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# Accelerated Turbulent Pipe Flow Study Using Various Turbulence Models

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## 1-Introduction

The study of unsteady turbulent pipe flow is valuable because it provides insight information to understand the phenomenon of turbulence. In such flows certain fundamental features of turbulent flow exist, which although present in steady turbulent flows are not apparent under such conditions. Unsteady turbulent pipe flows can be conveniently classified into two groups, namely periodic pulsating flows and non-periodic transient flows. Pulsating turbulent pipe flow has been studied mainly because of its practical applications and also because it can be easily generated. Non-periodic transient pipe flows have received little attention compared to pulsating pipe flows. The few works related to this kind of flow involved the effect of imposed excursions of flow rate. The fact that turbulence is out of equilibrium and that the re-laminarization and re-transition are dependent on the flow frequency makes a crucial difficulty for conventional Unsteady Reynolds - Averaged Navier-Stokes (URANS) models. Thus, a better understanding of the capabilities and limitations of URANS models is required.

The purpose of this study is to compare the predictions of five popular turbulence models applied to the flow in a pipe with experimental and numerical results. This benchmark satisfies a one-dimensional unsteady problem and contains many of the problems associated with transient pipe flow. It allows us to assess the models for pipe flow with defined boundary and initial conditions in an acceptable Reynolds number range. The goal is to evaluate the performance and precision of these models for prediction of the wall shear stress, Reynolds stress, turbulence viscosity, delay time in response and mean velocity.

## 2- Results

***Acceleration results (Evaluation with Experiments and Numerical Results)***

He and Jackson studied the accelerating and decelerating ramp-type turbulent flows in a pipe with 25.4 mm diameter. The ramp-up experiments were performed in which the ramp rate was varied by imposing excursions of flow rate during which the bulk velocity increased linearly with time from an initial value 0.138 m/sec to a final value of 0.891 m/sec in periods of time which ranged from 2 sec to 90 sec. The initial and final Reynolds numbers were constant at the values 7000 and 45200. Their experimental results not only showed how mean flow and turbulence respond to imposed transients but also provide new insight into turbulence dynamics. The present paper compares the predictions of the URANS models with the experimental data of He and Jackson mentioned above for 5 second ramp-up flow excursions. The results reveal that the response of the local velocity is different in core and wall regions. The performance of the BL model is poor and very under-estimated for the prediction of turbulent transient flow at these conditions. The agreement between the other models and the experimental one is excellent for all radial positions, except in the core (Re>32000). All the models tend to underestimate the velocity at the end of the acceleration stage at the centerline.

***Acceleration results (Evaluation with LES)***

The normalized axial velocity fluctuations of LES results of Jung and Chung for 3.8 sec acceleration from Re=7000 to Re=35000 is shown in Fig. 1. The velocities are normalized by the initial bulk-mean velocity. One of the important features of the response of velocity fluctuations to acceleration is the delay effect. It is clear from Fig. 1 that the magnitudes of axial velocity fluctuations change very little during the early acceleration, indicating that the turbulence is frozen in this early stage. This clearly indicates that turbulence production is delayed at the early stage of the transient (see also Fig. 2). Jung and Chung found that the response to the temporal acceleration of different velocity components is different from each other. This suggests that the anisotropy of the turbulence near the wall becomes manifested during the transient moving towards a single component state. A strong increase in axial velocity fluctuations occurs in the near-wall region, and this is closely associated with the turbulence production near the wall. The radial and azimuthal velocity fluctuations also show delayed responses compared to the axial velocity fluctuations. The distribution of normalized turbulence kinetic energy along the diameter is shown in Figure 2. This parameter is representative of all velocity fluctuations of LES results. Only k-ε-v2 results are shown in this Figure. The other model results are qualitatively the same as k-ε-v2. This Figure shows the delay effect at the early stage of acceleration like the LES results of Jung and Chung. Remember that the present results are taken from one dimensional code, so they are much faster than the LES codes.

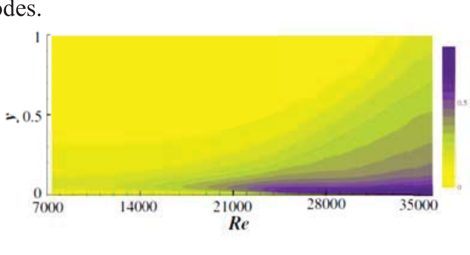


**Fig. 1 Distribution of normalized axial velocity fluctuations (LES Results) (Re = 7000 – 35000, T=3.8 sec)**

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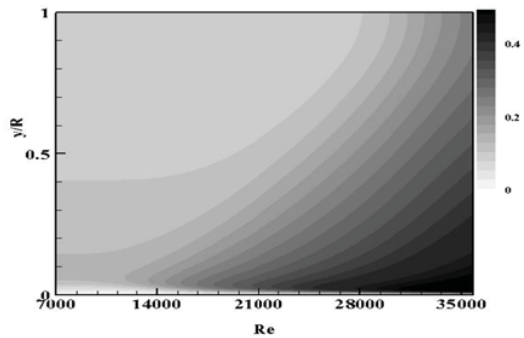


**Fig. 2 Distribution of normalized turbulence kinetic energy (k-ε-v2 results) (Re = 7000 – 35000, T=3.8 sec)**

## 3- Conclusion

In this paper, linear accelerated turbulent pipe flow has been simulated at various Reynolds numbers using five common turbulence models. A closer study of the efficiency and reliability of these models in predicting the wall shear stress, Reynolds stress, turbulence viscosity and mean velocity was desired. In order to verify the results, experimental and numerical (turbulence modeling and Large Eddy Simulation) results of the other researchers were employed. The results of this study are as follows:

- Delay in the response predicted by turbulent models (except BL Model) was relatively in good agreement with experimental data.
- Comparing the distribution of mean velocity, turbulent kinetic energy and turbulent viscosity showed that k-ε-v2 model has better accuracy than the other models.
- Shear stress showed nonlinear behavior during linear acceleration.
- Comparing quantities like mean velocity, turbulent kinetic energy and its production term with the corresponding results of Large Eddy Simulations and experiments showed the accuracy of one-dimensional models (except Model BL) at accelerated turbulent flows.
- One-dimensional turbulence models (except BL Model) can be used as an appropriate tool for accelerating turbulent pipe flow predictions compared to the other costly procedures such as Large Eddy Simulation and experiments.