Comparative Study between Results of Theoretical Calculation and Model Test for Performance Confirmation of "Crown Duct"

Kwi-Joo Lee[*], Jung-Sun An[*] and Han-Joung Kwak[**]

[*]Department of Naval Architecture and Ocean Engineering, Chosun University, Gwangju, Korea
[**]SPP Ship yard, Sacheon, Korea

ABSTRACT: *Chosun University, in cooperation with SPP shipyard, has developed an energy saving device based on a new concept: "Crown Duct." Crown Duct is composed of a semi-duct with short struts inside and outside the duct. Theoretical calculations for two different designs were carried out using the CFD code "Ship Flow." The design selected from these two different forms by the CFD code analysis was tested in a towing tank at SSPA. The results showed about 4% efficiency gain under a full-load condition and about 7% gain under a ballast condition in the towing tank test.*

1. Introduction

Vortices generated from the bilge at stern moves upward on both ship sides and moves downward near the center plane of the ship, leading to difference angle of attack of propeller blades on port and starboard side which may reduce the propeller efficiency.

Against the stern flow mechanism, the stator fins generally plays a role as flow guiding device making a wake field near the upper part of the propeller plane uniform by both deflecting flow toward propeller and reducing the wake peak at propeller top position(Lee et al., 1992 and Lee et al., 1994).

Conventional pre-swirl stator consists of several fins which have almost the same span length as the propeller radius and are fixed radially on the stern frame in front of the propeller as shown in Fig. 1. It is known that the wake factor (*1-w*) decreased considerably due to reflecting flow generated by stator fins in front of the propeller plane. But high stress fins concentrated at the standing point of side fin in heaving and pitching motion, and non-negligible added resistance due to this is the problem to be solved(Asaumi et al., Lee et al., 2012a).

2. Development of a New Type Energy-Saving Device "Crown Duct"

New type of complex stator having less added resistance and less stress on the stand point of side fins than conventional pre-swirl stator, has been developed by combination of semi-duct and minimum blades As shown in Fig. 2, small sized semi-duct having diameter almost equal to 50% of propeller diameter is attached to the tip of the short horizontal fin which is designed to decrease the tip vortex and to generate the uniform flow to the propeller(Lee et al., 2012b; Lee and An, 2012). As shown in Fig. 2, this new energy-saving device consists of three fins
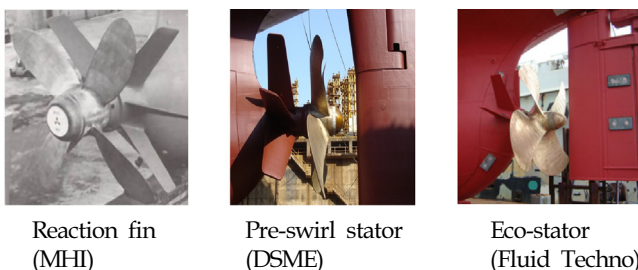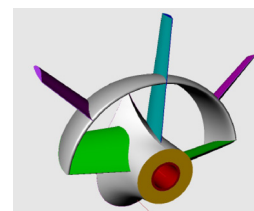

Reaction fin (MHI)

Pre-swirl stator (DSME)

Eco-stator (Fluid Techno)

Fig. 1 Pre-swirl stator

- Duct diameter   3.2 m
- Span of left stator   1.5 m
- Span of center stator   2.8 m
- Span of right stator   1.5 m

Fig. 2 Configuration of Crown Duct

on the stern frame and three plates on the duct.

Crown Duct(CD) is designed to reflect the stern vortices in the condition of the propeller rotation. This reflecting flow may reduce the wake near propeller tip and contribute to increase the equality of wake field, which may lead to a gain in propulsive efficiency.
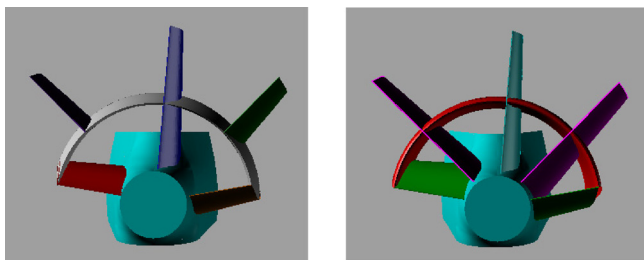
3. Theoretical Calculation

Computational Fluid Dynamics (CFD) is widely used in the ship design process. In particular during the initial design stage CFD has become an important tool. It enables the designer to evaluate a larger number of hull alternatives and thereby a better optimized and reliable design before the final validation. It is true that not only for new buildings but also for existing ships and retro fitting of ship energy saving devices. The tough competition on the shipbuilding market creates high demands on short lead times and competitive designs. This must be met by developments of effective CFD tools and integration with CAD.

CFD code makes cost down for the evaluation and prediction of performance of ship. Comparative theoretical calculation has been performed by CFD code of Shipflow for two different designs of Crown Duct configured as shown in Fig. 3.

Grid used for the calculation are as follows and shown in Fig. 4.

- 10 Component grids
- Total number of cells 4.9×106

The main Particulars of ship which has been simulated for

the resistance and propulsion performance at design speed is shown in Table 1.

3.1 Resistance Calculation Result

Resistance calculation results are compared in Table 2.

3.2 Self Propulsion Calculation Result

Self propulsion calculation results are summarized in Table 3. And slight retardation of velocity by stator in upper part visualized in Fig. 6 which leads to improve wake field. Wake results are shown in Fig. 5.

Table 1 Main Particular

Parameter	Ship
Length between perendiculars	174 m
Length at load water line	178 m
Breadth	32.2 m
Design draft	11 m
Design speed	7.72 m/s (15 kts)

Table 2 Comparison of resistance components

	Bare hull	with CD1	with CD2
k	0.354	0.354	0.354
C_W	1.468	1.519	1.612
C_{TM}	4.313	4.436	4.457

* k : form factor

Diffusive angle -6° (Downward to propeller section) CD1   Diffusive angle +12° (Upward to propeller section) CD2

Fig. 3 Two different design of Crown Duct
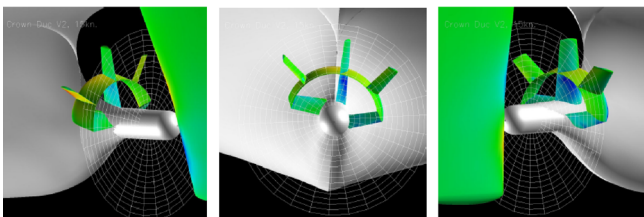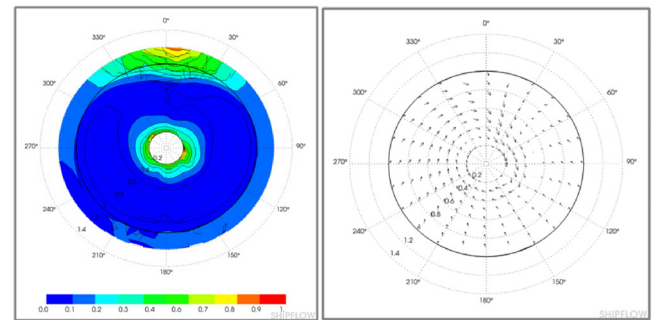

Fig. 4 Grids of Crown Duct
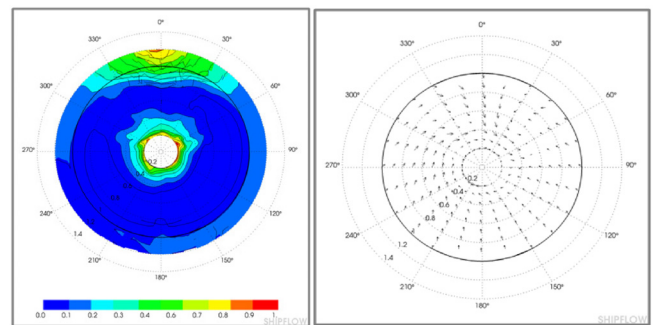
Bare hull

With Crown Duct 1

Fig. 5 Comparisons of wakes and transversal velocities in propeller disc

Table 3 Comparison of self propulsion components

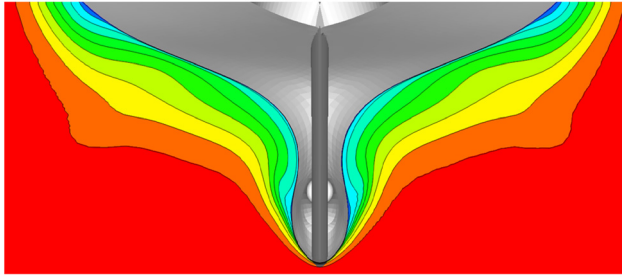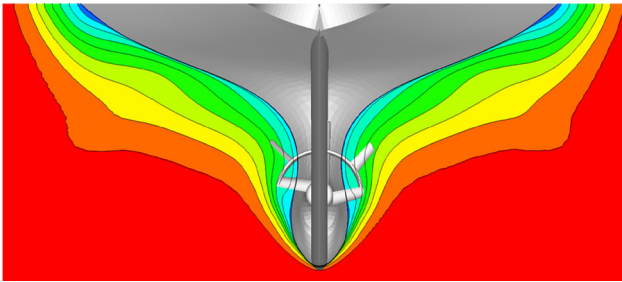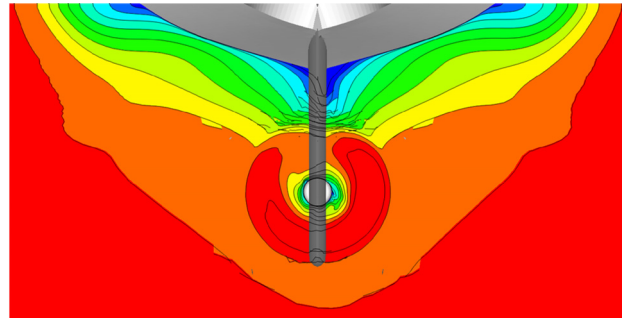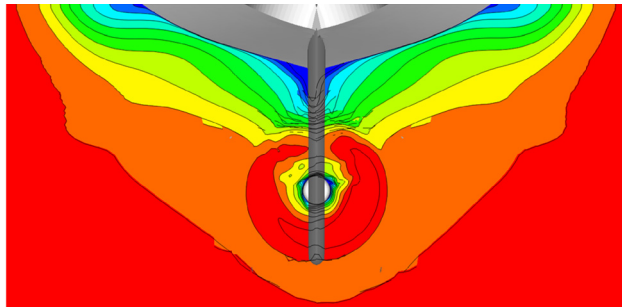|	P_E	$1-w$	$1-t$	η_R	η_O	η_D	P_D	%
Bare hull	4785	0.658	0.795	1.013	0.557	0.682	7016	
with CD1	4744	0.565	0.766	1.011	0.501	0.687	6905	-1.6
with CD2	4685	0.591	0.771	1.010	0.512	0.675	6940	-1.1

(a) Bare hull(Axial velocity contours at x=0.95)

(b) With Crown Duct 1(Axial velocity contours at x=0.95)

(c) Bare hull(Axial velocity contours at x=0.9799)

(d) With Crown Duct 1(Axial velocity contours at x=0.9799)

Fig. 6 Comparisons of axial velocity contours

4. Model Test

Model tests are carried out in the towing tank of SSPA(Lee et al., 2012).

4.1 Test facility

The towing tank has the following main particulars:
- Length 260 m
- Breadth 10 m
- water depth 5 m
- Maximum carriage speed V_{MAX}= 11 m/s

4.2 Hull model

Ship model was manufactured in divinycell, a foam plastic material. The model scale is 1: 25.417. The model has a turbulence trip wire at station 19. The ship model with Crown Duct and propeller is shown in Fig. 7.

4.3 Propeller model

The propeller model is fixed, right turning, four bladed propeller with dimensions according to Table 4.

4.4 Extrapolation by ITTC - 78 and Modified ITTC - 78

Without the crown duct mounted the predictions were made according to the 1978 ITTC extrapolation method.

With the crown duct mounted a somewhat modified wake
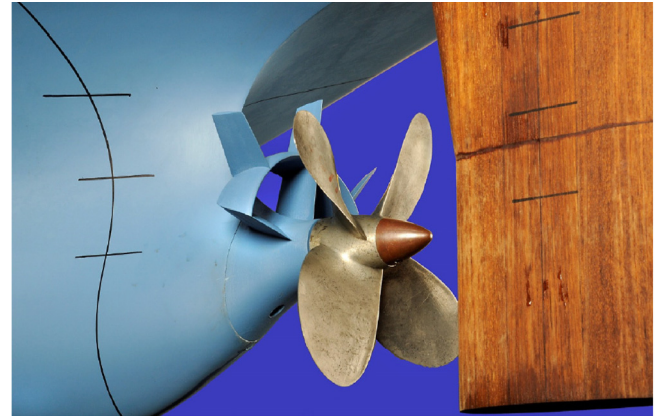

Fig. 7 Ship model with Crown Duct and propeller

Table 4 Main particulars for model propeller

Characteristic	Value
Diameter model scale	0.24 m
Diameter full scale	6.1 m
Pitch ratio P/D at r/R = 0.75	0.715
Blade area ratio A_D/A_O	0.53

scaling was used.

The method has been discussed within the 1999 ITTC and tentatively accepted for evaluation of pre-swirl stator concepts. The wake scaling presumes that tests with the same propeller but without the stator have been performed as well. The difference between model effective wake with stator and the model wake without stator is considered as a potential wake created by the stator.

The hull potential wake and the frictional wake are scaled as for the model with out stator according to the normal ITTC - 78 method, to which the stator potential part is added. The amount 0.04 represents the potential wake created by the rudder at the location of the propeller.

Thus is in the modified ITTC 1978 extrapolation the full scale wake(Lare et al., 2011).

$$W_{Tsw} = (t_{wo} + 0.04) + (W_{Tmwo} - (t_{wo} + 0.04))$$
$$* [(1+k)C_{Fs} + \triangle C_{Fs}/(1+k)C_{Fm}] + [W_{Tmw} - W_{Tmwo}]$$

where index
"W" stands for "with crown duct"
"wo" stands for "without crown duct"
"m" stands for "model"
"s" stands for "ship scale"
"T" stands for "thrust identity"

The form factor is based on the case without crown duct.

4.5 Result of model test

The results of model tests are compared in Table 5 for full load condition and in Table 6 for ballast condition. The P_D (kW) values are a ship trial prediction of SSPA.

4.6 Comparison of CFD calculation results with the result of model test

Comparative results of CFD calculation with model test ones are shown in Table 7. CFD Code "Ship Flow" is evaluated as applicable to the calculation of performance of ships with appendages.

5. Conclusions

Crown duct has been developed to recover the energy loss by improving propeller induced pre-rotating flow.

The model test result which is carried out in the towing tank shows that the wake factor(1-w) decreased up to considerable level.

Decreased wake factor supposed to be caused by reflecting flow generated from stator fins combination with semi-duct. Propeller revolution decreased at same thrust condition due to the decreased wake factor, and propulsive efficiency

Table 5 At Full load condition

Condition	$P_E(kW)$	w	t	η_R	η_O	η_D	$P_D(kW)$
Bare hull	4783	0.358	0.220	1.018	0.543	0.681	6740
With Crown Duct	4792	0.453	0.247	1.031	0.494	0.714	6444
Diff.	+0.19%	+0.095	+0.027	+0.013	-0.049	+0.033	-4.39%

Table 6 At Ballast condition

condition	$P_E(kW)$	w	t	η_R	η_O	η_D	$P_D(kW)$
Bare hull	4256	0.399	0.215	1.014	0.541	0.717	5724
with Crown Duct	4243	0.490	0.233	1.030	0.493	0.764	5331
Diff.	-0.31%	+0.091	+0.018	+0.016	-0.048	+0.028	-6.87%

Table 7 Comparison of CFD calculation results with the result of model test

		$P_E(kW)$	w	t	η_R	η_O	η_D	$P_D(kW)$
Bare hull	CFD result	4785	0.342	0.205	1.013	0.557	0.682	7016
	Model test result	4783	0.358	0.220	1.018	0.543	0.681	6740
	Diff.	-0.04%	+0.016	+0.015	+0.005	-0.014	-0.001	-3.93%
with CD	CFD result	4744	0.435	0.234	1.011	0.501	0.687	6905
	Model test result	4792	0.453	0.247	1.031	0.494	0.714	6444
	Diff.	+1.0%	+0.018	+0.013	+0.020	-0.007	+0.027	-6.68%

increased.

Resultantly, efficiency gain attained 4.4% at full load condition and 6.9% at ballast condition.

Theoretical calculation results in Table 7 shows possibility to be a useful tool in initial stage of design for ship energy saving device.

Acknowledgements

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