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

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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.*

KEY WORDS: Circulating Water Channel, Towing Tank, Froude Number, Reynold's Number

1. Introduction

A CWC is a useful facility for several types of tests that may be required in the development of new hull forms. The advantages of a CWC are the unlimited running period, the quick changes in test conditions, the easy observation of water surface wave profiles and the underwater flow patterns with using a simple tool. The disadvantage of a CWC compared to TT is the size of the facility and thus a limitation of model size.

The main purpose of this paper is to compare a number of measurements between CWC test in the CU for a 2.0m model and TT test in the KRISO for corresponding 7.0m model. The resistance, propeller open water, self propulsion tests were carried out in CWC and TT. Wake survey, wave profile and sinkage 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 problems.

2. Test Facilities

2.1 Circulating Water Channel in CU

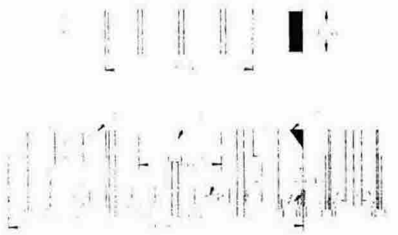


Fig. 1 schematic diagram of CWC
(1)Surface Flow Accelerator (2)Wave Maker (3)Measuring Section (4) 22kw Motor (5) Impeller

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 5.0m x 1.2m x 1.0m (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 ±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 1.0m/s is within ±2.0mm at the center of the working section. The mean gradient θ is given by the following equation.

$$\theta = 1.4 \times 10^{-3} \times \frac{V^2}{g \cdot H - V^2} \qquad (1)$$

where V, H and g are the flow velocity, gravitational acceleration and the depth of water in the working section 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 model were made of poly-urethane and aluminum alloy respectively. These principal particulars and the offsets of 2.0m model are shown in Tables 1 and 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 with the model guide apparatus.

The model was tested without appendages such as a rudder and bilge keel. In the resistance test, the correction for the mean gradient of free water surface made by the following equation.

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

Where R_{T0} is the pure resistance, R_T is the measured resistance, $\triangle$ is weight displacement of model and θ is mean gradient of free water surface.

The propeller open water test was conducted with an immersion of 100.0mm 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. Blockage correction for hull resistance and the correction for mean gradient of water surface were also made. The wake survey in the propeller plane was carried out by using propeller type velocimeter with a 3.0mm diameter rotor and with a mesh spacing of 7.5mm. 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 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 principal particulars of the model and corresponding ship and of propeller are listed in Tables 1 and 2.

The towing point was at the LCB and Vertical Center of Buoyancy (VCB). The model was used without appendage such as a rudder and bilge keel. The propeller open water test was conducted with an immersion of 300.0 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.

Table 1 : principal particulars of ship model

Descriptions	symbol	Act. Ship	For CWC	For TT
Scale Ratio			17.5	60.96
Length B.P.	L_{BP}	121.92	6.9669	2.0
Length WL	L_{WL}	123.9622	7.0836	2.0335
Breadth(MLD)	B_{MLD}	16.2555	0.9289	0.2667
Draft(MLD)	T_{MLD}	6.5014	0.3715	0.1067
Dis.(Vol.)	∇	7725.96	1.4416	0.0341
Wet Surface Area	S	2538.38	8.2886	0.6831
Mid. Sec. Area	A_M	103.28	0.3372	0.0278
Load WL Area	A_W	1408.4	4.5989	0.379
LCB from Mid.	LCB	-1.8087	-0.1034	-0.0297
KB abv BL	KB	3.4758	0.1986	0.057
Block Coeffi.	C_b	0.6	-	-
Mid. Sec. Coeffi.	C_M	0.977	-	-

Table 2 : principal particulars of propeller

Descriptions	symbol	Act. Ship	For CWC	For TT
Prop. Dia.	D [m]		0.07467	
Pitch Ratio	P	1.075	1.075	1.075
EAR	A_e/A_0	0.55	0.55	0.55
Blade Nos	Z	4	4	4

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. 2.1 for F_n = 0.22 and in Fig. 2.2 for F_n = 0.28.

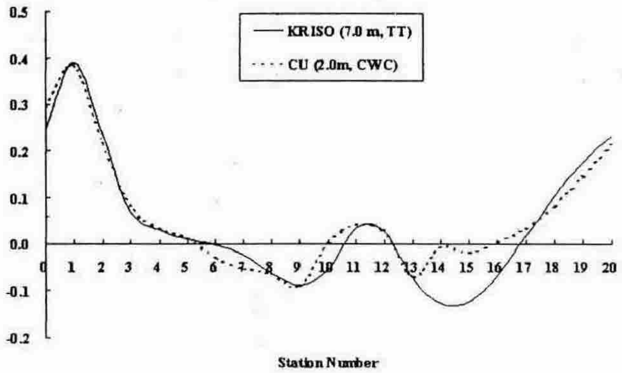


Fig. 2.1 non-dimensional wave profiles (F_n= 0.22)

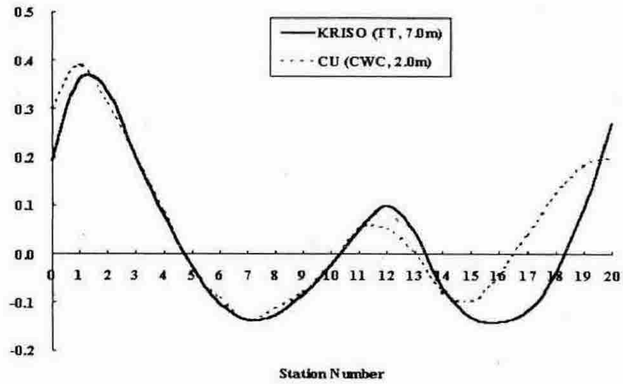


Fig. 2.2 non-dimensional wave profiles (F_n = 0.28)

The results of wave profile at fore body are quite close. but are large differences at after body compared in the CWC with the TT tests. The large differences at after body may be due to viscosity affecting the wave development, or may be on error due to the difficulty of the readings.

Following equation was used for non-dimensional flow height, H :

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

where H_w is flow height and U is flow speed.

The test results of trim and sinkage are shown in Fig. 3 with following non-dimensional value.

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

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

Where δd_a is the draft difference at AP, δd_f is the draft difference at FP , F_n is the Froude number and L is the length of ship.

In Fig. 3, 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 small models is greater than on the towing tank 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.

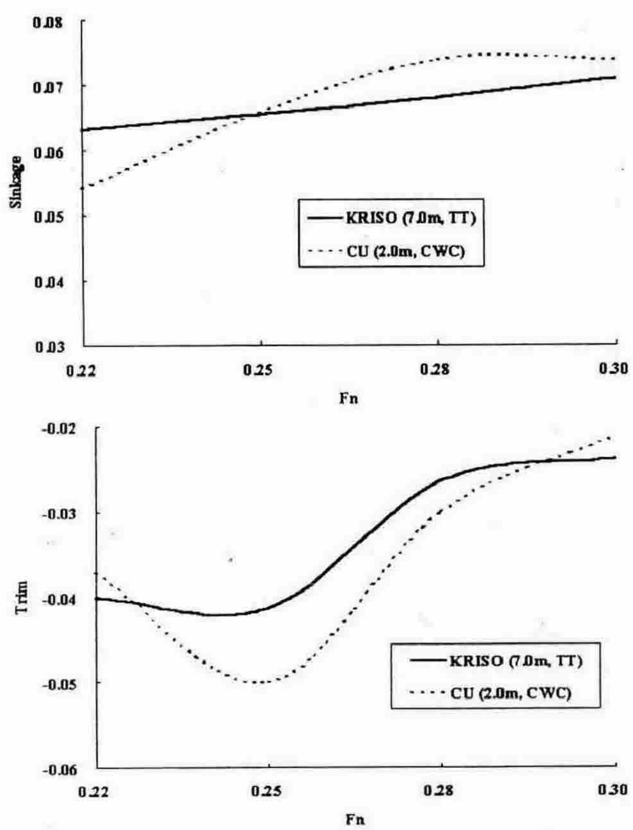


Fig. 3 non-dimensional sinkage and trim (series 60, C_b = 0.6)

The sinkage is caused by the vertical 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 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 form 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 equation (2) and equation (6) for free surface slope correction, blockage effect correction and stud drag correction.

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

where, $C_{SD}=2.6942\times10^{-6}\in N/S$, N is the number of stud and S is the wetted surface of model.

Residual resistances are compared in Fig. 4, these values being derived from the following simplified equation, without form effect correction.

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

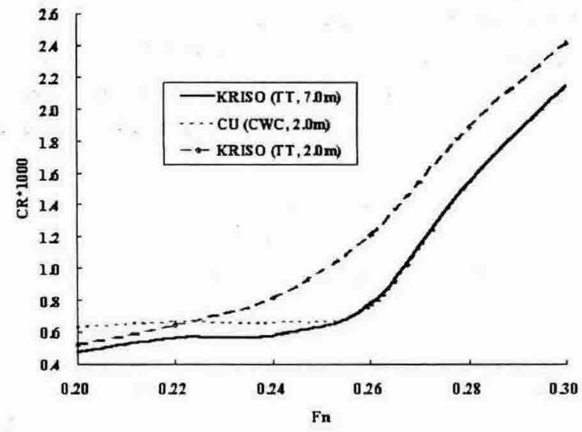


Fig. 4 residual resistance coefficient (Series 60, C_b = 0.6)

In addition to the two model resistance tests, the 2.0m model was tested in TT for the purpose of surveying the scale effect between 2.0m model and 7.0m model. Real differences of residual resistance between the CWC and TT can be derived after deduction of difference between these two tests in the towing tank. Final value of differences could be explained as the effect of different trim, sinkage and unequal characteristics of each facility. Ship total resistance coefficients are shown in Fig. 5.

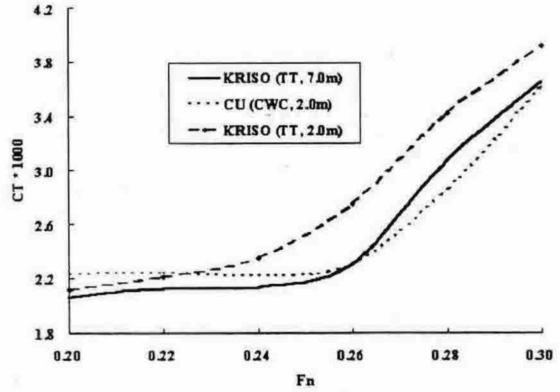


Fig. 5 total resistance coefficient (series 60, C_b = 0.6)

4.2 Propeller Open Water Test

Propeller open water test at 10, 15 and 20 rps was carried out in CU and KRISO. The test results are shown in Fig. 6.

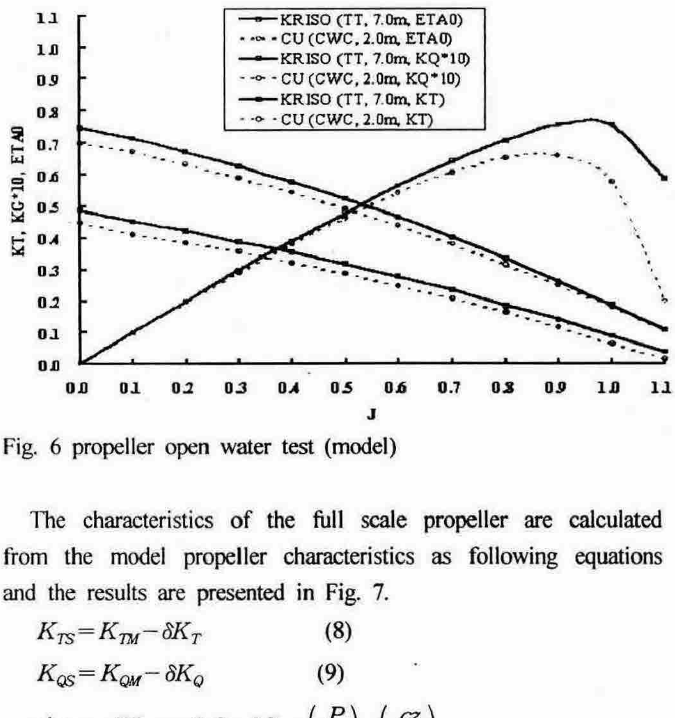


Fig. 6 propeller open water test (model)

The characteristics of the full scale propeller are calculated from the model propeller characteristics as following equations and the results are presented in Fig. 7.

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

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

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 δC_D is

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

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

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

c is the chord length, t is the maximum thickness, P/D is the pitch ratio and R_{lre} is the local Reynolds number at r/R=0.75. The blade roughness K_P is taken as 10×10^{-6} m..

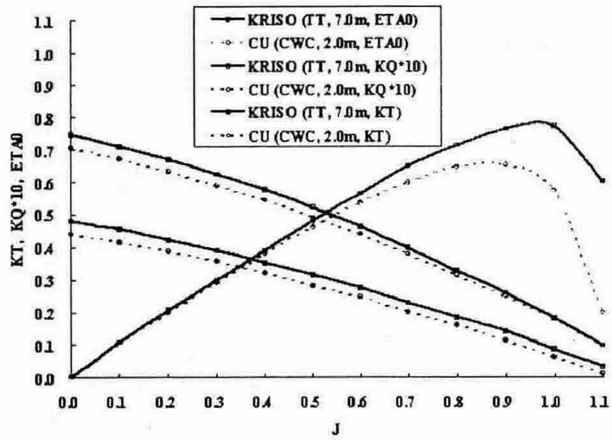


Fig. 7 characteristics of full scale propeller.

4.3 Self-Propulsion Test

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

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

with K_{TM} as input data J_{TM} and K_{QTM} are read off from the model propeller characteristics and the wake fraction..

$$W_{TM}=1-\frac{J_{TM}\cdot n\cdot D}{V}$$

The relative rotational efficiency,

$R=\frac{K_{QTM}}{K_{QM}}$ is calculated.

The thrust deduction is obtained from

$$t=\frac{T+F_D-R_C}{T}$$

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

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

where, C_{FMC} is the frictional coefficient at the temperature of the self-propulsion test. The full scale wake is calculated from the model wake, W_{TM}, and the thrust deduction, t :

$$W_{TS}+(t+0.04))$$

$$+(W_{TM}-t-0.04)\cdot\frac{(1+k)\cdot C_{FM}+\triangle C_F}{(1+k)\cdot C_{FM}}$$

(0.04 is to take account of rudder effect)

The load of the full scale propeller is obtained from

$\frac{K_T}{J^2}=\frac{S}{2D^2}\cdot\frac{C_{TS}}{(1-t)(1-W_{RS})^2}$ with this $\frac{K_T}{J^2}$ 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 :

$$n_s = \frac{(1-W_{TS}) \cdot V_s}{J_{TS} \cdot D} \quad [r/s]$$

- The delivered power :

$$P_{DS} = 2\pi \cdot \rho \cdot D^5 \cdot n_S^3 \cdot \frac{K_{QTS}}{\eta_R} \times 10^{-3} \quad [kw]$$

- The thrust of the propeller :

$$T_S = \frac{K_T}{J^2} \cdot J_{TS}^2 \cdot \rho \cdot D^4 \cdot N_S^2 \quad [N]$$

- The torque of the propeller :

$$Q_S = \frac{K_{QTS}}{\eta_R} \cdot \rho \cdot D^5 \cdot N_S^2 \quad [N\text{-}m]$$

The results of tests and calculations of propulsive coefficients are presented in Fig. 8 to Fig. 10, and comparisons of delivered powers are shown in Fig. 11.

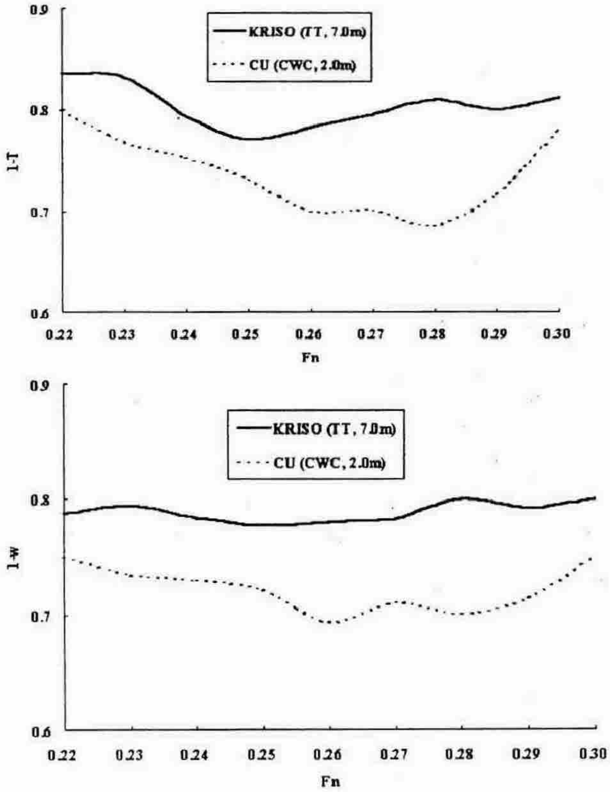


Fig. 8 wake and thrust-deduction fraction.

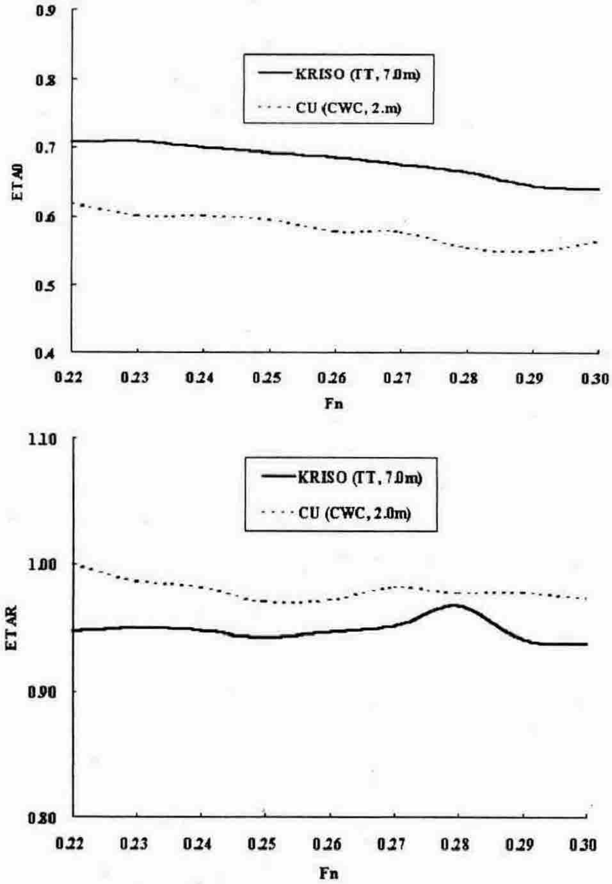
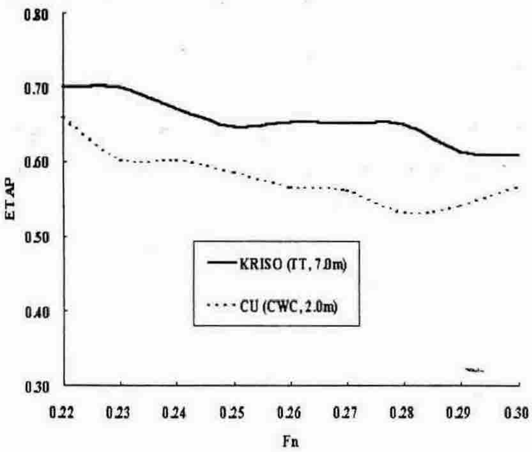


Fig. 9 relative rotational efficiency and open water efficiency



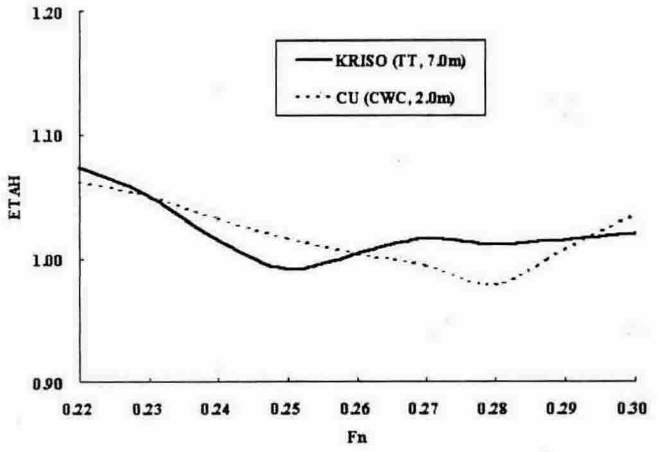


Fig. 10 propulsive and hull efficiency

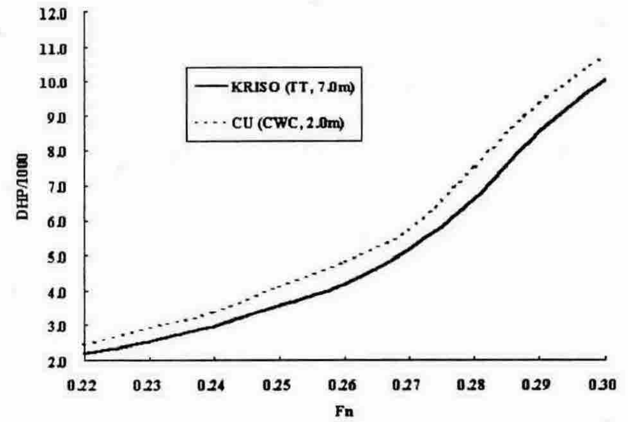
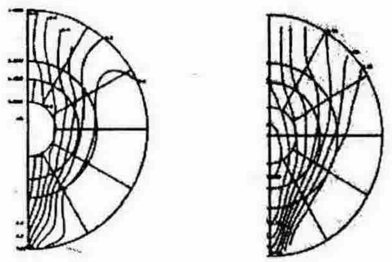


Fig. 11 delivered power

4.4 Wake Survey

The results of wake survey, which were carried out in two facilities are presented in Fig. 12. These data are not extrapolated value.



TT CWC

Fig 12: wake measurements at F_n = 0.266(sSeries 60, C_b= 0.6)

5. Discussion and Conclusion

As mentioned in section 4, 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 these different scale models could be reduced form 10% to 4% by carrying out scaling correction of form factor and wave resistance coefficient.

In propeller open water test, the differences between two CWC could be caused by the different dynamometers, not same characteristics of CWC and slight different water velocity in the channel due to different calibration device. And the differences between TT and CWC are large at high value. I appear 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 η_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. 8 to Fig. 10 provides the possibility of estimating ship power using correlation data between CWC and TT.

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