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RESEARCH ON RAPID GENERATION OF DUCTED PROPELLER MODEL AND ITS OPEN WATER PERFORMANCE

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ABSTRACT

Using coordinate transformation method, two-dimensional blade section of ducted propeller is converted to three-dimensional coordinate system. The ducted propeller is built by NURBS surface. The generation of the ducted propeller is based on AutoCAD and Excel secondary development by Visual Basic 6.0. There, the ducted propeller model can be parameterized by one click. Calculating the thrust and torque values of ducted propeller at different speed coefficients by RNGk — ε turbulence model equation.

1. Introduction

Ducted propeller is the main propeller of small ships, AUV and UUV. Its design performance and manufacturing accuracy directly determine the ship's fast, noise and other performance [1-3].

The difficulty of 3D ducted propeller modeling is that it is difficult to obtain the spatial coordinates of the blade. The ducted propeller blade cannot be expressed accurately by function [4]. However, the two-dimensional blade section of ducted propeller can be converted to three-dimensional blade by coordinate transformation.

Manual calculation is complicated in the whole process [5]. In order to quickly realize the modeling, the diameter, blade numbers and pitch ratio of the ducted propeller are parameterized, and the Excel and AutoCAD are secondary developed by Visual Basic 6.0.

2. ANALYSIS OF DUCTED PROPELLER'S SURFACE

In order to research how 3D model of ducted propeller is established, the blade can be cut out by a cylindrical surface (Figure 1).

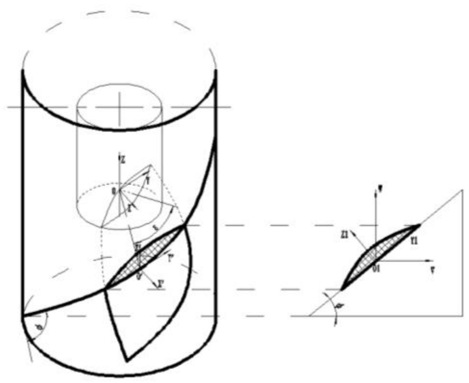

Figure 1: The principle of 3D surface point transformation for ducted propeller

Where, ϕ represents pitch angle, ε represents longitudinal oblique angle.

In order to switch to the bus based condition, the transformation is shown as shown in Figure 2.

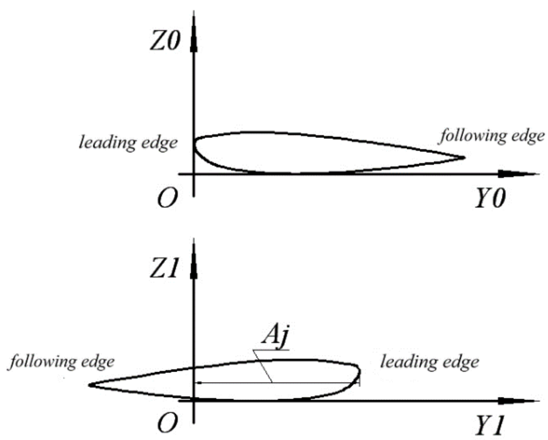

Figure 2: Conversion coordinate of propeller blade

So,

$$\begin{bmatrix} Y_1 \\ Z_1 \end{bmatrix} = \begin{bmatrix} Aj - Y_0 \\ Z_0 \end{bmatrix} \qquad (1)$$

In form (1), Aj represents the distance from the leading edge to the Z1 axis.

In Figure 1, the coordinate system $O_1X_1Y_1Z_1$ coincides with the coordinate system O_1UVW by clockwise rotation of the pitch angle (ϕ). So,

$$\begin{bmatrix} U \\ V \\ W \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & -\sin\phi \\ 0 & \sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix} \quad (2)$$

Then, Converting the points on the O_1UVW coordinate system to the cylinder plane on the $OXYZ$ coordinate system.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} R_i \cos\frac{V}{Ri} \\ R_i \sin\frac{V}{Ri} \\ W - R_i \tan\varepsilon \end{bmatrix} \quad (3)$$

Where, R_i represents the radius of the cylinder of the intercepted ducted propeller's blade。

From form (1) to (3),

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} R_i \cos\frac{(Aj - Y_0)\cos\phi - Z_0 \sin\phi}{Ri} \\ R_i \sin\frac{(Aj - Y_0)\cos\phi - Z_0 \sin\phi}{Ri} \\ (Ah - Y_0)\sin\phi + Z_0\cos\phi - R_i \tan\varepsilon \end{bmatrix} \quad (4)$$

The 2D blade section of propeller can be converted into 3D blade section by form (4).

3. Establishment of ducted propeller model by Visual Basic 6.0

3.1 Ducted propeller generation steps

a) Input propeller design parameters (diameter, blade area ratio, etc.).

b) Getting the blade section offsets from Excel, calculating each blade section.

c) Calculation the maximum blade width, blade thickness, the distance from the edge to the bus, Yo value and Zo value.

d) Calculation R_i and pitch angle.

e) Calculation 3D points of value from form (4)

f) 3D ducted propeller can be generated by AutoCAD secondary development of Visual Basic 6.0.

3.2 Three-dimensional ducted propeller

NUBRS curve, that is, the non-uniform rational B spline curve. It is a mathematical method that unifies the B spline curve and can accurately represent the curve [6-8]. In this paper, the NURBS curve is used to get 2D blade of ducted propeller and the NURBS surface is used to generate 3D ducted propeller. The parameters of ducted propeller are shown in Table 1.

Table 1: The parameters of ducted propeller

Diameter /mm	Pitch ratio	Propeller type	Blade area ratio	Disk ratio	ratio of hub	Direction of rotation
120	1.2	Ka	4	0.7	0.18	right

2D blade of ducted propeller is generated by NURBS curve (Figure 3).

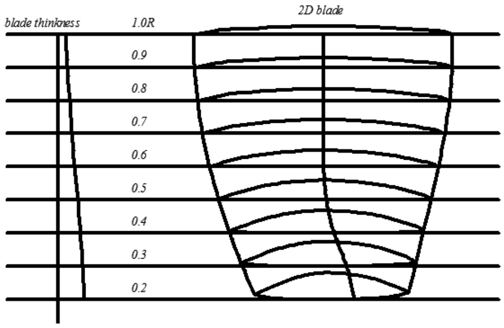

Figure 3: Three-dimensional ducted propeller (Ka type)

3D ducted propeller is generated by NURBS surface (Figure 4).

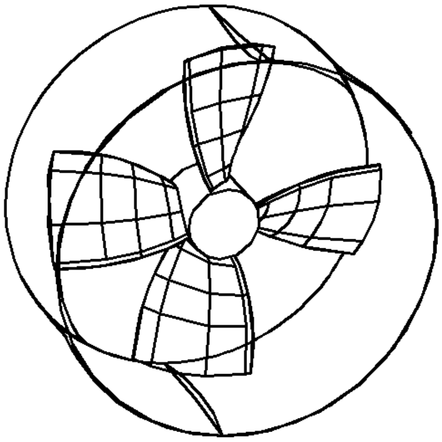

Figure 4: Three-dimensional ducted propeller (Ka type)

4 BASIC THEORY OF FLUID MECHANICS

4.1 Control equation

The continuity equation and momentum equation for incompressible viscous fluid are:

$$\frac{\partial \overline{u_i}}{\partial x_i} = 0 \quad (5)$$

$$\rho\frac{\partial \overline{u_i}}{\partial t} + \rho\partial\overline{u_j}\frac{\partial \overline{u_i}}{\partial x_i} = \rho\overline{F_i} - \frac{\partial \overline{p}}{\partial x_i} + \frac{\partial}{\partial x_j}(\mu\frac{\partial \overline{u_i}}{\partial x_j} - \rho u_i' u_j') \quad (6)$$

Where, ρ is density, μ is Viscosity Coefficient, $\overline{p}$ is average pressure, $\overline{F_i}$ is external force, $\overline{u_i}$ is mean velocity, u_i' is fluctuating velocity, $-\rho u_i' u_j'$ is reynolds stress.

4.2 Turbulence model

In order to make the equation closed, a new turbulent model equation must be introduced to link the fluctuating values with the time average in the stress terms [9,10]. There, we chose the $RNGk-\varepsilon$ equtions. The transport equations of turbulent kinetic energy and turbulent fluctuation intensity in the $RNGk-\varepsilon$ equation are:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}[\alpha_k \mu_{eff}\frac{\partial k}{\partial x_j}] + G_k - \rho\varepsilon + S_k \quad (7)$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_i}(\rho\varepsilon u_i) = \frac{\partial}{\partial x_j}[\alpha_k \mu_{eff}\frac{\partial \varepsilon}{\partial x_j}] + G_{1\varepsilon}\frac{\varepsilon}{k}G_k - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} - R_\varepsilon + S_\varepsilon \quad (8)$$

Where, $\mu_{eff} = \mu + \mu_t$, $\mu_t = \rho C\mu\frac{k^2}{\varepsilon}$, $G_k = -\rho\overline{u_i' u_j'}\frac{\partial u_j'}{\partial x_i}$, $R_\varepsilon = \frac{C_\mu \rho\eta^3(1-\frac{\eta}{\eta_0})}{1+\beta\eta^3}\frac{\varepsilon^2}{k}$, $\eta \equiv \frac{Sk}{\varepsilon}$, $S = \sqrt{2S_{ij}S_{ij}}$, $S_{ij} = \frac{1}{2}(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i})$, S_k and S_ε are user-defined