Assessment of RANS Turbulence Models for Turbulence-Induced Secondary Flows

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1. Introduction

Secondary flow plays an important role correctly interpreting the turbulent flow in the bundle by using RANS methods [1]. The secondary flow in the turbulent flow has been of significant interest to many researchers since it was studied by Prandtl. The secondary flow can be divided into two cases, which are usually caused by shape or external force, and those caused by the asymmetry of the turbulent flow. In the flow inside a bare rod bundle (i.e. rod bundle without grid spacer), the secondary flow due to the asymmetry of the turbulent flow occurs. The turbulent duct is a representative flow that has secondary flow due to asymmetric turbulence. We are to contribute to the development of the RANS methodology to accurately analyze the turbulent flow in the bare rod bundle. As a first step, in the present study we investigate the prediction capability of RANS turbulence models for turbulent flow in a square duct.

2. Numerical methods

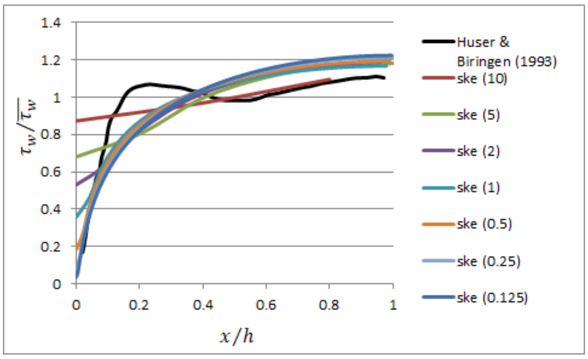
In the present study, several RANS models including three types of k-e models (standard k-ε, RNG k-ε, realizable k-e), two types of k-w models (standard k-w, SST), and Reynolds stress model (RSM) are considered in order to perform a comprehensive assessment of prediction capability of RANS models for turbulent secondary flow. As the RSM model, the LRR version is considered.

Because the results from RANS models are dependent on the numerical accuracy, we are also to perform grid resolution studies for each RANS model. Otherwise, we may not evaluate well the performance of RANS models because the uncertainties of the model and numerical accuracy could be compensated.

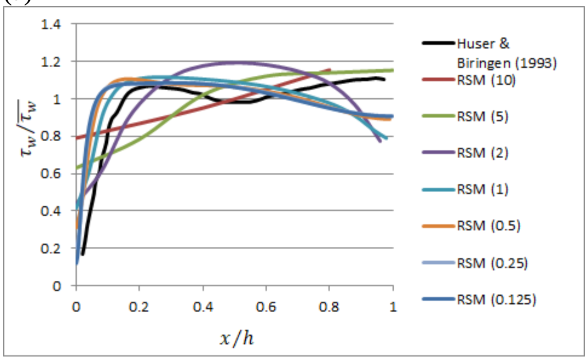
In the present study, the calculations by using turbulence models are based on ANSYS Fluent. All the calculations are steady RANS ones. For the spatial discretizations, the second-order scheme is adopted for the convection, whereas the first-order scheme is adopted for the terms related to the turbulence quantity.

3. Numerical results

Fig. 1 shows the skin friction distributions along the wall in a square duct. For comparison the previous DNS data [2] are included. As shown in Fig. 1, the skin friction near the corner (x=0) is increased due to the presence of the secondary vortex. In Fig. 1, the number in the parentheses means the grid size along the width. Here, the width of the square duct is 50mm. Fig. 1 shows that the SKE fails to predict the increase of the skin friction near the corner. On the other hand, the RSM shows a reasonable agreement with the previous DNS data. These behaviors from the RANS models could be understood from the investigation of the secondary flows.



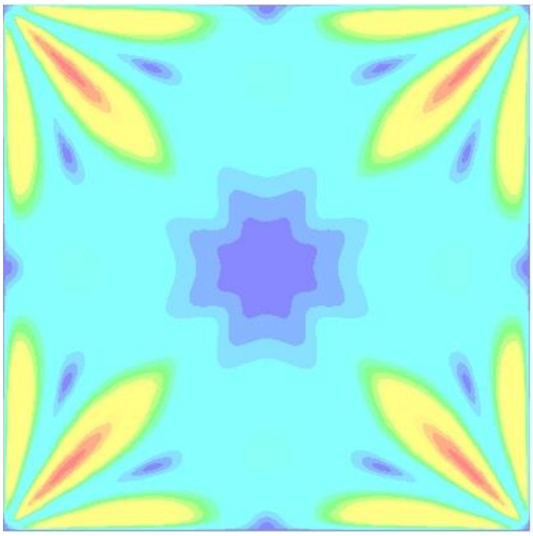
(a)



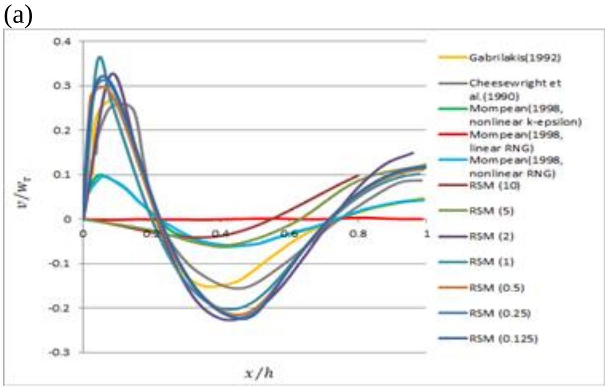
(b)

Fig. 1. Skin friction distributions from (a) standard k-e model and (b) Reynolds Stress model (RSM).

Fig. 2 shows the RSM model results for the secondary flow. Except for the RSM model, all the other models fail to predict the secondary flow as well known in the literature (not shown here). As shown in Fig. 2(a), the RSM model show the reasonable prediction of the secondary flow pattern. As in the literature, along with the corner bisector, the secondary flow magnitude has



(a)



(b)

Fig. 2. RSM results of (a) Contour of secondary flow magnitude and (b) the secondary flow profiles at y/h=0.5. Here, h is half width of the square duct.

higher values. Also, the position of the secondary flow is in good agreement with that observed in [2].

To see the RSM model prediction capability for the secondary flow in more detail, the secondary flow profiles are also presented in Fig. 2(b). As shown in Fig. 2(b), the RSM model show good agreement with the DNS results [2] and other RANS results found in the literature.

4. Conclusions

In the present study, the prediction capability of RANS models for turbulent secondary flow is investigated. Several RANS models including three types of k-e models (standard k-ε, RNG k-ε, realizable k-e), two types of k-w models (standard k-w, SST), and Reynolds stress model (RSM) are considered in order to perform a comprehensive assessment of the prediction capability of RANS models for turbulent secondary flow. Also, in order to minimize the effect of numerical accuracy, the grid resolution studies are performed in a comprehensive way.

All the linear eddy viscosity models considered in the present study failed to predict the skin friction distributions. On the other hand, the RSM, which is nonlinear model, shows a reasonable agreement with the DNS data in the literature. This is attributed to the fact that the secondary flow is well predicted by the RSM model, but is not predicted by the linear eddy viscosity model.

In the talk, the details of the RANS results including the Reynolds stresses would be presented.

ACKNOWLEDGEMENT

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REFERENCES

[1] E. Baglietto and H. Ninokata, A turbulence model study for simulating flow inside tight lattice rod bundles, Nuclear Engineering and Design, Vol. 235, pp. 773-784, 2005.
[2] A. Huser and S. Biringen, 1993, Direct numerical simulation of turbulent flow in a square duct, Journal of Fluid Mechanics, Vol. 257, pp. 65-95.
[3] B. E. Launder, G. J. Reece and W. Rodi, 1975, Progress in the development of a Reynolds stress turbulence closure, Journal of Fluid Mechanics, Vol.68, pp. 537-566.