

## Correlative Experimental Study Between The Results of Circulating Water Channel and Towing Tank Tests

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회류수조와 예인수조 시험결과의 상호관계의 실험적 연구

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### Abstract

Model tests using 2.0m model of the series 60 form( $C_b = 0.6$ ) were carried out in the Circulating Water Channel (CWC) in the Chosun University (CU, Korea) for the purpose of a correlative study with Towing Tank (TT). Resistance, propeller open water, self propulsion and wake survey tests were carried out and the results were extrapolated to the ship scale.

These results were compared with the extrapolated ship values based on the model test of 7.0m model in the TT at the Korea Research Institute of Ships and Ocean Engineering (KRISO, Korea). The CWC test results were correlated with the results of the towing tank tests.

※Keywords: Circulating Water Channel(회류수조), Towing Tank(예인수조), Froude Number(푸루드수), Reynolds Number(레이놀드수)

### 1. Introduction

The main purpose of this paper is to compare a number of measurements between the CWC test in the Chosun University(CU) for a 2.0m model and the TT test in the Korea Research Institute Ships and Ocean

Engineering (KRISO) for a 7.0m model. The resistance, propeller open water and self propulsion tests were carried out in CWC and TT. Wake survey, wave profile and sinkage measurements were also made in these facilities and compared with each other. Finally the results from the different facilities were extrapolated to ship scale or transferred to non-dimensionalized and compared to study the correction works.

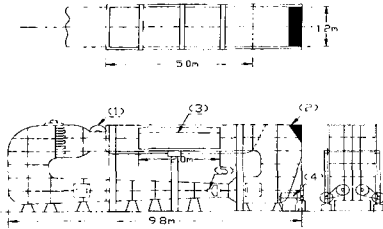
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## 2. Test Facilities

### 2.1 Circulating Water Channel in CU



**Fig. 1** Schematic diagram of CWC  
 (1) Surface Flow Accelerator (2) Wave Maker  
 (3) Measuring Section (4) 22kw Motor (5)  
 Impeller

A schematic diagram of the CWC, which was used in this test is shown in Fig. 1. This vertical type CWC with two impellers is 9.8m long and has a working section dimension of 5.0 m x 1.2 m x 0.9 m (Length x Width x Depth). A rotary type free flow accelerator and a water filter are also installed. The main performances of this CWC are as follows.

(1) The variation of velocity distribution at 1.0 m/s is within  $\pm 2.0$  %.

(2) The maximum flow velocity in the working section is 1.7 m/s

(3) The mean gradient of free water surface at 1.0 m/s is 1/6,500 and the amplitude of surface fluctuation at 1.0 m/s is within  $\pm 2.0$ mm at the center of the working section.

The mean gradient  $\theta$  [rad] is given by the following equation. (Lee, K. J., 1998)

$$\theta = 1.32 \times \frac{V^2}{g \cdot H - V^2} \times 10^{-3} \quad (1)$$

where,  $V$ ,  $g$  and  $H$  are the flow velocity [m/s], gravitational acceleration [ $m/s^2$ ] and the depth of water in the working section [m] respectively.

### 2.2 Towing Tank in KRISO

The dimensions of towing tank are as follows:

- ① Length : 223.0 m    ② Width : 16.0 m
- ③ Water Depth : 7.0 m

## 3. Model Test Techniques

### 3.1 CWC Model Test Technique

The ship and the propeller models were made of poly-urethane and aluminum alloy respectively. These principal particulars of 2.0m model are shown in Table 1 and Table 2. The towing point was located at the Longitudinal Center of Buoyancy (LCB) and 85mm above the still water surface. Yaw and sway of the model were prevented from the model guide apparatus. The model was tested without appendages such as a rudder and bilge keels. In the resistance test, the correction for the mean gradient of free water surface made by the following equation.

$$R_{T0} = \frac{R_T}{\cos \theta} - \Delta \cdot \sin \theta \quad (2)$$

Where,  $R_{T0}$  is the pure resistance,  $R_T$  is the measured resistance,  $\Delta$  is weight displacement of model and  $\theta$  is mean gradient of free water surface. The blockage correction was used the Tamura's method and the frictional resistance coefficient was calculated based on the 1957 ITTC Line. The propeller open water test was conducted with an immersion of 100.0 mm for three rates of revolution of the propeller (10, 15 and 20 rps). In the self-propulsion test, the propeller load varying test method was used, in which the thrust, torque and the tow force was measured at a constant propeller speed. The self-propulsion factors were analyzed using

thrust identity using the results of the propeller open water test at  $n = 15$  rps. The wake survey in the propeller plane was carried out by using propeller type velocimeter with a 3.0 mm diameter rotor and with a mesh spacing of 7.5 mm. The trim and sinkage were measured by using the angle meter located at the FP and the AP of the model.

### 3.2 Towing Tank Model Test Technique

The principal particulars of the models and actual ship are listed in Table 1. And those of propeller are listed in Table 2.

**Table 1** Principal particulars of ship model

Descriptions	Symbol	Act.Ship	TT	CWC
Scale Ratio			17.5	60.96
L.length B.P.	LBP [m]	121.92	6.9669	2.0
Length WL	LWL [m]	123.9622	7.0836	2.0335
Breadth(MLD)	B <sub>MLD</sub> [m]	16.2555	0.9289	0.2667
Draft(MLD)	T <sub>MLD</sub> [m]	6.5014	0.3715	0.1067
Dis.(Vol.)	$\nabla$ [m <sup>3</sup> ]	7725.96	1.4416	0.0341
Wet Surface. A	S [m <sup>2</sup> ]	2538.38	8.2886	0.6831
Mid. Sec. Area	A <sub>M</sub> [m <sup>2</sup> ]	103.28	0.3372	0.0278
Load WL Area	A <sub>W</sub> [m <sup>2</sup> ]	1408.4	4.5989	0.379
LCB from Mid.	LCB [m]	-1.8087	-0.1034	-0.0297
KB abv BL	KB [m]	3.4758	0.1986	0.057
Block Coef.	C <sub>b</sub>	0.6	-	-
Mid. Coef.	C <sub>M</sub>	0.977	-	-

**Table 2** Principal particulars of propeller

Descriptions	Symbol	Act. Ship	For TT	For CWC
Prop. Dia.	D [m]			0.07467
Pitch Ratio	P	1.075	1.075	1.075
EAR	A <sub>e</sub> /A <sub>0</sub>	0.55	0.55	0.55
No. of Blade	Z	4	4	4

The 7.0 m model and propeller model used in this test was made of wood and aluminum alloy respectively to scale 1/17.5.

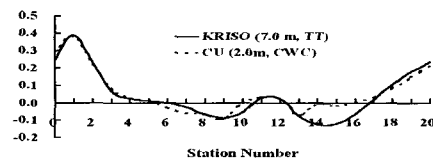
The towing point was at the LCB and Vertical Center of Buoyancy (VCB). The model was used without appendages such as a rudder and bilge keel. The propeller open

water test was conducted with an immersion of 300 mm and a rate of revolution of the propeller of 8.7 rps. In the self-propulsion test, the propeller load varying test method was used and the analysis was based on the thrust-identity method. Wake survey in the propeller plane was carried out by using the 5-hole pitot tube rake assembly. The trim and sinkage were measured by using the digital indicator with incremental encoder.

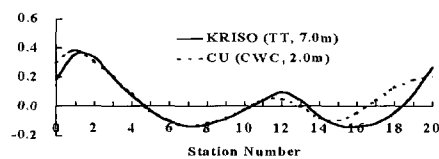
## 4. Model Test Results

### 4.1 Resistance Test

Wave profile, trim and sinkage were measured prior to the resistance measurement to survey the flow condition in CWC. The non-dimensional wave profiles are shown in Fig. 2 for  $F_n=0.22$  and in Fig. 3 for  $F_n=0.28$ .



**Fig. 2** Non-dimensional wave profiles ( $F_n=0.22$ )



**Fig. 3** Non-dimensional wave profiles ( $F_n=0.28$ )

The wave profiles at fore body are quite close, but are big differences at after body between the CWC test and the TT tests. The differences at after body may be due to viscosity effecting the wave development, or

an error due to the difficulty of the readings under curvature. Following equation was used for non-dimensionalized flow height  $H$  [m] ; (Lee, K. J., 2000)

$$H = H_w \cdot \frac{2g}{U^2} \quad (3)$$

where,  $H_w$  is flow height [m] and  $U$  is flow speed [m/s].

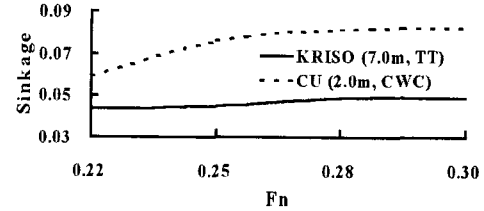
The test results of trim and sinkage are shown in Fig. 4 with following non-dimensionalized Eqs. (4) and (5).

$$Sinkage = 2 \left( \frac{\delta d_a + \delta d_f}{F_n^2 \cdot L} \right) \quad (4)$$

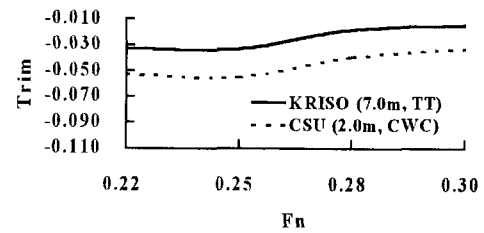
$$Trim = 2 \left( \frac{\delta d_a - \delta d_f}{F_n^2 \cdot L} \right) \quad (5)$$

Where,  $\delta d_a$  is the draft differences at AP,  $\delta d_f$  is the draft differences at FP,  $F_n$  is the Froude number and  $L$  is the length of ship.

In Fig. 4, the trend of the curve showed fairly good agreement with each other, but the differences are not negligible. It is noticeable that the sinkage on the CWC models is greater than that on the TT model at all speeds and the difference becomes larger as the speed increases. On the other hand, the trim is less with the smaller CWC models. These differences could be caused by the followings, ① different towing point ② blockage effect in CWC ③ free surface slope in CWC. The sinkage is caused by the vertically resolved normal pressures and skin friction forces acting on the hull. These forces also contribute to the trim but in addition there is a couple acting on the model due to the different vertical positions of the



(a) Sinkage



(b) Trim

Fig. 4 Non-dimensional sinkage and trim (series 60,  $C_b=0.6$ )

tow point and line of action of resistance. The resistance line of action is also dependent on the resolved normal pressure distribution and the net horizontal skin friction resistance distribution. If sinkage and trim are little affected by small changes in tow point, this indicates the flow on the different scale models is the prime cause of the difference, in which case it is very difficult to reconcile the results from the two facilities. This is an area of uncertainty that is worthy of further investigation. The values of resistance test results in CWC were corrected by Eq. (2) and Eq. (6) for free surface slope correction, blockage effect correction and stud drag correction.

$$R_{SD} = 0.5 \cdot \rho \cdot C_{SD} \cdot S \cdot V^2 \quad (6)$$

where,  $C_{SD} = 2.6942 \times 10^{-6} \cdot N/S$ ,  $N$  is the number of stud and  $S$  is the wetted surface area of model.

Residual resistances are compared in Fig. 5, these values being derived from the following simplified Eq. (7) without form effect correction. Total resistance coefficients are shown in Fig. 6.

$$C_R = C_{TM} - C_{FM} \quad (\text{ITTC } 57) \quad (7)$$

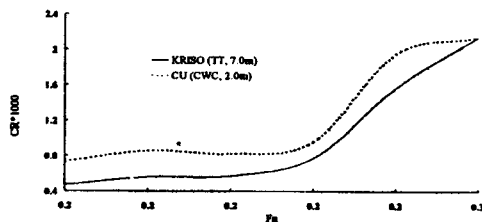


Fig. 5 Residual resistance coefficient (Series 60,  $C_b=0.6$ )

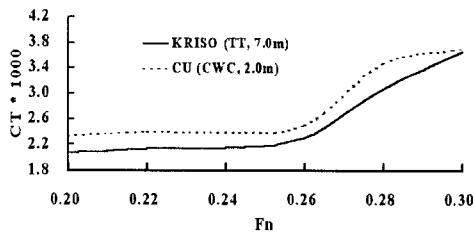


Fig. 6 Total resistance coefficient (series 60,  $C_b=0.6$ )

#### 4.2 Propeller Open Water Test

Propeller open water test at 10, 15 and 20 rps was carried out in CU and KRISO. The Reynolds numbers are  $0.484 \times 10^5$ ,  $0.727 \times 10^5$  and  $0.969 \times 10^5$  for 10, 15 and 20 rps respectively. The test results are shown in Fig. 7.

The characteristics of the full scale propeller are calculated from the model propeller characteristics as following equations and the results are presented in Fig. 8.

$$K_{TS} = K_{TM} - \delta K_T \quad (8)$$

$$K_{QS} = K_M - \delta K_Q \quad (9)$$

Where,  $\delta K_T = -0.3 \cdot \delta C_D \cdot \left(\frac{P}{D}\right) \cdot \left(\frac{cz}{D}\right)$ ,  
 $\delta K_Q = -0.25 \cdot \delta C_D \cdot \left(\frac{cz}{D}\right)$ .

The difference in drag coefficient,  $\delta C_D$  is

$$\delta C_D = C_{DM} - C_{DS} \quad (10)$$

where,

$$C_{DM} = 2 \left( 1 + 2 \frac{t}{c} \right) \left\{ \frac{0.044}{(R_{lve})^{1/6}} - \frac{5}{(R_{lve})^{2/3}} \right\}$$

$$C_{DS} = 2 \left( 1 + 2 \frac{t}{c} \right) \left\{ 1.89 + 1.62 \cdot \log \frac{c}{K_p} \right\}^{-2.5}$$

$c$  is the chord length [m],  $t$  is the maximum thickness [m],  $P/D$  is the pitch ratio and  $R_{lve}$  is the local Reynolds number at  $r/R=0.75$ . The blade roughness,  $K_p$  is taken as  $10 \times 10^{-6}$  [m].

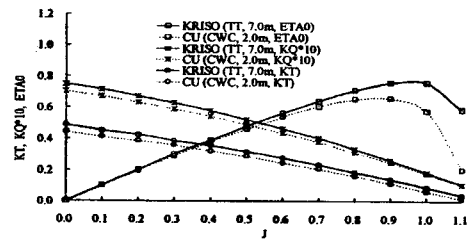


Fig. 7 Propeller open water test (model)

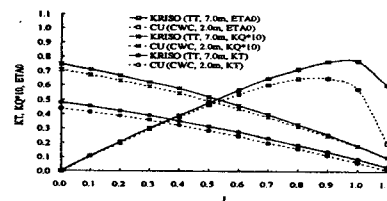


Fig. 8 Propeller open water test (full scale)

### 4.3 Self-Propulsion Test

Thrust,  $T$  and torque,  $Q$  measured by the self-propulsion tests are expressed in non-dimensional form as bellows,

$$K_{TM} = \frac{T}{\rho n^2 D^4}, \quad K_{QM} = \frac{Q}{\rho n^2 D^5} \quad (11)$$

where,  $\rho$  is the mass density of fluid [kg/m<sup>3</sup>],  $n$  is the rate of revolution [r/s],  $D$  is the diameter of propeller [m]. with  $K_{TM}$  as input data  $J_{TM}$  and  $K_{QM}$  are read off from the model propeller characteristics and the wake fraction,  $W_{TM}$  and the relative rotational efficiency,  $\eta_R$  are calculated in Eq. (12) and Eq. (13) respectively.

$$W_{TM} = 1 - \frac{J_{TM} \cdot n \cdot D}{V} \quad (12)$$

$$\eta_R = \frac{K_{QTM}}{K_{QM}} \quad (13)$$

The thrust deduction,  $t$  is obtained from Eq. (14),

$$t = \frac{T + F_D - R_C}{T} \quad (14)$$

where,  $R_C$  is the resistance corrected for difference in temperature between resistance and self-propulsion tests :

$$R_C = \frac{(1+k) \cdot C_{FMC} + C_R}{(1+k) \cdot C_{FM} + C_R} \cdot R_{TM} \quad (15)$$

where,  $C_{FMC}$  is the frictional coefficient at the temperature of the self-propulsion test.

The full scale wake fraction is calculated from the model wake fraction,  $W_{TM}$ , and the thrust deduction,  $t$  :

$$W_{TS} = (t + 0.04) + (W_{TM} - t - 0.04) \frac{(1+k) \cdot C_{FM} + \delta C_F}{(1+k) \cdot C_{FM}} \quad (16)$$

where,  $\delta C_F$ , the correction factor for surface roughness, is :

$$\delta C_F = \left\{ 105 \left( \frac{k_s}{L_{WL}} \right)^{1/3} - 0.64 \right\} \times 10^{-3} \quad (17)$$

where,  $k_s$  = surface roughness =  $150 \times 10^{-3}$ .

The load of the full scale propeller is obtained from,

$$\frac{K_T}{J^2} = \frac{S}{2 D^2} \cdot \frac{C_{TS}}{(1-t)(1-W_{TS})^2} \quad (18)$$

with this  $K_T/J^2$  as input value the full scale advance coefficient  $J_{TS}$  and the torque coefficient  $K_{QTS}$  are read off from the full scale propeller characteristics and the following quantities are calculated.

- The rate of revolutions,  $n_s$  [r/s] :

$$n_s = \frac{(1-W_{TS}) \cdot V_s}{J_{TS} \cdot D} \quad (19)$$

- The delivered power,  $P_{DS}$  [kw] :

$$P_{DS} = 2\pi \cdot \rho \cdot D^5 \cdot n_s^3 \cdot \frac{K_{QTS}}{\eta_R} \times 10^{-3} \quad (20)$$

- The thrust of the propeller,  $T_s$  [N] :

$$T_s = \frac{K_T}{J^2} \cdot J_{TS}^2 \cdot \rho \cdot D^4 \cdot n_s^2 \quad (21)$$

- The torque of the propeller,  $Q_s$  [N-m] :

$$Q_S = \frac{K_{QTS}}{\eta_R} \cdot \rho \cdot D^5 \cdot n_s^2 \quad (22)$$

- The effective power,  $P_{ES}$  [kw] :

$$P_{ES} = 0.5 \cdot C_{TS} \cdot \rho \cdot V_s^2 \cdot S \cdot 10^{-3} \quad (23)$$

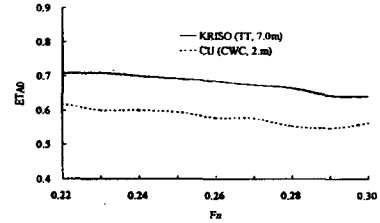
- The propulsive efficiency,  $\eta_{PS}$  :

$$\eta_{PS} = \frac{P_{ES}}{P_{DS}} \quad (24)$$

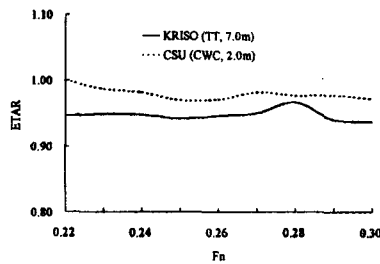
- The hull efficiency,  $\eta_{HS}$  :

$$\eta_{HS} = \frac{1-t}{1-W_{TS}} \quad (25)$$

The results of tests and calculations of propulsive coefficients are shown in Fig. 9 to Fig. 11, and comparisons of delivered powers are shown in Fig. 12.

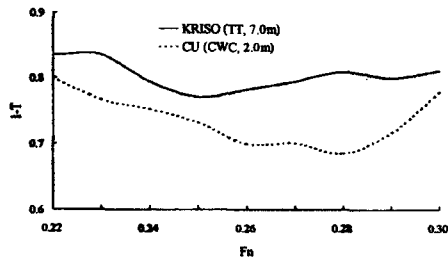


(a) Open water efficiency

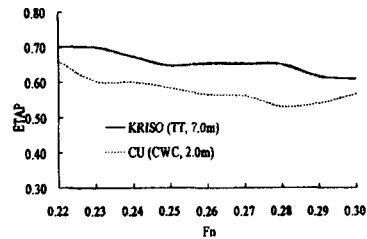


(b) Relative Rotational Efficiency

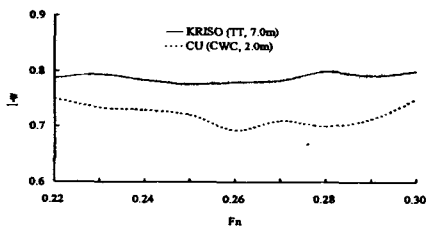
Fig. 10 Open water efficiency and relative rotational efficiency



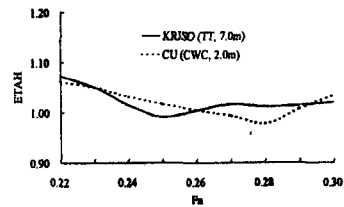
(a) Thrust-deduction factor



(a) Propulsive efficiency



(b) Wake factor



(b) Hull efficiency

Fig. 9 Thrust-deduction and wake factors

Fig. 11 Propulsive and hull efficiency

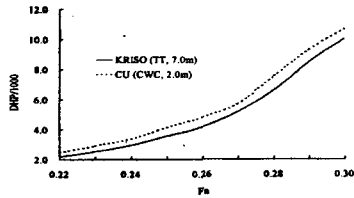


Fig. 12 Delivered power

#### 4.4 Wake Survey

The results of wake survey, which were carried out in two facilities are presented in Fig. 13. These data are not extrapolated value.



Fig. 13 Wake measurements at  $F_n=0.266$   
(Series 60,  $C_b=0.6$ )

#### 5. Discussion and Conclusion

The differences of resistance data between CWC and TT tests could be caused by the flow on the different scale models, in which case we need the accumulated correlative data between small and large models to investigate the area of scaling uncertainty by experimental way. The maximum deviation of EHP between the different scale models could be reduced from 10 % to 4 % by carrying out scaling correction of form factor and wave resistance coefficient.

In propeller open water test, the differences between TT and CWC are large at high  $J$  value. It appears to be due to a Reynolds number effect, and it is difficult to say so far if the propeller open water test in the CWC

could be applied generally to the full scale prediction because of 5~13 % differences near design speed. Propeller open water test results of small model should be used only for the analysis of self-propulsion coefficient  $\eta_R$ ,  $1-t$  and  $1-w$ . For actual ship, propeller efficiency of a series test results of large model should be used.

In self-propulsion test, we still have uncertainty of scaling problem for not only propeller but also flow around ship model that is worthy of further investigation. However, the good agreement of tendency of propulsive coefficients as shown in Fig. 9 to Fig. 11 provides the possibility of estimating ship power using correlation data between CWC and TT.

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