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The Battle Royal of Energy Saving Devices for a Ship

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ABSTRACT

In recent years, ship owners have come to seek a more fuel-efficient ship operation at lower cost. In addition, since the start of the EEDI regulations, the shipyard has begun to focus on the further development of high performance ships. In such a background, many ship designers and manufacturers developed a variety of products such as the propeller cap with fin, rudder bulb and duct.

On the other hand, when the ship is installed with several energy saving devices, the reduction amounts of the fuel consumption from synergistic effects are sometimes unclear at the design stage. These issues are highly complicated because designs of those energy saving devices are different and moreover the detail profiles of energy saving devices are confidential. Therefore, it is very difficult to evaluate the total performance at the design stage. However, Nakashima propeller CO., LTD produces not only the high performance propeller, it is also feasible to design of energy saving devices such as ECO-Cap of the propeller cap with fins (Okada, et al. 2013), Ultimate Rudder Bulb (Okada, et al. 2015) and Neighbor Duct (Katayama, et al. 2017).

In this paper, the authors conducted the model tests for three kinds of energy saving devices by using the model ship of 82kBC. Furthermore, the different combinations were carried out in model tests and CFD analysis. This paper summarizes the synergistic effect of energy saving devices on the basis of the model test and CFD results.

Keywords

Energy saving device, ECO-Cap, Ultimate Rudder Bulb, Neighbor Duct, EEDI

1 INTRODUCTION

There are many energy saving devices available in market of merchant vessel. For example, a propeller cap with fins, rudder bulb and duct are popular products for improvement of fuel oil consumption. However, there are few available research results for combination of their individual effects.

Firstly, the propeller cap with fins is well-known product for energy saving because of easy installation and inexpensive. In particular, PBCF is very famous products for this kind of device (Kawamura et al 2013). Another product, which recently released to the market, is called as ECO-Cap (See Figure 1). This propeller cap has small seven fins for recovery of negative pressure at the propeller cap end. Furthermore, the thickness of such fins can thin because of FRP made, and this leads to reduce the drag. In previous study, the efficiency increased by ECO-Cap was abt.1.2% in the model test (Katayama et al 2015). However, ITTC referred the model test results and the results of full scale analyses, 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 (Bose et al 1999). Furthermore, the full-scale improvement rate of propulsion efficiency by ECO-Cap was changed by propeller particulars, and it was 1.5 to 3.2 times greater than in the model scale (Okazaki et al 2015).

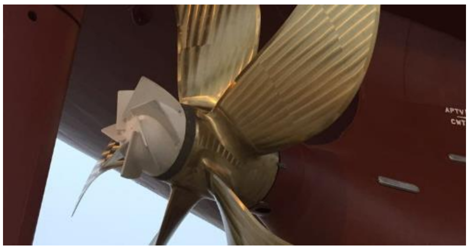

Figure 1: ECO-Cap adopted on the actual vessel

Secondly, the rudder bulb is also a popular energy saving device and has a long history for the delivery. The rudder bulb was developed by Costa in 1952 and the efficiency increase by rudder bulb for container vessel was 1% on average (Mewis and Deichmann 2013). Mitsui Engineering and Shipbuilding developed "MIPB (Mitsui Integrated Propeller Boss)" as advanced rudder bulb

(Fujii et al 1995). The feature of MIPB had streamlined profile, which were smoothed from a propeller cap to rudder. According to their paper, the efficiency increased by installing MIPB was 2-4%. The reason of the efficiency increase of the rudder bulb is wake gain and recovery of hub vortex. Therefore, the bulb position that is close to the propeller plane is more preferable. In the case of MIPB, the bulb position was closer than general rudder bulb by installation of divergent propeller cap and the efficiency was increased. Thereafter, some makers installed the divergent propeller cap for their own rudder bulb. However, it is difficult to make a rounded cap profile by the casting of Ni-Al-Bronze, thus the divergent propeller cap is generally liner outline. If the propeller cap become to rounded profile, then the efficiency will increase by upgrading of wake gain. Ultimate Rudder Bulb for propeller cap were adopted FRP and was able to obtain the rounded profile (see Figure 2). Okada et al. (2015) optimized profile of Ultimate Rudder by CFD and confirmed efficiency increase by abt.5-6% in the self-propulsion test.

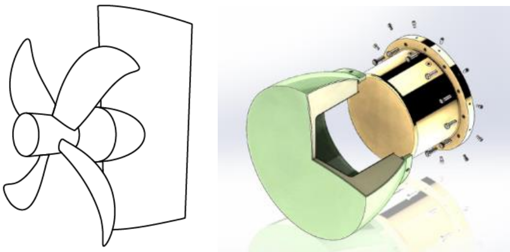

Figure 2: Structure of Ultimate Rudder Bulb

Thirdly, the duct is one of the most effective energy saving devices. There are many similar ducts in the market. Weather Adapted Duct (hereinafter, referred to as WAD) was developed by NMRI. The feature of WAD is small size and the harmful cavitation on the propeller blade is hardly occurred. The effect of power reduction by WAD is 3-7% (Kawashima et al 2014).

Another duct called as Neighbor Duct developed by authors (see Figure 3), gains the improvement of thrust deduction fraction (1-t). This duct is vertically long elliptical profile and there is little influence on wake fraction (1-w). The improvement of propulsion efficiency is 4.7% in the model test. The section of Neighbor Duct has a very complicated profile for the optimization confirmed by CFD. For that reason, FRP is planned to adopt for the material of Neighbor Duct.

As described above, each saving devices has the increase of the efficiency and integrated optimal design of those devices should be considered for the market of merchant vessel. In addition, energy saving devices with FRP can be advantage in terms of efficiency compared with those with conventional material. Therefore, the three energy saving devices with FRP were developed in this study. The authors carried out a model test to clarify the combined the effect from those energy saving devices. CFD calculation was performed to analyze the mechanism of improvement.

Figure 3: Neighbor Duct for 82kBC in model test

2. MODEL TEST BY 82kBC

2.1 TEST CONDITIONS

The self-propulsion tests were conducted at 400m long towing tank in NMRI. In the model test, 82kBC developed by NMRI was used. Table 1 shows the principal particulars of 82kBC. The blade number of propeller was four and the actual diameter was 6.4 m.

ECO-Cap, Ultimate Rudder Bulb and Neighbor Duct for 82kBC were designed in this study. Figure 4 shows the image of Ultimate Rudder Bulb and ECO-Cap for 82kBC. In addition, the model tests in each device and combined condition with each device were conducted.

Table 1: Principal particulars of 82kBC

NMRI 82Pana_Max Bulk Carrier			
Condition	Designed Full		
Principal Dimension		Actual	Model
Length Between Perpendiculars	(m)	222	7.631
Length on Designed Load Water Line	(m)	225	7.734
Bredth	(m)	32.26	1.109
Depth	(m)	19	0.653
Design Draft	(m)	12.2	0.419
Block Coefficient		0.87	0.87

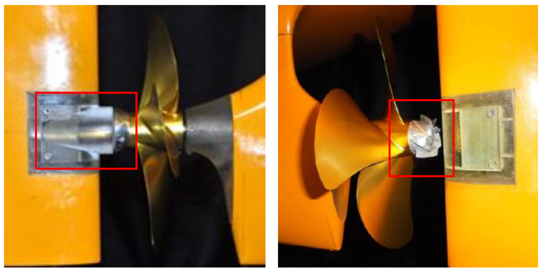

Figure 4: Ultimate Rudder Bulb and ECO-Cap

2.1 TEST RESULTS OF EACH DEVICE

Figure 5 shows the model test results with each device. Vertical axis in Figure 5 indicates the ratio of “with” and “without” each device in the self-propulsion factors. All energy saving devices showed effective for improvement of efficiency.

In the results, Neighbor Duct was the most effective and Δη (energy saving index) was 4.7%, while that index of Ultimate Rudder Bulb and ECO-Cap was 3.9% and 2.9%, respectively. The definition of each item is described below.

$$\eta = (1-t) / (1-w) \ \eta_O \eta_R$$

$$\Delta\eta = \eta_{with} \ / \ \eta_{without}$$

η : Propulsive efficiency

1-t : Thrust deduction fraction

1-w : Wake fraction

η_O : Propeller open water efficiency

η_R : Relative rotative efficiency

The results of 1-w and 1-t for three energy saving devices indicated the better trend in terms of efficiency. 1-w showed negative trend while 1-t showed positive trend. This leads to improve the efficiency with each device.

It was confirmed that Neighbor Duct and Ultimate Rudder Bulb had a better improvement effect because the degree of the absolute ratio for 1-t is large compared with that for 1-w. The tendency of the improvement of Neighbor Duct was similar compared with Ultimate Rudder Bulb. On the other hand, ECO-Cap was effective in terms of the improvement of η_R.

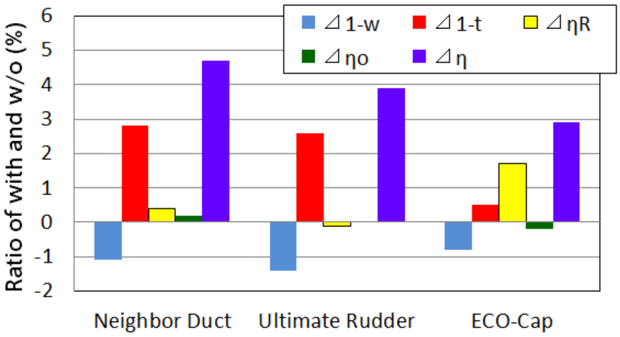

Figure 5: Model test results of each device

2.2 TEST RESULTS OF DEVICE COMBINED

The combination of energy saving devices was selected and the most effective combination was investigated. Figure 6 shows the combination test results for Neighbor Duct and ECO-Cap. The energy saving index of combination of Neighbor Duct and ECO-Cap was 6.2%.

This seems that the improvement effect of 1-t from Neighbor Duct and the improvement effect of η_R from ECO-Cap were not canceled out. Therefore, the improvement effect by different items such as 1-t and η_R is not canceled in this model test.

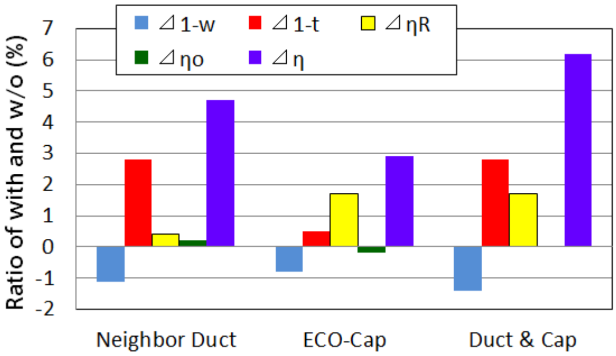

Figure 6: Model test results of combined condition

Figure 7 shows the combination test results for Neighbor Duct and Ultimate Rudder Bulb. The energy saving index of combination of Neighbor Duct and Ultimate Rudder Bulb was 8.7%. The improvement tendency of self-propulsion factors from both Neighbor Duct and Ultimate Rudder Bulb showed similar. The highest improvement effect was obtained from the combination of Neighbor Duct and Ultimate Rudder. This is because that the increase of 1-t was highest in all energy saving effects examined.

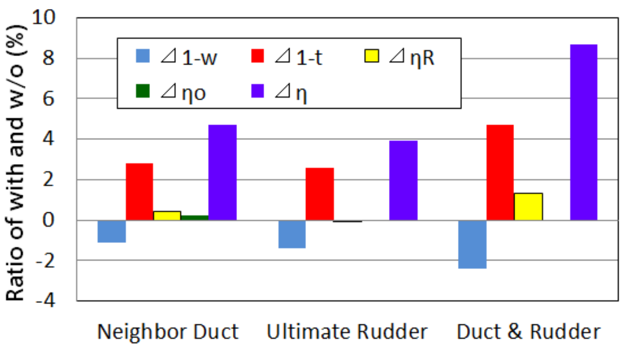

Figure 7: Model test results of combined condition

3 CFD ANALYSIS

3.1 ANALYSIS CONDITION

CFD analysis was conducted to investigate the synergistic effect between Neighbor Duct and Ultimate Rudder Bulb.

RANS calculations were performed by SOFTWARE CRADLE SCRYU/Tetra Ver.13 which was a commercial CFD code and was based on a finite volume method with an unstructured grid. The Shear Stress Transport k-ω model was applied to the turbulence model of the present simulations. The flow field around a propeller in non-uniform wake flow was simulated. The computational domain was composed of the inner rotational part including the propeller and the outer stationary part. The stationary part and the rotational part were connected discontinuously. Constant velocity and zero pressure were prescribed at the inlet and the outlet boundary, respectively. Figure 8 shows the computational domain and Figure 9 shows analysis model of propeller and energy saving devices. The numerical mesh was an unstructured grid, and basic cells were tetrahedral and prismatic cells were 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^+) =1. The total number of elements was about 45 million.

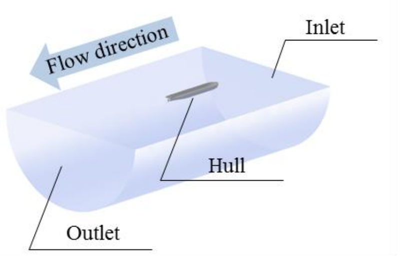

Figure 8: Computational domain

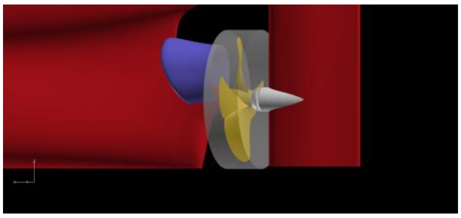

Figure 9: Propeller and energy saving devices for CFD

3.2 ANALYSIS RESULT

Figure 10 shows the analysis results for combined condition by CFD. It was confirmed that the improvement tendency of 1-w and 1-t from both Neighbor Duct and Ultimate Rudder Bulb were similar.

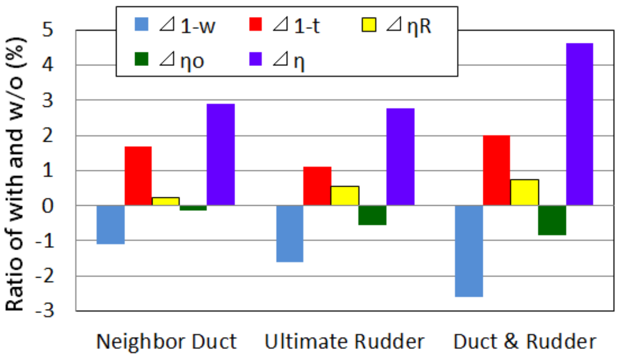

Figure 10: Analysis results of combined condition

In particular, the ratios for 1-w and 1-t from both devices showed negative and positive trends which lead to improve efficiency in those devices. Furthermore, the synergistic effects from combined those devices was observed from CFD analysis. This analysis result was in accordance with model test results in terms of the tendency.

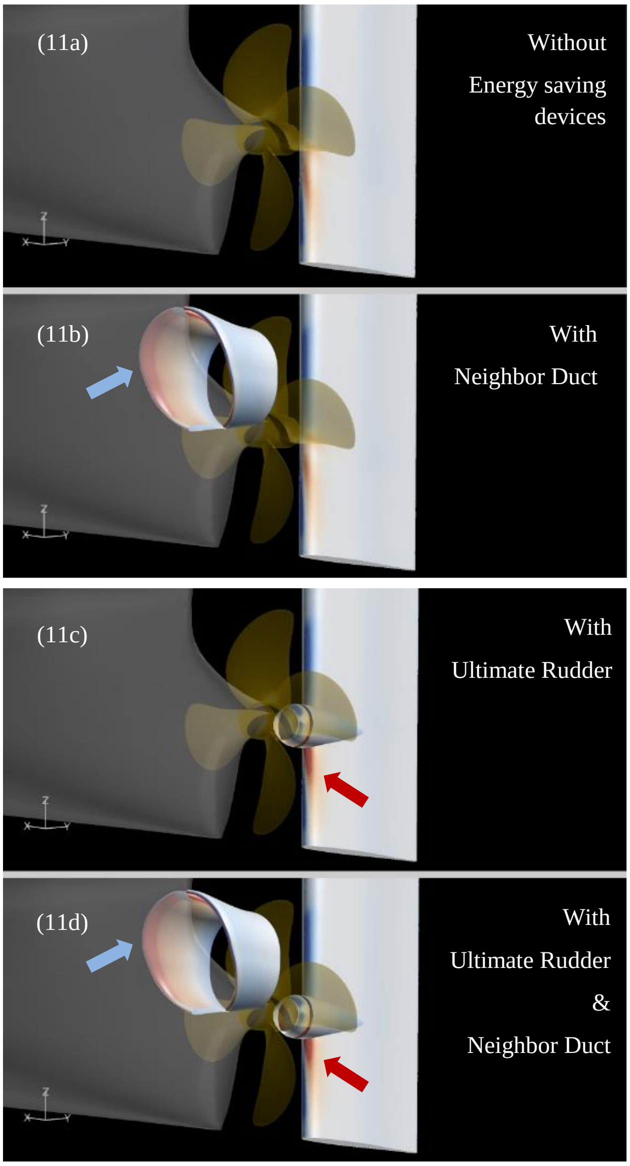

Figure 11: Comparison of pressure distribution

Figure 11 shows the pressure distribution from combined conditions analyzed by CFD. Red color contour indicates negative pressure and blue color contour indicates positive pressure. Red color contour at the leading edge of Neighbor Duct and Ultimate Rudder Bulb means increase of thrust.

Comparison of Figures 11a and 11c, red color contour area was extended by Ultimate Rudder Bulb. Therefore, the thrust from the rudder was increased by Ultimate Rudder Bulb. As the results, the value of 1-t from Ultimate Rudder Bulb was improved.

On the other hands, it was confirmed that the red color contour area of Neighbor Duct without Ultimate Rudder Bulb (Figure 11b) was almost same compared with Neighbor Duct and Ultimate Rudder Condition (Figure 11d). The value of 1-t from Neighbor Duct was improved by duct thrust effect. Therefore, the interference effect of Neighbor Duct and Ultimate Rudder Bulb was small.

From the above calculation results, in the case of the combination of energy saving device for improving different elements, the combined condition is effective for energy saving.

4 CONCLUSIONS

The authors confirmed the following contents from the model test and CFD analysis by energy saving devices.

1) From the model test results for 82kBC, ECO-Cap, Ultimate Rudder Bulb and Neighbor Duct were effective for energy saving. In terms of tηe amount of energy saving index, ECO-Cap was 2.9%, Ultimate Rudder Bulb was 3.9% and Neighbor Duct was 4.7%. ECO-Cap improved η_R, and Neighbor Duct and Ultimate Rudder Bulb improved especially 1-t.

2) In combined results from the model test, it was confirmed that the combination of each energy saving devices were effective. The energy saving index from combination of Neighbor Duct and ECO-Cap was 6.2%, and combination of Neighbor Duct and Ultimate Rudder Bulb was 8.7%.

3) From the CFD analysis results, the tendency of the value of 1-w and 1-t for both Neighbor Duct and Ultimate Rudder Bulb were similar. CFD analysis showed synergistic effect in terms of energy saving index.

4) It was confirmed 1-t of Ultimate Rudder Bulb was improved by rudder thrust and 1-t of Neighbor Duct was improved by Duct thrust in CFD analysis. The combination of energy saving devices with different improvement effects is effective.

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