Impacts of Rudder Profiles on UV Maneuverability Based on Numerical Simulation

Kunyu Han1,2, Xide Cheng1,2, Chenran Huang3, Kangli Tan1,2
1. Key Laboratory of High Performance Ship Technology, Wuhan University of Technology, Ministry of Education, Wuhan, China
2. School of Transportation, Wuhan University of Technology, China
3. China Ship Development and Design Center, Wuhan, P.R.China

ABSTRACT
In this paper, submarine models with various rudder profiles are studied and commercial CFD software STAR-CCM+, based on RANS simulations, is carried out to numerically simulate self-propulsion maneuvering motions of the underwater vehicles with different appendages. Finite volume method based on incompressible solver with SST k-ω turbulence model and unstructured grid are applied to study the flow field characteristics. The self-propulsion horizontal turning movement of the SUBOFF models equipped with various rudder profiles are simulated directly to analyze the motion characteristics in each simulation; finally, the impacts of rudder profiles on UV maneuverability are discussed and concluded.

KEY WORDS: CFD; underwater vehicle; self-propulsion; rudder profiles; maneuverability; turning motion; hydrodynamic characteristics

INTRODUCTION
The maneuverability of the underwater vehicles (UVs) is one of the most important performance in UVs research, and accurately predicting its motion characteristics in maneuvering motion is very necessary for the safety and design. The evaluation of the maneuverability of UVs is traditionally solved by simplified System-Based Models, based on captive model tests or Computational Fluid Dynamics method. Lin (2018) established the Planar Motion Mechanism (PMM) experiments in the towing tank to analyze maneuvering derivatives of a half-scale submerged body DARPA SUBOFF and evaluate the maneuvering derivatives by a Fourier transform. Pan (2012) adopted steady and unsteady RANS simulations and dynamic mesh method to numerically simulate the oblique towing experiment and the PMM experiment performed on the SUBOFF submarine model. Wu (2015) established a hybrid reference frames method that combined the rotating reference frame method and an added momentum source method to investigate the influences of the rotating arm radius and linear velocity in the numerical simulations.

With the large progress of the computer technique, people pay more attention to the simulation of the self-propelled test. G. Dubbioso (2017) presented and discussed the results of the free running maneuvering simulations of a fully appended submarine with two different configurations of the stern appendages. Feng (2018) used the volume force method to realize the self-propelled movement of submarine and obtained the trajectory and kinematic parameters. K. Petterson (2018) reported additional simulations of the self-propulsion conditions at ±10 yaw by LES method.

UVs’ maneuverability determines the responses to the navigation orders and the rudder plays an important role on it. Indeed, various rudder profiles have different hydrodynamic performances (Thieme 1962). Mostly the rudder forces are estimated by empirical formulas in MMG model, therefore the contribution to the UVs’ maneuverability with various profiles should be simulated accurately.

In the present paper, four kinds of rudder profiles (NACA 0015, NACA 0018, NACA 0020, NACA 0024) are selected, meanwhile DRAPA SUBOFF submarine model is studied and commercial CFD software STAR CCM+, based on RANS simulations, is carried out to directly simulate self-propulsion maneuvering motions of the UVs with appendages. Finite volume method based on incompressible solver with SST k-ω turbulence model and unstructured grid are applied to study the flow field characteristics; the DFB module and body-force propeller model are used to study the flow field calculation of self-propulsion movement of various rudder profiles on the UV. The free running turning motion simulations of the fully appended DARPA SUBOFF equipped with various rudder profiles at 3 kinds of rudder deflections (6deg, 12deg and 18deg) show that, the submarine equipped with NACA 0024 will display the best maneuverability performance among all the models. And based on the turning parameters, with the increase of rudder thicknesses, the UV will show the better turning abilities and rudder response abilities.

MATHEMATICAL MODEL AND NUMERICAL METHOD
Rudder Profiles
There are various kinds of rudder profiles can be selected according to the requirement on UVs, such as the hydrodynamic characteristics,