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A numerical study of scale effects on performance of a tractor type podded propeller

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ABSTRACT: *In this study, the scale effect on the performance of the podded propeller of tractor type is investigated. Turbulent flow computations are carried out for Reynolds numbers increasing progressively from model scale to full scale using the CFD analysis. The result of the flow calculation for model scale Reynolds numbers agrees well with that of the experiment of a large cavitation tunnel. The existing numerical analysis indicates that the performance of the podded propeller blades is mainly influenced by the advance coefficient and relatively little by the Reynolds number. However, the drag of pod housing with propeller in operation is different from that of pod housing without propeller due to the acceleration and swirl of propeller slipstream which is altered by propeller loading as well as the pressure recovery and friction according to Reynolds number, which suggests that the pod housing drag under the condition of propeller in operation is the key factor of the scale effect on the performance between model and full scale podded propellers. The so called 'drag ratio', which is the ratio of pod housing drag to total thrust of podded propeller, increases as the advance coefficient increases due to accelerated flow in the slipstream of the podded propeller. However, the increasing rate of the drag ratio reduces continuously as the Reynolds number increases from model to full scale progressively. The contribution of hydrodynamic forces, which acts on the parts composed of the pod housing with propeller operating in various loading conditions, to the thrust and the torque of the total propeller unit are presented for a range of Reynolds numbers from model to full scales.*

KEY WORDS: Podded propeller; Pod housing; Full scale; Model scale; Scale effect; CFD.

INTRODUCTION

A podded propeller is consisted of propeller and pod housing which is usually composed with pod, strut and fin. In case of a tractor-type podded propeller, since its slipstream is disturbed by the pod housing located behind the propeller, the performance of the propeller blades is different from that of a conventional propeller. Also the force acting on the pod housing has different characteristics compared to the drag in uniform flow because of flow acceleration, pressure change and swirl flow, which are induced by rotating propeller blades. Therefore, in order to design a podded propeller with a good propulsive performance, it is necessary to understand not only how the interaction between propeller and pod housing has an effect on propulsive performance, but also which components of the performance are influenced by propeller loading and Reynolds number. However, the

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information mentioned above is rarely found, especially regarding the full scale propulsive performance, because there exist difficulties in obtaining the full scale performance of a podded propeller from model test due to the limitation of experimental facility and the uncertainty of full scale extrapolation method. Currently, there are various methods for estimating the full scale performance of a podded propeller (ITTC, 2005; 2008). It is mostly accepted that the ITTC correction method can be applied for the propulsive performance of propeller with the consideration of the interaction. Meanwhile, in case of a full scale drag of the pod housing, various methods considering acceleration of propeller slipstream and Reynolds number have been suggested (Holtrop, 2001; Sasaki et al., 2004). Also, the method for utilizing the drag ratio of model scale to full scale using CFD has been proposed (Lobatchev and Chicherine, 2001; Chichern et al., 2004). Considering the difficulty of a full scale experiment, this can be measured as a reasonable option. The applications of CFD analysis to podded propeller continue to grow and the studies on the drag of pod housing (Sanchez-Caja and Pylkkanen, 2004; Deniset et al., 2006) and the interaction of podded propeller (Kim and Kim, 2002; Ohashi and Hino, 2004; Sanches-Caja and Pylkkanen, 2006; Gaggero et al., 2010; Zhang and Wang, 2006) have been performed.

Despite the studies mentioned above, the CFD analysis of podded propeller performance in both model and full scale did not yet improve the method of estimating the full scale performance of podded propellers from model tests nor provide any significant result useful to design better propeller and pod housing. Especially, the study regarding the pod housing drag, which changes according to propeller loading and Reynolds number and the change of propeller performance induced by the effect of pod housing, is lacking despite its high importance.

In this study, the CFD analysis for a tractor type podded propeller is carried out. The performance of the podded propeller is analyzed from model to full scale to investigate its scale effects. The pod housing drag is scrutinized specifically to find out its variation with propeller loading and Reynolds number. Also, in order to study how the propulsive performance of propeller blades and the drag of pod housing are influenced by the interaction between the propeller and the pod housing, the calculations for both propeller without pod housing and pod housing without propeller are performed.

DESCRIPTION OF GEOMETRY AND CONDITIONS

Geometry

The tractor type podded propeller consists of propeller, pod, strut and fin. The principal dimensions of the podded propeller are given in Table. 1. The features of pod housing include the cross-sectional area, in which the pod is 21% of propeller disk area, and the relatively thick strut.

Table 1 Principal dimensions of the podded propeller.

Classification	Model	Full
Length of the podded propeller (L, *m*)	0.404	11.30
Pod length (L_{pod}, *m*)	0.326	9.139
Pod diameter (D_{pod}, *m*)	0.091	2.560
L_{pod} /D_{pod}	3.570	3.570
Propeller diameter, D_P (*m*)	0.200	5.600
Gap between hub and housing (*mm*)	0.3	8.4
No. of blades, Z	4	
Expanded area ratio, A_E/A_O	0.6068	
Mean pitch ratio	1.007	
Pitch ratio at 0.7r/R	1.078	
Hub/Dia. ratio. d/D_P	0.285	
Blade section	NACA 66	