ABSTRACT

To evaluate the availability of traditional turbulence stimulator in the towing tank test by using model ship at very low speed condition, we carried out a direct numerical simulation for boundary layer flow with a trapezoidal stud. The two Reynolds numbers were tested by changing inflow speed, and mean and turbulent properties were investigated at some downstream positions from DNS data. At the case of low Reynolds number, turbulence stimulation was weak and fully-developed turbulent boundary layer could not obtained. However, at the case of relatively-large Reynolds number, some spanwise roll vortex structures were mutually interfered and transited to longitudinal three-dimensional turbulent structured. Therefore, the trapezoidal stud was able to realize turbulent stimulation quickly and effectively at high Reynolds number.

KEY WORDS: Turbulence stimulation; boundary layer; direct numerical simulation.

INTRODUCTION

At the design process of large commercial ship, a full-scale ship with the length of several hundred meters is sale-downed to a model ship with the length of 3-7 meters, and a resistance test is conducted in a towing water tank and the performance at the full-scale is estimated. The flow field around ship is characterized by Froude ($Fr$) and Reynolds ($Re$) numbers, and based on the Froude hypothesis, a towing test is carried out under the same Froude number between the full and model scales. And then, Reynolds number cannot be equaled between these two scales: $Re \sim 10^6$ at the model scale, $Re \sim 10^9$ at the full-scale. If a towing tank test is done without additional devices on the model, the property of boundary layer on the ship hull is laminar or laminar-turbulence transition region. On the other hand, the boundary layer at the full-scale is turbulent boundary layer and so we have to realize a turbulent boundary layer at the model scale with some methods for estimating a friction resistance curve from the low Reynolds number. In order to solve this problem, at standard towing tank test, some small devices are attached at the ship bow which is called turbulence stimulator, and the flow is forced to turbulence. The method for using turbulence stimulator is defined in the ITTC guideline (ITTC, 2002) and its validity was confirmed at the relatively high Reynolds number. The shape of turbulence stimulator defined in the ITTC guideline is a cylindrical stud but a trapezoidal stud (Tagori, 1961) is usually used at Japan, and so we have used the latter one in the present study. In addition to these stud shapes, other devices such as trip wire, Hama stripe (Hama, 1957), and sand grains are utilized for fluid dynamic research including aerospace science, but comprehensive study on turbulence stimulator is insufficient and actual turbulence simulation depends on an empirical knowledge in each technology fields.

Recently, in ship engineering, zero-emission vehicle is highly required for reducing greenhouse gas, and ship engineers are supposing and developing new innovative vehicles. One of the zero-emission vehicles is a large blunt ship sailing a very low speed, and its propulsion performance must be estimated by a towing tank test. However, it is not confirm whether the conventional turbulence stimulation method can available at a very low speed test or not, and an advanced turbulence stimulation or optimization for conventional method may be required. From this background for a towing tank test with low speed condition, a large-eddy simulation (LES) for the boundary layer on a flat plate has been reported (Lee et al, 2021). However, LES needs turbulence model, that is, sub-grid scale (SGS) model for estimating unresolved turbulent motion under grid resolution, and the validation for used SGS models must be done carefully. In the present study, in order to give an exact numerical result for revealing the basic mechanism of turbulence stimulation in boundary layer, we have carried out a direct numerical simulation resolving a smallest turbulence eddy for a boundary layer flow on a flat plate with a trapezoidal stud, and investigated the availability of the conventional turbulence stimulation at a low Reynolds number.

NUMERICAL METHOD

The governing equations are the following incompressible Navier-Stokes an continuity equations:

\[ \frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = -\frac{1}{\rho} \nabla p + \nu \nabla^2 \mathbf{u} \]

\[ \nabla \cdot \mathbf{u} = 0 \]