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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.

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1- Introduction

The transition phenomenon and its simulation play a key role in science and engineering applications. The phenomenon occurs 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 the transition from laminar to turbulent flow in a pipe. Abraham et al., in another research [5], studied the γ-Re_θ model for internal flow with varying cross-section area. Menter et al. [6] in their study implemented some improvements to the γ-Re_θ model. It was a transition model based on local correlations. 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 have been implemented on c_{e2} and $c_{\theta t}$ which are the coefficients of dissipation ($E_{\gamma 2}$) and production ($P_{\theta t}$) terms.

2- 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) to (6):

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

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

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

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

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

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

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

3- Results and Discussion

The model presented by Menter et al. [7] is modified to simulate the internal flows. It was stated that two coefficients

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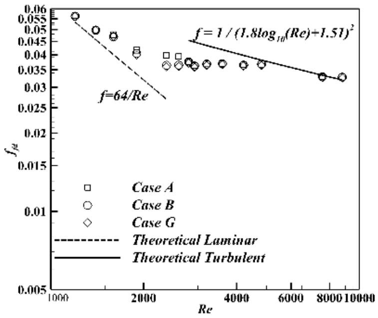
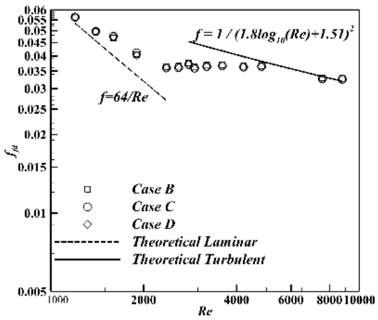
Table 1. Implemented turbulence coefficients

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



(a)



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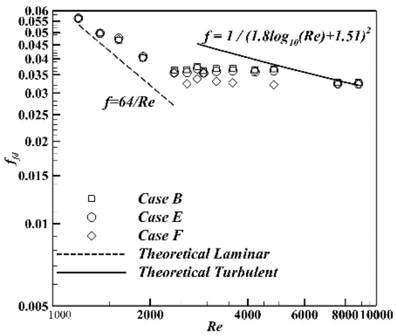
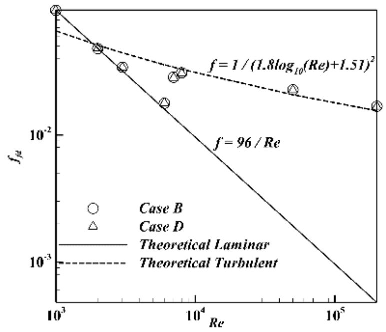


(c)

Fig. 1. Fully developed friction factor in an axisymmetric pipe



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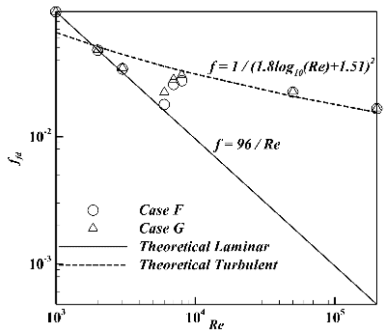

(b)

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

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.

3- 1- Flow in an axisymmetric pipe

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

As 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.

3- 2- The flow between two parallel plates

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

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 at 8.566 and 9.4 respectively.

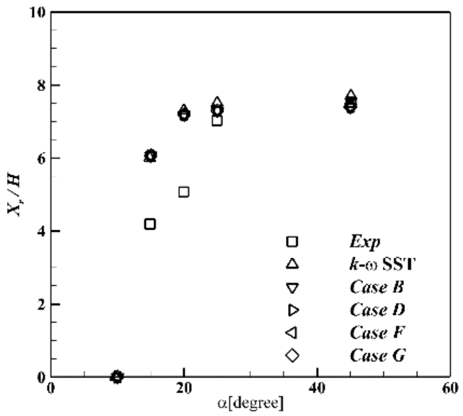

Fig. 3. Comparing reattachment length for different expansion angles in a backward-facing step with a Reynolds number equal to 6.4×104

3- 3- Flow in a backward-facing step

In this TC the capability of the proposed turbulence coefficients is investigated in 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 is displayed in Fig. 3.

4- Conclusions

In this paper capability of different combinations of turbulence coefficients in the simulation of various flow, regimes were 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 to 70, and $C_{\theta t}$ equal to 0.015
C_{e2} equal to 90, and $C_{\theta t}$ equal to 0.015

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