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Subgrid Scale Model Based on Resolved Pressure Gradient for Shear Flows

Li Li[1*], Zhe Chen[2] and Xinliang Li[3]

[1] Institute of Mechanics, Chinese Academy of Sciences ,
Beijing 100190, China, lilili606@163.com

[2] Institute of Mechanics, Chinese Academy of Sciences ,
Beijing 100190, China, chenzhe1028@yahoo.cn

[3] Institute of Mechanics, Chinese Academy of Sciences ,
Beijing 100190, China, lixl@imech.ac.cn

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Introduction

The eddy-viscosity models often lead to unrealistic subgrid-scale(SGS) dissipation effect in most shear flows. Many attempts have been made to handle this problem, including the dynamic procedure[1], nonlinear constitutive relation[2], etc. These methods have made great improvement on the conventional model, while are limited to the constitutive relation between the SGS stress and resolved strain rate tensor. As is recognized in this research, the pressure gradient plays an important role in shear flows, and the redistribution among SGS stresses caused by pressure gradient even dominant the production of SGS stress under some extreme conditions. The main objective of the present study is to incorporate the pressure gradient effect into the SGS model.

New model based on pressure gradient

Most of the turbulent flows are anisotropic (shear) flows, where the pressure transport is very important. Pressure gradient transports energy between SGS components from those of high energy levels to lower ones, and provides additional SGS stress to the production terms.
A new model is proposed to describe the effects in this research. The new SGS model is divided into two parts respectively for energy cascade and SGS stress redistribution. The first part is described by the Smagorinsky term, while the second part can be extracted from the SGS stress transport equation. A linear function of the redistribution term is adopted when deriving the explicit expression of the second term. The final SGS stress model is as follows:

$$\tau_{ij} = 2C_s\Delta^2|S|\bar{S}_{ij} + C_p\Delta^2|S|\left(\frac{\partial^2\bar{p}}{\partial x_j\partial x_k}\bar{S}_{ik} + \frac{\partial^2\bar{p}}{\partial x_i\partial x_k}\bar{S}_{jk}\right)/\left|\frac{\partial^2\bar{p}}{\partial x_k\partial x_k}\right|$$

The coefficients Cs and Cp are calculated by dynamic procedure. The spanwise averaged coefficient values in channel flow is shown in Figure 1. The value of Cs is essentially positive which indicates that the energy is transferred from large scale to small scale. While the value of Cp is essentially negative, which is a hint of physical mechanism of the second term. This property is also useful to formulate a constant coefficient model and reduce computing time caused by dynamic procedure.

As is shown in Figure 2, the proportion of the first part in the new model falls from about

90% in sub-viscous layer to nearly 60% in the log-law layer, which indicates that the redistribution effect cannot be neglected in shear flows.

Figure 3 and Figure 4 show the profile of streamwise velocity of channel flow calculated by different models, which suggests the good correspondence of results from the present model and DNS.

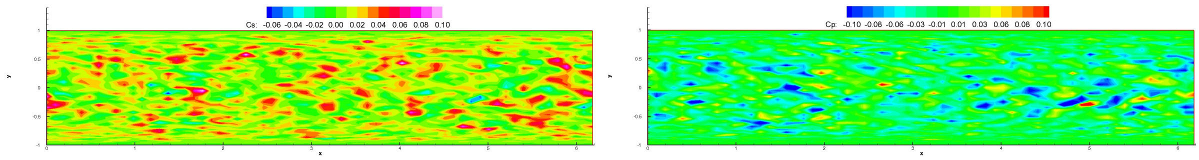

Fig. 1: spanwise averaged Cs (top) and C_p (bottom)

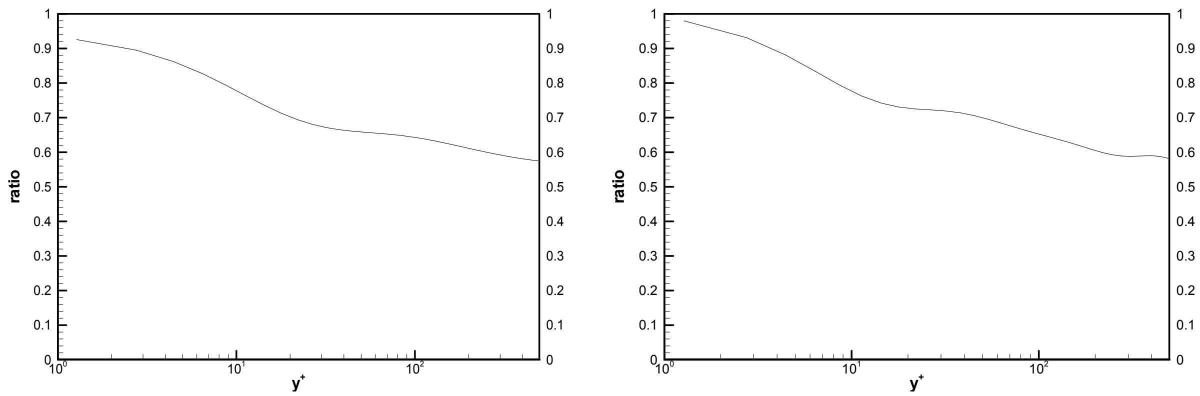

Fig. 2: the ratio of the first part in τ_{11} (left) and τ_{33}(right)

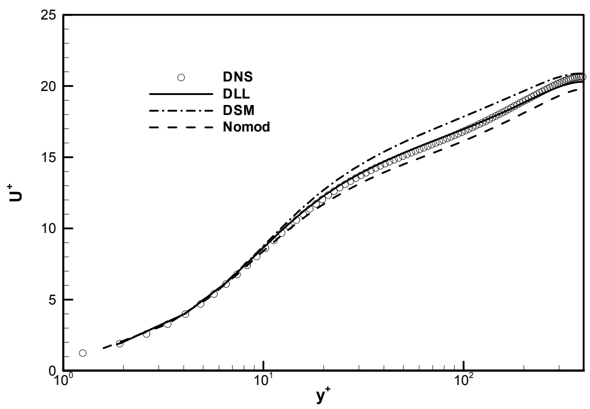

Fig. 3: Velocity profile in the case Re_τ=395
DLL : present model Nomod : no model.
DSM : dynamic Smagorinsky model

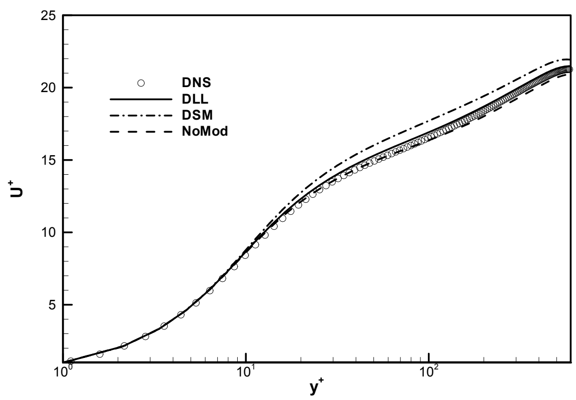

Fig. 4: Velocity profile in the case Re_τ=590
DLL : present model Nomod : no model.
DSM : dynamic Smagorinsky model

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