International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 30, No. 3, September 2020, pp. 318–326; https://doi.org/10.17736/ijope.2020.ts20

http://www.isope.org/publications

Hydrodynamic Performance of the Conformal Rudder

Shuo Zhai
National Key Laboratory of Science and Technology on Vessel Integrated Power System
Naval University of Engineering, Wuhan, Hubei, China

Zhihua Liu†
College of Ship and Ocean, Naval University of Engineering
Wuhan, Hubei, China

Conformal rudder is a new kind of submarine stern control surface composed of a fixed fin and a rotatable rudder. Water tunnel tests and numerical simulations based on Reynolds-averaged Navier-Stokes method were carried out to research the open water hydrodynamic performance of the conformal rudder. It is found that sealing the gap between the rudder and the fin can effectively improve the hydrodynamic performance by suppressing the flow separation. The lift of rudder increases with chord ratio and aspect ratio. The hydrodynamic performance of the conformal rudder on a SUBOFF hull was studied and compared with the conventional stern control surface. The results indicate that the vertical force and the pitching moment of the submarine increased by 35% to 70%.

INTRODUCTION

Rudders are the main steering device of most marine vessels including submarine, other underwater vehicles, and ships of all sizes. The design of the rudder is always a hot-button issue in the study of maneuverability.

The performance of the rudder is affected by the design choices. Molland and Turnock (2007) systematically introduced the rudder design strategy and design application. Kim et al. (2012) proposed a rudder design procedure based on an investigation of the rudder design process at major Korean shipyards. Liu and Hekkenberg (2017) reviewed the design choice of rudder and the impacts on the maneuverability of marine vessels.

The rudder profile has a great impact on the hydrodynamic performance. NACA, wedge-tail, and IFS are all famous profiles with high performance. Schilling rudder is also a kind of high-efficiency airfoil rudder (Bingham and Mackey, 1987). Liu et al. (2016) studied the impacts of the rudder profile on maneuvering performance.

The flapped rudder is a kind of high lift rudder derived from the design of the aircraft wing. It is made up of two portions. The forward portion can be considered an all-movable spade rudder, with the aft portion an independently adjustable flap hinged from the forward part. Its hydrodynamic characteristic was studied systematically by experiments and numerical simulation (Kerwin et al., 1972; Guo et al., 2008; Yang et al., 2017; J Liu et al., 2018).

Because the control surface not only provides the steering force but also provides good stability to the submarine, the stern control surface of numerous submarines consists of two portions. The forward portion is a fixed fin (stabilizer) attached to the hull, which improves the stability of submarines and provides protection for the rotatable rudder. The aft portion is a rotatable rudder to provide steering force. It is similar to the flapped rudder but not exactly the same.

As for the conventional submarine stern control surface, the rotatable rudder has a complete airfoil profile, as shown in Fig. 1. To reduce the power of the steering gear, the rudder stock is located at the hydrodynamic center. There is a break between the fin and the rudder. Wu et al.'s (2008) study concluded that this layout resulted in the reduction of rudder efficiency in the case of small deflection angle, as the leading edge of the rudder is in the wake flow of the fin.

To solve these problems, some submarines are equipped with the conformal rudder, a kind of control surface with a new layout of fin and rudder, as shown in Fig. 2. The main characteristic of the conformal rudder is that the gap between the fixed fin and the rotatable rudder is very small, and the two parts form a complete airfoil profile together. The outline of the conformal rudder remains smooth during the rotation.

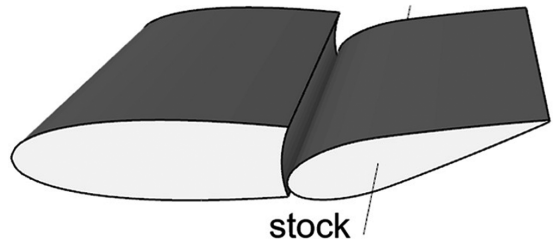

Fig. 1 Conventional submarine stern control surface

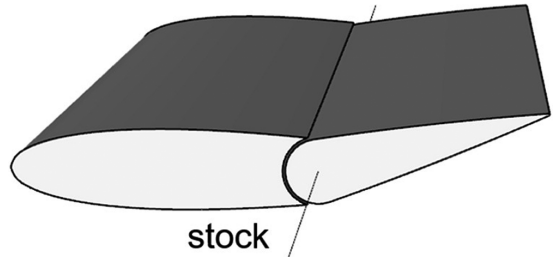

Fig. 2 Conformal rudder

†Corresponding author
Received April 16, 2019; revised manuscript received by the editors October 10, 2019. The original version was submitted directly to the Journal.
KEY WORDS: Submarine stern control surface, conformal rudder, hydrodynamic performance, water tunnel test, computational fluid dynamics.