Investigation of different internal flows using different transitional models

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ABSTRACT

Prediction of flow behavior in the transition region is the key issue in many scientific problems. Many attempts have been made by researchers to propose and modify the models estimating the flow behavior in this region. In these flows, the governing equations, including the continuity, the Navier-Stokes, and the transmittance along with the Shear Stress Transport models are solved simultaneously to predict the flow behavior. There are several coefficients in the governing equations which affect the flow simulation. In this study, the transitional Shear Stress Transport model is modified by altering two coefficients in the intermittency equation. A combination of these coefficients is implemented, and the effects are studied. To assess the accuracy of the proposed coefficients in simulation, they are applied to three individual internal flows, including a smooth axisymmetric pipe, two parallel plates, and a backward-facing step. Different variables such as the friction factor coefficient, fully developed friction factor, and the reattachment length are explored. A comparison between the results and both analytical and experimental data confirms a good accuracy in the predictions. Furthermore, using the presented models the entrance length is well predicted in turbulent and transitional flows.

KEYWORDS

Internal Flows, Turbulence Model, Transitional Shear Stress Transport, Numerical Simulation

Introduction

Transition phenomenon and its simulation plays a key role in science and engineering applications. The phenomenon is occurred through three different mechanisms including natural transition [1], bypass transition [2], and separation-induced transition [3]. Abraham et al. [4] in their study, developed the main γ-Re_θ model for internal flows. They investigated transition from laminar to turbulent flow in a pipe. Abraham et al., in another research [5] , studied γ-Re_θ model for internal flow with varying cross section area. Menter et al. [6] in their study implemented some improvements to γ-Re_θ model. It was a transition model based on local corrolations. In the present study, the transition phenomenon in internal flows has been investigated. In this manner, a range of turbulence coefficients has been studied to propose the best combination. The improvements has been implemented on c_{e2} and $c_{\theta t}$ which are the coefficients of dissipation ($E_{\gamma 2}$) and production ($P_{\theta t}$) terms.

Methodology

The flow is considered incompressible and unsteady. Hence the governing equations of the unsteady flow including the continuity, momentum, transition, and additional equations for turbulent closures are given in Eqs. (1)-(6):

$$\frac{\partial u}{\partial x} = 0 \tag{1}$$

$$\frac{\rho \partial}{\partial t}(u_i) + \frac{\rho \partial}{\partial x_j}(u_i u_j) = -\frac{\partial p}{\partial x_i} + \rho g_i + \frac{\partial}{\partial x_j}(\tau_{ij}) \tag{2}$$

$$\frac{\rho \partial(\gamma)}{\partial t} + \frac{\rho \partial(u_j \gamma)}{\partial x_j} = P_{\gamma 1} - E_{\gamma 1} + P_{\gamma 2} - E_{\gamma 2} + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\gamma}\right)\frac{\partial \gamma}{\partial x_j}\right] \tag{3}$$

$$\frac{\rho \partial\left(Re_{\theta t}\right)}{\partial t} + \frac{\rho \partial\left(u_j Re_{\theta t}\right)}{\partial x_j} = P_{\theta t} + \frac{\partial}{\partial x_j}\left[\sigma_{\theta t}\left(\mu + \mu_t\right)\frac{\partial Re_{\theta t}}{\partial x_j}\right] \tag{4}$$

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$$\frac{\rho\partial(k)}{\partial t}+\frac{\rho\partial(u_j k)}{\partial x_j}=\frac{\partial}{\partial x_j}[(\mu+\sigma_k\mu_t)\frac{\partial k}{\partial x_j}]+P_k-D_k \qquad (5)$$

$$\frac{\rho\partial(\omega)}{\partial t}+\frac{\rho\partial(\overline{u_j}\omega)}{\partial x_j}=\frac{\partial}{\partial x_j}[(\mu+\alpha_\omega\mu_t)\frac{\partial\omega}{\partial x_j}]+\alpha\frac{P_k}{\upsilon_t}-D_\omega+Cd_\omega \qquad (6)$$

Three different test cases (TC) are considered to evaluate the modified model capabilities including flow in an axisymmetric pipe, flow between two parallel plates, flow in a backward-facing step.

Discussion and Results

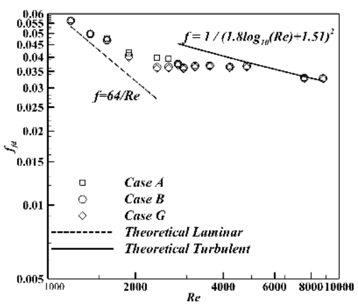
The model presented by Menter [7] is modified to simulate the internal flows. It was stated that two coefficients including C_{e2} and $C_{\theta 2}$ can be modified in the model. Therefore, in the present study 7 different combinations of these coefficients are proposed.

Table 1 Implemented turbulence coefficients

Combination	c_{e2}	$c_{\theta t}$
A	70	0.008
B	70	0.015
C	80	0.008
D	80	0.015
E	90	0.008
F	90	0.015
G	90	0.0115

1.1. Flow in an axisymmetric pipe

Flow inside an axisymmetric pipe was studied as the first TC. Fully developed friction factor using the proposed combination of coefficients were studied in this geometry. The results are presented in figure 1.



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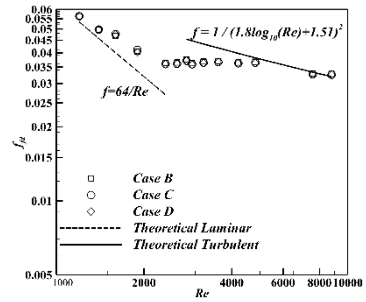

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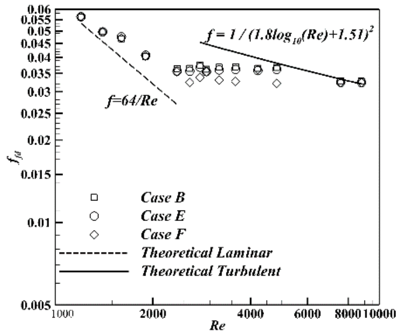


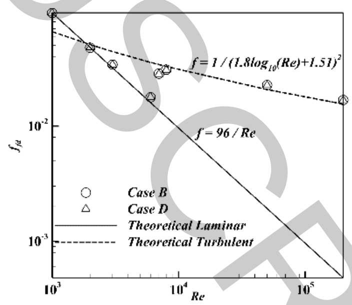
(c)

Figure 1 Fully developed friction factor in an axisymmetric pipe

As it can be observed, the results tend to theoretical laminar and turbulent flow values for Reynolds numbers less than 1900 and greater than 4000 respectively. Reynolds numbers between 1900 and 4000 are referred to as transition regions where no sufficient theoretical values are available.

1.2. Flow between two parallel plates

Flow between two parallel plates is considered as the second TC. Fully developed friction factor can also be examined as it was performed in flow inside an axisymmetric pipe.



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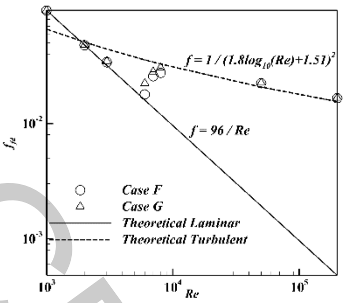

(b)

Figure 2 Fully developed friction factor in the flow between two parallel plates

The results can be divided into three different regions including laminar, transition ,and turbulent flows. The results for Reynolds numbers between 10^3 to 3×10^3 and 8×10^3 to 2×10^5 are in good agreement with previous results [8]. Maximum error reported for laminar and turbulent flows are equal with 8.566 and 9.4 respectively.

1.3. Flow in a backward-facing step

In this TC the capability of the proposed turbulence coefficients are investigated in a geometry with varying cross section area. The inlet Reynolds number considering the geometry is set to 6.4×10^4 to validate the results with previous experimental results [9]. The reattachment length for different inclination angles are displayed in figure 3.

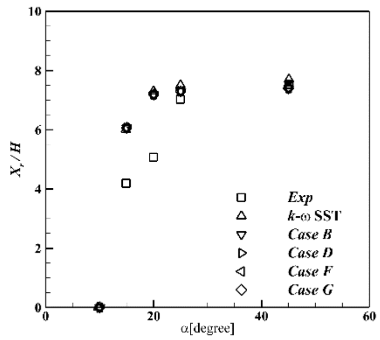

Figure 3 Comparing reattachment length for different expansion angles in a backward-facing step with a Reynolds number equal to 6.4×10^4

Conclusions

In this paper capability of different combinations of turbulence coefficients in the simulation of various flow regimes was studied. Three different test cases, including flow in an axisymmetric pipe, flow between two parallel plates, and flow in a backward-facing step, were selected to assess the proposed models. The results were compared with the results reported in previous studies and theoretical data. Finally the best combinations were reported as follows:

C_{e2} equal with 70, and $C_{\theta t}$ equal with 0.015

C_{e2} equal with 90, and $C_{\theta t}$ equal with 0.015

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