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Original Article

An integral panel method for the hydrodynamic analysis of hybrid contra-rotating shaft pod propulsors

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Abstract

The present work is devoted to developing an efficient method for the analysis and design of hybrid contra-rotating shaft pod (HCRSP) propulsors. The geometry of contra-rotating propulsor (CRP) was then analyzed, and a steady integral panel method that treats the forward and aft propellers as a whole part is presented. During the study, the control equation of the steady integral panel method for CRP is derived in detail. From the experience of developing an integral panel method for CRP, the characteristics of panel singularity strength in HCRSP propulsor was analyzed. Based on this analysis, an integral panel method for HCRSP propulsor is developed and the wake model discussed. Then, the method is applied in the performance analysis of HCRSP propulsor. Comparison between experimental data and numerical results shows that the steady integral panel method has good accuracy in terms of open water performance. Regarding the latter, the error source in the steady integral panel method is discussed.

Keywords: Hybrid contra-rotating shaft pod propulsor; Surface panel method; Integral calculation model; Wake model.

1. Introduction

Hybrid contra-rotating shaft pod (HCRSP) propulsor is defined as propulsion system which consists of a conventional shaft propeller in before and a pod propulsion or Z-drive in behind. The application of this type of propulsive device to modern ships becomes even more attractive, considering the recent developments in podded propulsion and the increased emphasis on fuel economy. Despite the hydrodynamic advantages that the HCRSP propulsors concept could offer, application to ships has been limited. A reasonable explanation can be given by considering the structure complexity, the lacking of effectively design approach. Since the HCRSP propulsor was first applied to full-scale ships by ABB in 2001, test procedures [1–3] and viscous flow methods [4,5] have been developed. According to these studies and the works of Chang and Seokcheon [6], Quereda et al. [7], and Sasaki et al. [8], guidelines for HCRSP propulsor model tests were first recommended by the 27th ITTC Propulsion Committee [9]. Detailed research on the computer processing of the viscous numerical method for HCRSP propulsor analysis has been conducted by Wang et al. [10]. Additional interesting research on HCRSP propulsor has been carried out under the auspices of the EU TRIPOD project [11], in which a conventional propeller was replaced by a contracted and loaded tip (CLT) propeller to improve propulsion efficiency.

Experimental methods and the viscous flow method have used in the analysis of HCRSP propulsors; however, little research has focused on the potential flow method, due mainly to the complexity of such an iterative method [12–14] when applied to the analysis of HCRSP propulsors. While an iterative method is widely used in the study of propulsors consisting of two components, an iterative process could become very complicated when applied to more than two components, such as a HCRSP propulsor. In light of the limitation of a numerical method based on potential flow, it is very difficult to design a HCRSP propulsor.

The purpose of this paper is to provide a solution to the analysis of HCRSP propulsors using the surface panel

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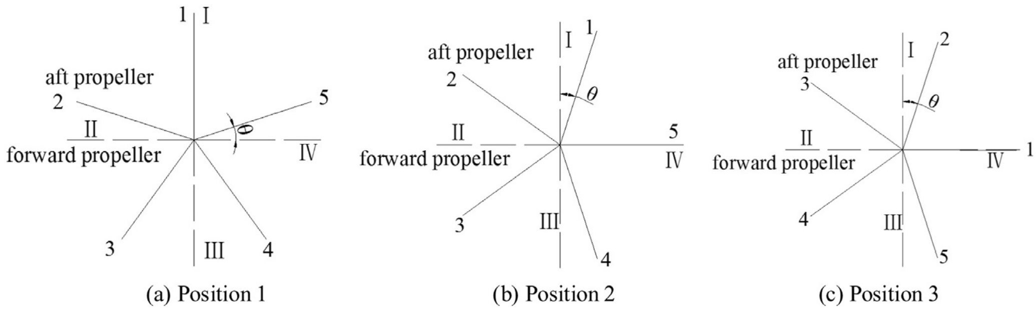

Fig. 1. The position of forward propeller and aft propeller.

method. To that end, a steady surface panel method that treats a HCRSP propulsor as a complete part is presented. Thus, this work strives to devise a high efficiency numerical method for the performance design and analysis of HCRSP propulsors; it also provides research ideas for propulsors consisting of more than two components.

2. Numerical method

When the surface panel method is applied, the flow around the propeller is considered to be incompressible, inviscid, and irrotational; moreover, the viscous wake flow is considered to be no thickness boundary of potential flow. The flow condition around propeller and its wake can be simulated by inducing singularity on the propeller and wake surface. Then, the perturbation potential ϕ, whose spatial derivatives represent the component of the perturbation velocity vector, satisfies the Laplace equation. From Green's formula, an integral equation [15–17] can be written for unknown potential values at point p as follow:

$$2\pi\phi(p) = \iint_{S_B+S_W}\left[\phi(q)\frac{\partial}{\partial n_q}\left(\frac{1}{r(p,q)}\right) - \frac{\partial\phi(q)}{\partial n_q}\frac{1}{r(p,q)}\right]dS \tag{2.1}$$

where the field point p and control point q is on the surface of propeller and its wake. S_B is the surface of propeller and hub, S_W is the surface of the wake, $r(p, q)$ is the distance between points p and q, and n_q is the unit normal vector pointing into the flow. The value of $\partial\phi(q)/\partial n_q$ on the propeller can be determined by boundary conditions while on the wake its value is zero; the value of $\phi(q)$ on the wake can be determined by the Kutta condition [18]. In the numerical process, the propeller and vortex sheet are discretized with hyperboloidal panels carrying constant strength sources and dipoles. For a steady problem of a single traditional propeller, only one blade (the key blade) needs to be solved due to the symmetrical in-flow condition and propeller geometry. This will significantly reduce the surface panel and solution time. Generalizing S_B and S_W in Eq. (2.1), the governing equation for a HCRSP propulsor is obtained. However, the symmetry of the singularity strength in forward or aft propeller is broken even in uniform flow. In this case, the HCRSP propulsor could not be solved as a unit by the old surface panel method which only solves for one bale of a propeller. In addition, the processing is very complicated when an unsteady surface panel method [19,20] is employed to obtain the solution. In order to establish an integral panel method for HCRSP propulsors, a steady integral panel method for contra-rotating propulsors (CRPs) is discussed first.

2.1. Integral panel method for CRPs

For convenience, a four bladed forward propeller and a five bladed aft propeller system was chosen as our experimental CRP. It should be noted here that the conclusions reached are also suitable for other numbers of blades. A diagram of the CRP is shown in Fig. 1. The forward propeller blades are represented by dashed lines and the blade numbers are denoted by Roman numerals I–IV. The aft propeller blade is represented by solid lines and the blade numbers are denoted by Arabic numerals 1–5. The position of solid line (or dash line) is the position of aft (or forward) propeller reference line.

In Fig. 1, for position 1, blade I overlaps with blade 1 and then rotates the forward (or aft) propeller by θ, to reach position 2, in which blade IV overlaps with blade 5. Rotating the forward (or aft) propeller in position 1 by five times θ, to reach position 3, where blade IV overlaps with blade 1. As shown in Fig. 1, for uniform flow conditions, the force of the forward and aft propeller blade change periodically and the period are different. But the periods of the forward and aft propeller forces are the same, and thus the forces of the propellers in positions 1, 2 and 3 as shown in Fig. 1 are the same. In some sense, the propeller force is an average force in terms of open water performance. We can choose several positions as the solving position, and then average the singularity strength at these positions. The detailed processing is discussed in the following section.

We choose blade I of forward propeller and blade 1 of aft propeller as the solving blades (key blades), and then rotate blade I (or blade 1) one revolution with interval angle of θ (as labeled in Fig. 1), taking every multiple of θ as the solving position. Obviously, in every solving position, the forces of the forward and aft propellers are the same. For the blade numbers chosen in this paper, we can know that the value of

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