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Research on Overload Method Based on Known Ice Resistance for Self-Propulsion Test in Conventional Towing Tank

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ABSTRACT

In this paper, a series of tests for a polar carrier were carried out in the large-scale conventional towing tank of China Ship Scientific Research Center (CTT-CSSRC). In order to obtain thrust identity, lifting surface theory was applied to evaluate and design a pair of ice class propeller according to parameters of stock propeller from towing tank of KRYLOV. Ship model and propeller models were manufactured by CSSRC for self-propulsion test of CTT. Overload method was employed in low speed condition based on ice resistance known from ice tank of KRYLOV. Compared to test results of towing tank of KRYLOV, the difference in thrust and revolutions in full scale were 0.2~7% at almost, at the same time, the icebreaking performance in full scale were calculated and compared with prediction results of ice tank of KRYLOV, the difference in icebreaking thickness were 3.5~7.8% at same condition. The measured results indicated that it is very effective to assess performance of polar carrier using this overload method at CTT, and it can supply acceptable evaluation result for designer.

KEY WORDS: Conventional towing tank; Overload method; Self-propulsion test; Ice resistance.

NOMENCLATURE

F_D	Towed force
H_i	Ice thickness
J	Advance coefficient
K_T	Thrust coefficient
K_Θ	Torque coefficient
N	Propeller revolution
P_D	Delivered power
Q	Torque
R_i	Ice Resistance
T	Thrust
V	Ship speed
g	Gravity acceleration

INTRODUCTION

Compared to towed self-propulsion in ice tank, there would be some advantages using overload method in conventional towing tank for polar ship. If hydrodynamics effect can be separated from the ice effects, it can supply important reference for investigating self-propulsion factor in ice model test, propulsion efficiency of ice class propeller and power performance prediction. At the same time, it can also service balance design of open water and ice region for icebreaker by studying relationship between propeller performance parameters and hydrodynamics. Thus, there have two purposes for polar ship using overload self-propulsion test in open water, as follows:

If the interaction between propeller and ice is slight, overload experiment could be applied in open water to aid propeller design and icebreaking capability prediction.

If the interaction between propeller and ice is serious, overload experiment could be also applied in open water to aid separate hydrodynamics, and then, torque added from ice impact was obtained, and it would be easy to analyze the interaction between propeller and ice.

The standard procedure for overload self-propulsion test in open water was given by ITTC Recommended Procedures (2019), in fact, overload method is also recommended in ice by ITTC Recommended Procedures (2011). It is very similar between in open water and in ice. However, Takatoshi Matsuzawa (2017) found that it is necessary to correct test results due to complicated parameters of model ice and ice non-uniform nature. Therefore, another important advantage of carrying out towed self-propulsion test using overload method in open water, would be that modification measurement results owing to distribution flaw of model ice could be avoided, and, it is more convenient to prediction self-propulsion factor, thrust and delivered power.

In this paper, the author performed a series of propeller open water test and towed self-propulsion test to verify the possibility of overload method in CTT, meanwhile, ice resistance known from ice tank of KRYLOV was exerted by adopting weight simulation in order to simulate factual ice environment, only the interaction between propeller and ice was not considered in model test. As a probe, for such method of overload, test results, including thrust, revolutions and icebreaking thickness, were compared with those from KRYLOV.

OVERLOAD METHOD

The procedure for overload method at low speed condition is described in ITTC Recommended Procedures (2019). When self-propulsion is carried out in open water, towed force F is measured by resistance dynamometer, propeller thrust T and propeller torque Q are measured synchronously by self-propulsion dynamometer. During towed propulsion test, keeping constant towing speed, and changing revolutions of propeller, ship model is propelled by balance of towed force, propeller thrust and open water resistance, and, at least three revolutions are recorded at every run. In order to simulate known ice resistance, hung weight is adopted in model test. The measurement scheme is shown in Figure 1.

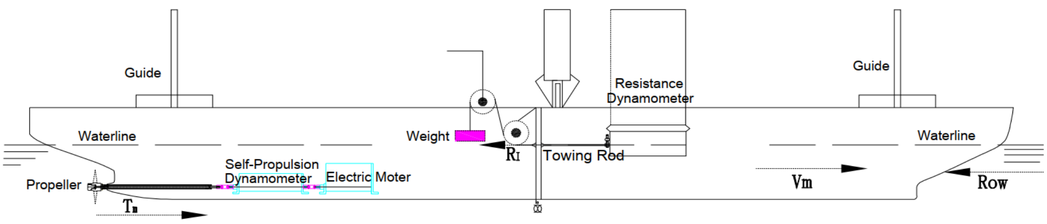

Figure 1. Measurement principle for ice resistance known in towed self-propulsion test

The weight force is equal to ice resistance to balance propeller thrust T and towed force F, as shown in Figure.1. In the method above, measurement principle is similar to conventional towed propulsion test, by changing different dead weight according to known ice resistance at every run test, the parameters such as F, T, Q and N are measured directly. Self-propulsion factors, thrust T, revolutions N and delivered power P_D can be calculated with reference to ITTC 1978 performance prediction method, the detailed performance prediction diagram is illustrated in Figure 2.

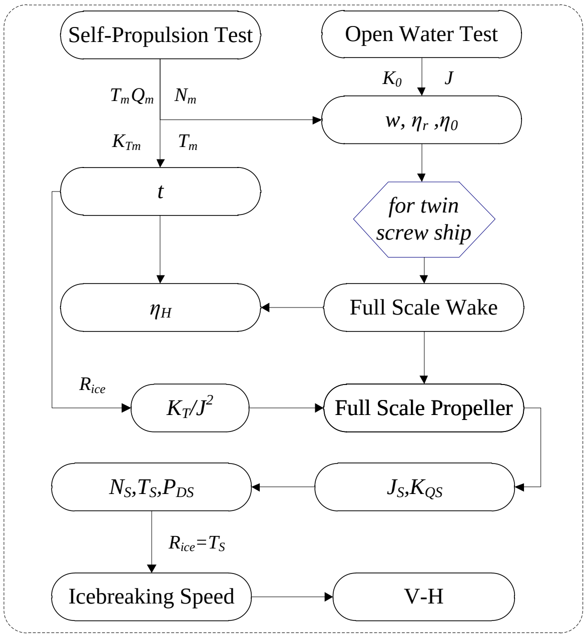

Figure 2. Performance prediction flow for towed self-propulsion test in CTT

DATA EXTRAPOLATION

The thrust deduction is expressed as:

$$t = \frac{T_{Pm} + F_D - R_{ice}}{T_{Pm}} \tag{1}$$

Where T_{Pm} is thruster thrust, F_D is towed force, R_{ice} is ice resistance.

The thrust at full scale:

$$T_{Ps} = \frac{\rho_s}{\rho_m} \lambda^3 T_{Pm} \tag{2}$$

The torque at full scale:

$$Q_S = \frac{\rho_s}{\rho_m} \lambda^4 Q_m \tag{3}$$

The revolutions of propeller at full scale:

$$N_s = \frac{N_m}{\sqrt{\lambda}} \tag{4}$$

The delivered power at full scale:

$$P_D = 2\pi N_S Q_S \tag{5}$$

Where ρ_s is density of sea water, ρ_m is density of fresh water, λ is scale ratio, m denotes model, s denotes full scale.

The net thrust of thruster is given by：

$$T_{net} = (1-t)T \tag{6}$$

According to balance of ice resistance and net thrust:

$$T_{net} = R_{ice} \tag{7}$$

The relationship between icebreaking thickness and ship speed at the same delivered power by equations (7) can be linearly expressed as:

$$H_i = mV_i + n \tag{8}$$

Where, m and n are coefficients of the linear equation.

MODEL TEST

Ship Model and Test Description

The model tests were carried out for a polar carrier at KRYLOV in Russia, in the conditions of the level ice with the flexural strength of 500kPa in full scale. The ice class requirement with ARC 6 in RMRS is fulfilled for this ship which can voyage in ice with ice thickness of 1.5m and ship speed of1.0kn around of year. The minimum power is met at ice class of ARC6 with power of 32MW for this ship.

Under a range of speeds from 0.4 to 3.8kns, the ice resistance tests were performed in the condition of the full load condition and ballast condition, with two ice thicknesses, 1.3m and 1.6m, respectively. In addition, under a range of speeds from 0 to 5kns, the overload propulsion tests in open water were carried out at its conventional towing tank with a pair of stock propellers mounted, at the full load condition and ballast condition, respectively, as shown in Figure3. The main particulars were listed Table 1.

Figure 3. Model tests in ice and open water at KRYLOV

In order to research overload method in towed self-propulsion test at CTT-CSSRC, a wooden ship model was made for this polar carrier by CSSRC, with the twin screw propulsion, at a scale ratio of 35. The length between perpendiculars are 7.4057m. The ship model is shown in Figure 4.

Figure 4. Ship model

Table 1. Hull form particulars and geometric coefficients

Items	Unit	Full Load		Ballast	
		Full Scale	Model	Full Scale	Model
L_{PP}	*m*	259.2	7.4057	259.2	7.4057
L_{wl}	*m*	273.8	7.8237	247.8	7.0800
B	*m*	44	1.2571	44	1.2571
T_M	*m*	15.805	0.4516	10.580	0.3023
∇_0	m^3	145900	3.4029	92585	2.1594
S_0	m^2	17146	13.9967	13840	11.2980
C_B	-	0.8688		0.7672	

Propeller Model

The prediction results of ice resistance and effective thrust in full scale from KRYLOV were utilized to design a pair of new propellers for the twin screw propulsion test, with the aid of lifting surface theory of propeller, and to assess overload method in CTT-CSSRC. The main parameters of design propeller are listed in Table 2.

According to the parameters of design, a Controllable Pitch Propeller (CPP) with material of aluminum alloy was manufactured by CSSRC, as shown in Figure 5.

Figure 5. Propeller model

Table 2. Main parameters of propeller

Particulars	Symbol	Unit	Propeller	Model
Diameter	D	m	6.80	0.1943
Chord length in 0.7R	$c_{0.7\mathrm{R}}$	m	3.4525	0.0986
Maximum Thickness in 0.7R	$t_{0.7\mathrm{R}}$	m	0.0985	0.0028
Number of Blades	Z	-	4	
Pitch Ratio in 0.7R	$P/D_{0.7\mathrm{R}}$	-	0.8659	
Disk Area Ratio	$A_\mathrm{E}/A_\mathrm{O}$	-	0.75	

Propeller Open Water and Towed Self-Propulsion Test

The towed model tests were carried out in the deep water towing tank, which is 474m long, 14m wide and with water depth of 7m, the model test as follows:

In the propeller open water tests, the propeller rate of revolution was kept constant while the towing speed was varied during a single run in the towing tank. The propeller thrust, torque, rate of revolution, and towed speed were measured during the tests. Rate of revolution 16Hz was applied in the tests, with running ahead and astern, respectively. Propeller open water test is shown in Figure 6.

Figure 6. Propeller open water tests

During the towed self-propulsion tests, the ship model was equipped with rudder without bilge keels. The model propeller was fitted in its correct position at the stern of the model and connected through the shaft to one end of the propeller dynamometer for measuring the propeller thrust and torque at various revolution rates. The tripwire as turbulence stimulator was not installed in self-propulsion tests to simulation the same condition with KRYLOV towing tank. Overload method was applied in the tests with dead weight hung to simulation ice resistance from results of ice tank of KRYLOV as mentioned above. The towed forces were also measured at different rates of revolution for each speed. The self-propulsion values were obtained by interpolation. The detailed running condition is listed in Table 3. Towed self-propulsion tests are as shown in Figure 7.

Table3. Running conditions for towed self-propulsion test

Load Conditions	V_S (kn)	N_m(r/s)
Full Load (Running Ahead)	0, 1, 2, 3, 4	6,7,8,9,10,11,12,13,14
Full Load (Running Astern)	0, 1, 2, 3, 4	6,7,8,9,10,11,12,13,14
Ballast (Running Ahead)	0, 1, 2, 3, 4	6,7,8,9,10,11,12,13,14

Figure 7.Towed self-propulsion tests with running ahead and astern

TESTING RESULTS AND ANALYSIS

Test Results

According to standard flow diagram of performance prediction and data extrapolation method, as shown in Figure 2 and formula (1)~(8) , measured towed force, thrust and torque were extrapolated to full scale, and taken into account wake influence. The results form was expressed a relationship for effective thrust and ship speed, because the relationship between ship speed and icebreaking thickness were obtained by equality of ice resistance and effective thrust, so, it is also convenient to compare with test results of KRYLOV.

The test results for full load condition with running ahead are as shown in Figure 8.

The test results for full load condition with running astern are as shown in Figure 9.

The test results for ballast condition with running ahead are as shown in Figure 10.

It is noted that it is not possible to voyage in polar region for this polar carrier with running astern according to the prediction results of effective thrust, which is less than ice resistance at 1.3m condition of ice thickness, as seen from Figure 9. It means that the 32MW power are not fulfilled requirement for continuous icebreaking.

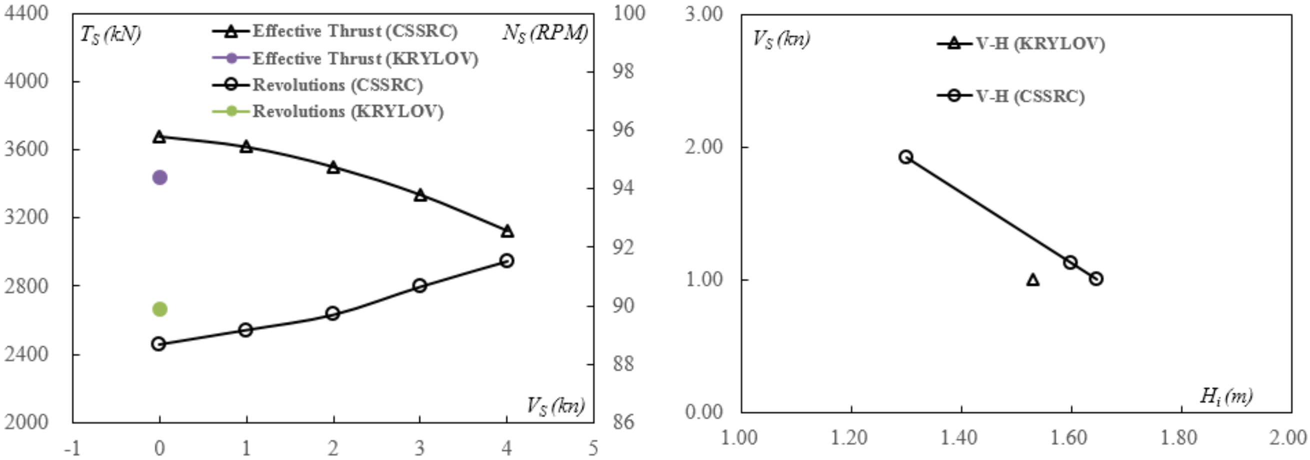

Figure 8. Performance prediction Results with running ahead at full load condition

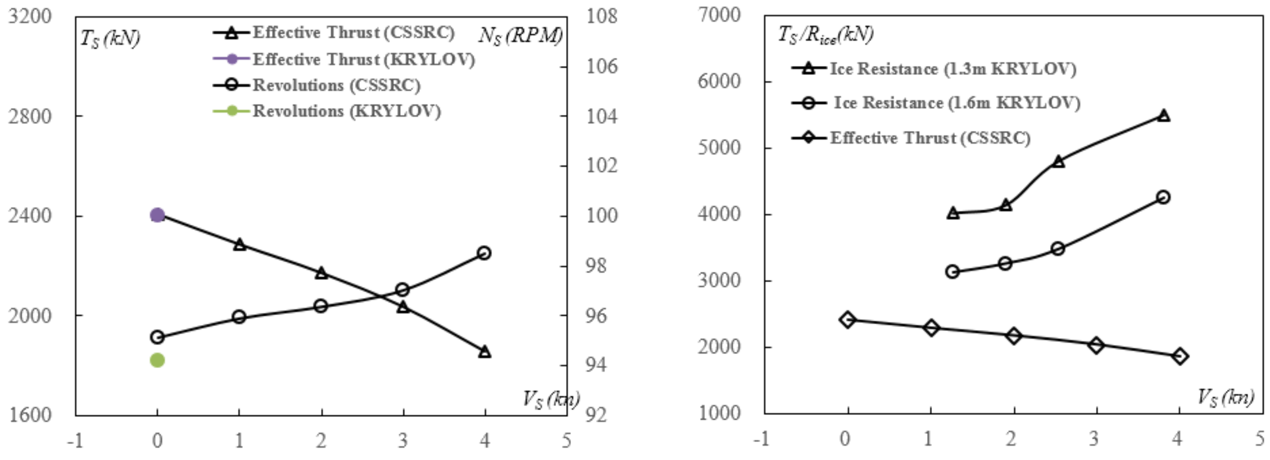

Figure 9. Performance prediction Results with running astern at full load condition

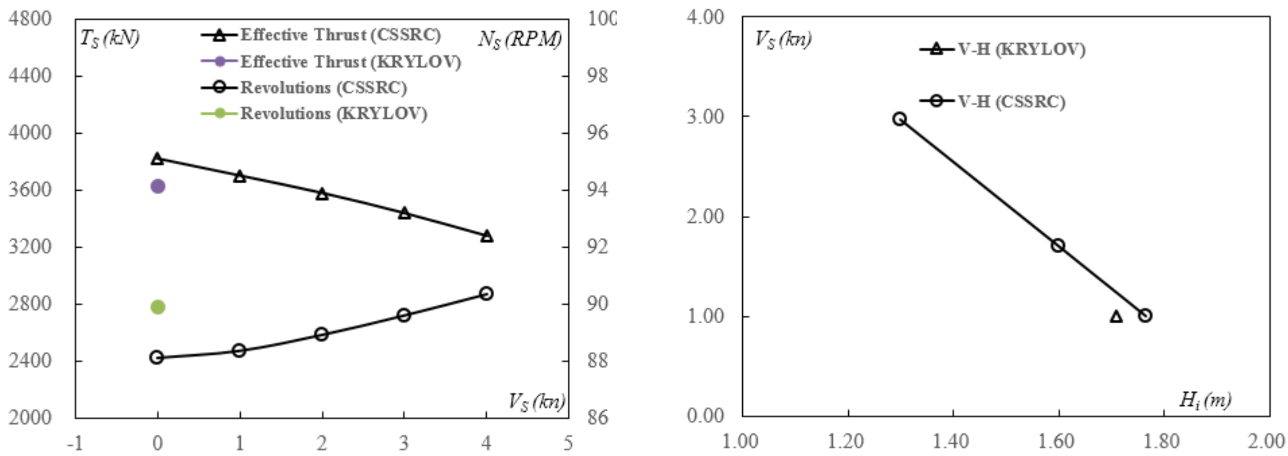

Figure 10. Performance prediction Results with running ahead at ballast condition

Comparison and Analysis

In order to compare test results from towing tank between CSSRC and KRYLOV, a part of data from KRYLOV were processed and listed in Table 4 and Table 5, respectively. Firstly, test results from two sides were analyzed, and then, possibility of overload method with known ice resistance for towed self-propulsion test in CTT was further verified.

Table4.Effective thrust and revolutions

Load Conditions	V_S (kn)	P_{DS} (MW)	CSSRC		KRYLOV	
			T_S(kN)	N_S(RPM)	T_S(kN)	N_S(RPM)
Full Load (Running Ahead)	0	32	3680	88.7	3435	89.9
Full Load (Running Astern)	0	32	2410	95.1	2404	94.2
Ballast (Running Ahead)	0	32	3824	88.1	3632	89.9

Table5.Icebreaking thickness

Load Conditions	V_S (kn)	P_{DS} (MW)	CSSRC H_i(m)	KRYLOV H_i(m)
Full Load (Running Ahead)	1.0	32	1.65	1.53
Full Load (Running Astern)	1.0	32	Not Sufficient	Not Sufficient
Ballast (Running Ahead)	1.0	32	1.77	1.71

Compared with KRYLOV results, the effective thrust in CSSRC increases by 7.1% and the rotating speed of propeller decreases by 1.3% in case of the propeller delivered power of 32MW under the condition of bollard pull. Hence, for the icebreaking speed of 1kn, the icebreaking thickness would increase by 0.12m with icebreaking mode of running ahead under full load draught.

While under ballast draught, also compared with KRYLOV results, the effective thrust increases by about 5.3%, which is less than the 7.1% mentioned above, and the rotating speed of propeller decreases by 2.0%. As for the icebreaking thickness, it increases by 0.06m slightly.

When comparing the results between full load draught and ballast draught by CSSRC itself, the effective thrust for the latter increases by 3.9%. For the situation of KRYLOV, the increment is 5.7%. It can be noticed that there is some difference for the prediction results between the two sides. The largest probability is regarded as that the model propellers used are not exactly the same though the propeller tested in CSSRC was designed according to the main parameters of the stock propeller used in KRYLOV. In detail, the propeller modeled with lift-surface theory in CSSRC keeps the same diameter as one in KRYLOV, while the pitch ratio, the expanded area ratio and the profile section are in fact different. Otherwise, the results from the two sides would less differ from each other.

And, for full load conditions with running astern, it is found that effective thrust and revolutions almost keep the same, the effective thrust adds by 0.2%, and the revolutions increase by 0.95%.

Generally speaking, the test results indicated that the predicted performance differences are quite small between the two sides. The overload method for carrying out towed self-propulsion test in conventional towing tank with known ice resistance is practicable to some extent.

CONCLUSIONS

The overload test method with known ice resistance is analyzed on basis of the towed self-propulsion tests carried out in CTT-CSSRC. Compared with those from tank of KRYLOV, the test results have shown that it is acceptable to perform towed self-propulsion test in conventional towing tank. It is noted that ice resistance obtained from ice tank is necessary to be simulated with weight force for overload method in conventional towing tank, although the interaction between propeller and ice is not considered in open water. The overload method of towed self-propulsion test in open water based on known ice resistance is about satisfying for performance prediction, in the view of this point, can aid design of polar ship to some extent.

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