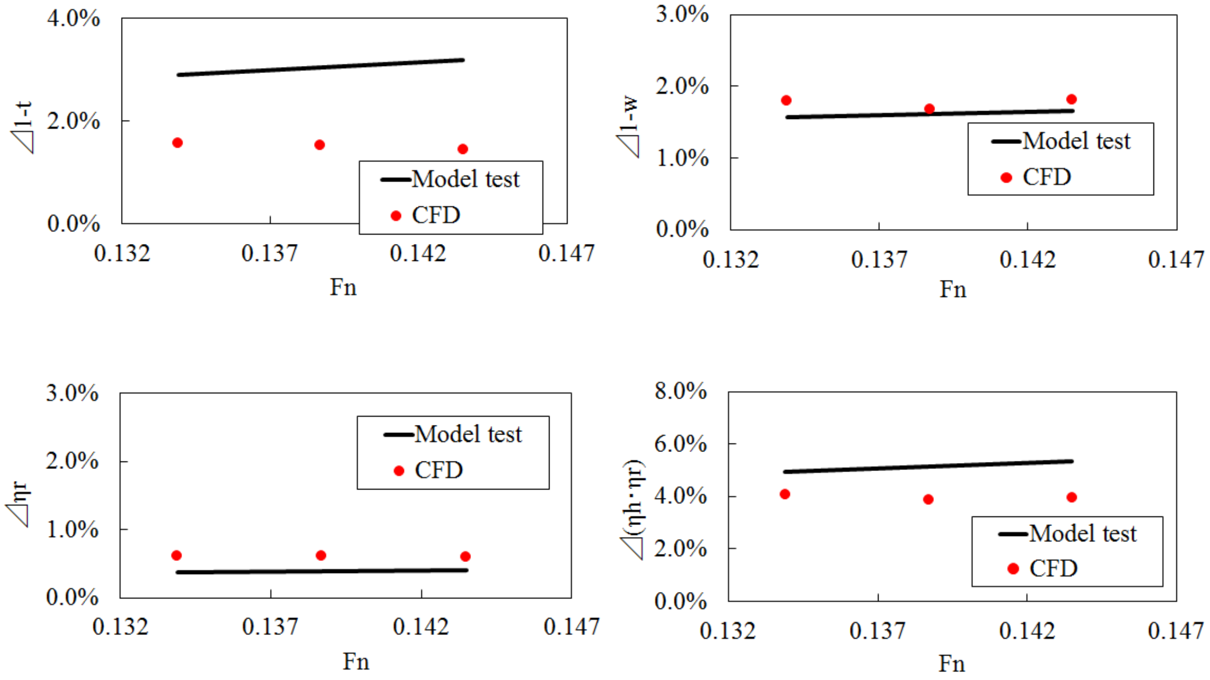


Figure 11 Self-propulsion factors by model test and CFD

5 CONCLUSIONS

1) The improvement of efficiency by Ultimate rudder installed rounded cap was confirmed by CFD analysis. The improvement of $\eta h \cdot \eta r$ by CFD analysis was 3.5% at UR1 and was 4.1% at UR2 compared with the normal rudder.

2) The following effects of Ultimate Rudder were confirmed by visualization of CFD analysis.
   - ・Decrease of the turbulent energy due to the propeller hub vortex
   - ・Revision of the pressure at the propeller cap rear and at the leading edge of rudder

3) The improvement of self-propulsion factors was confirmed by model test results. The ηh・ηr of UR2 at each Fn were increased from 4.9 to 5.4%. The tendency of improvement of self- propulsion factors by Ultimate rudder could be estimated by CFD.

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