Self-propelled Test Study of A Four-propeller Ship

J.Y. Bi & Z. Zong
School of Naval Architecture, Dalian University of Technology, Dalian, Liaoning, China

State Key Laboratory of Structural Analysis of Industrial Equipment, Dalian, Liaoning, China

ABSTRACT: In order to ensure consistent increase of speed and tonnage, we study four-propeller ship. Based on design demand of ship speed, four model speeds are chosen to experiment. For every model speed, we do three experiments by changing rotation rate of propellers. Due to the four-propeller ship is different to single-propeller and twin-propeller ship, analysis is necessary with different method from single-propeller and twin-propeller ship.

1 INTRODUCTION

Speed and tonnage become more important for ship growing development at present. People design various ships for high speed navigating. Most ships which navigate at high speed can not bear great tonnage. In order to satisfy consistent requirement of speed and tonnage, we adopt four screw propellers to propel ship hull. Four propellers are used only in naval ships now, for example aircraft carriers, cruiser and destroyer. To extend four propellers used in civil ships becomes significant.

Experiment need to be done for new ship design. Resistance test, open-water test, wake test and self-propelled test are essential experiment for studying four-propeller ship. Resistance test is done to obtain ship hull resistance. Open-water characteristics of propellers are attained from open-water test. Wake fraction is measured to describe the retardation of wake behind model by wake test. Self-propelled test study propeller-hull interactions. In this paper we introduce self-propelled test of four-propeller model.

Propeller's thrust T, torque Q, shaft rotation rate n, and drag force Ra are obtain from self-propelled test. By introducing model resistance, we could obtain propulsive efficiency of model. The propulsive efficiency is thus given by

$$\eta = \frac{RV}{2\pi nQ} = \eta_0 \eta_H \eta_R \tag{1}$$

where R is the resistance which propeller overcomes, V is the velocity of model, η_0 is the open-water propeller efficiency, η_H is called the hull efficiency, η_R is the relative rotative efficiency.

Propulsive efficiency is obtained for each single propeller. Propulsive efficiencies of different propellers show the different characteristics for various propellers of four-propeller model.

2 EXPERIMENT

In this experiment of self-propelled test, we require four dynamometers, one resistance dynamometer, and two electrical motor connected with four dynamometers. Five-blade propellers are used for four-propeller ship propulsion.

Four dynamometers are connected with four drive shafts linking to four propellers respectively. The thrust and torque are outputted from dynamometers when propellers are rotating. Resistance dynamometer is connected with ship hull. When model driven by propellers hasn't reach demanded speed, there will be drag force applied to model. As rotation rate increases, drag force will reduce gradually. Two electrical motors are used to drive dynamometers working normally. The electrical motor controls the rotation rate of propellers. The arrangement of these equipments is shown in Figure 1.

Propellers used in self-propelled test are constant-pitch propellers. They belong to B series. The position where propellers are placed is important. We choose to place these propellers in same lever of lengthways (see Fig. 2), that is four propeller discs are lay in one plane. The interval between inner propeller and outer propeller is shown in Figure 3. The distance from mid-ship to each hub is also revealed in Figure 3. Inner propeller and outer propellers are symmetrical to mid-ship separately.

Four propellers are comprised of two right-handed propellers and two left-handed propellers. Based on different rotating direction, we arrange every propeller on different position.

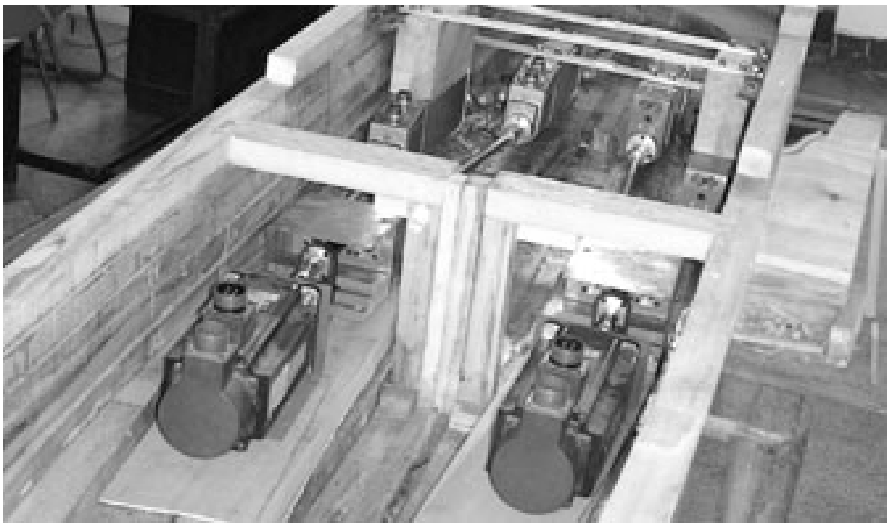

Figure 1. Arrangement of equipments

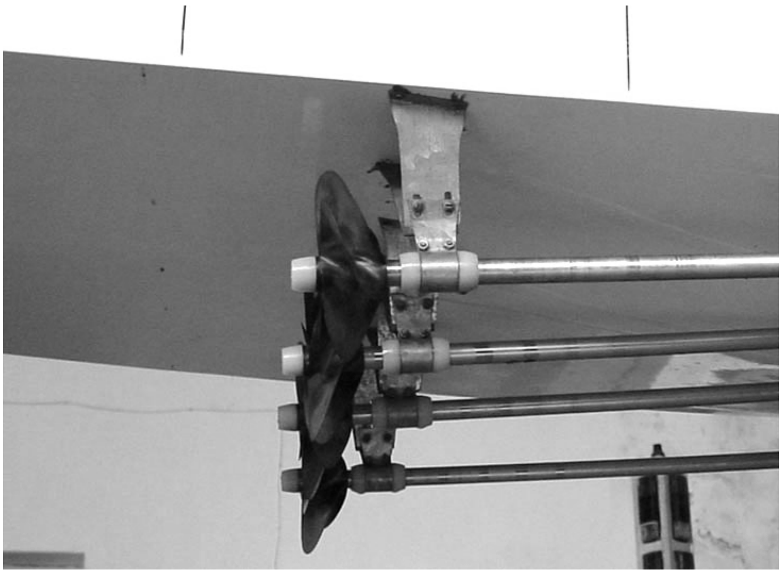

Figure 2. Arrangement of propellers

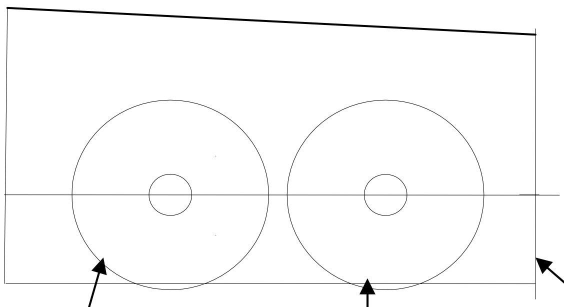

Figure 3. Position of propellers

3 ANALYSIS

In order to ensure that the load of model propellers is approximate to ship propellers, we introduce frictional resistance allowance, which is obtained by difference between model frictional resistance and ship frictional resistance. Frictional resistance allowance is the drag force which we want to obtain. But in experiment we couldn't give exact rotation rate to obtain the demanded drag force. So we get the demanded drag force by interpolation, based on three measured drag force in self-propelled test. Experiment data measured are shown in Table 1.

Table 1 Experiment data

Model speed	rotation rate	drag force	average of thrust of outer propellers	average of thrust of inner propellers	average of torque of outer propellers	average of torque of inner propellers
m/s	rps	kgf	kgf	kgf	kgf-m	kgf-m
	28.500	0.443	1.205	1.509	0.023	0.036
2.482	28.250	0.837	1.106	1.413	0.023	0.033
	28.000	1.191	1.011	1.329	0.022	0.031
3.172	38.500	0.767	2.656	2.997	0.055	0.065

	38.250	1.194	2.545	2.887	0.052	0.064
	38.000	1.358	2.488	2.833	0.051	0.061
	46.667	0.322	3.948	4.459	0.082	0.097
3.861	46.250	1.353	3.700	4.220	0.078	0.093
	46.000	1.522	3.641	4.139	0.077	0.092
	53.667	1.253	4.884	5.590	0.105	0.129
4.551	53.333	1.733	4.727	5.438	0.103	0.124
	53.133	2.155	4.621	5.339	0.101	0.120

The resistance which propeller overcomes in formula (1) is the difference of model resistance and drag force. In order to obtain values of model resistance and drag force for different propellers, we analyze the state of every propeller.

From Table 1 we find that thrust and torque of inner propeller are larger than outer propeller even if rotation rate is same for every propeller. The reason is the influence of wake fraction. We know that the distribution of stem wake is not uniform according to wake test. So the state of every propeller is various certainly. Likewise, the resistance which propeller overcomes is various.

We need to distribute model resistance and drag force to every propeller. Drag force measured and model resistance from resistance test could be divided with different methods. Equal division is beyond reason due to the different state of propellers mentioned above. In this paper we choose to distribute drag force and model resistance according to different thrusts of propellers. Based on thrust ratio of inner propeller and outer propeller, we allocate different model resistances and drag force to every propeller.

Through interpolating and allocating resistance, we get relative data of single propeller in Table 2.

Table 2 Single propeller data

model speed	m/s	2.482	3.172	3.861	4.551
model resistance (Rm)	kgf	5.809	11.793	16.788	21.514
drag force (Ra)	kgf	0.570	0.817	1.083	1.365
ratio		1.281	1.134	1.136	1.150
Rm of outer propeller	kgf	1.273	2.763	3.931	5.003
Rm of inner propeller	kgf	1.631	3.133	4.463	5.754
Ra of outer propeller	kgf	0.125	0.191	0.254	0.317
Ra of inner propeller	kgf	0.160	0.217	0.288	0.365
rotation rate	rps	28.420	38.472	46.372	53.587
thrust of outer propeller	kgf	1.174	2.643	3.766	4.847
torque of outer propeller	kgf-m	0.023	0.054	0.079	0.105
thrust of inner propeller	kgf	1.478	2.984	4.285	5.554
torque of inner propeller	kgf-m	0.035	0.065	0.094	0.128

Base on these data of Table 2, we calculate propulsive efficiency for every model speed and every propeller according to formula (1).

Table 3 Propulsive efficiency

model speed	m/s	2.482	3.172	3.861	4.551
propulsive efficiency	outer	0.697	0.621	0.613	0.605
	inner	0.583	0.587	0.586	0.571

From Table 3, we find that propulsive efficiency of outer propeller is larger than inner propeller for every model speed even if values of others variables of outer propeller is smaller than inner propeller. Propulsive efficiencies decrease when velocities of model increase gradually. According to various states of different propellers, we proposal that rotation rate might be various for different propellers. Thus, efficiency and abrasion would be same for all propellers.

4 CONCLUSION

Based on analysis above, we know that four-propeller ship's self-propelled test is different to single propeller test and twin propelled test. For single propeller, the drag force and model resistance needn't to be distributed. The thrust of the single propeller is used to even overcome all resistance. For twin propellers, the drag force and model resistance are distributed evenly due to two propellers are symmetrical to mid-ship completely. The four propeller model is more complicated. The position of propellers is very important. Because of the different position for inner propellers and outer propellers, the distribution of drag force and model resistance is different. In addition, when the position of inner propeller and outer propeller is changed, propulsive efficiency would vary for different propellers. The problem will be study in further.

REFERENCES

Harvald, Sv.Aa. 1983. *Resistance and Propulsion of ships*. New York: Wiley.
Newman, J.N. 1977. *Marine hydrodynamics.* Cambridge, Mass.: The MIT Press.
Schneekluth, H. 1977. *Hydromechanik zum schiffsentwurf.* Herford: Koehler.
Wang, G.Q. & Sheng, Z.B. 1985. *Ship propulsion*. Peking: National Defence Industry Press.