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Numerical Study of Mixing in Shear Layers

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ABSTRACT

This paper describes the numerical analysis of the mixing phenomena based on shear layers in a rectangular duct. The shear flow between two parallel streams of flows in the same rectangular duct divided into two zones is analyzed. Then, the effect of variation of velocities and flow directions in the above model is analyzed and discussed.

Three different cases have been studied in this analysis. A simple rectangular duct is used where two flows of velocities in same and different proportions and along with same and different directions are studied. After going through sample simulations using various turbulence models, the numerical analysis was carried out using the SST $k - \omega$ model as it gave better results. The results indicate that asymmetry in velocity and direction leads to better mixing. The case where the two flows having velocities 5 m/s and 10 m/s were simulated with their direction being different, the estimated turbulent kinetic energy was highest for this case with a maximum value of 3 m^2/s^2

KEY WORDS: Numerical, Layers.

1. INTRODUCTION

Mixing is a phenomenon that we come across every day. There is mixing starting from the kitchen and it goes up to the high level combustion chambers of aircraft gas turbine engines and rocket motors. Mixing of two streams of airflow in the right proportion and time is the basis of noise suppression in gas turbine engines. Further, fluid mixing is required at several other chemical and biological labs and during welding for shield gases.[1-6]

Shear layer plays an important role in mixing. The layer between flows of different velocities is known as a shear layer. The flow in this region is turbulent. Mass moves across this layer as the level of turbulence spreads throughout and it is known as mass entrainment.

Model for Analysis: The model that will be used for analysis is determined here. It is a rectangular duct of 10 cm length and 2 cm breadth. The duct has a velocity inlet at the left side and the outlet on the other side. The entire duct is separated into two zones, the upper zone and the lower zone. The conditions of velocity inlets for the zones can be set up separately. The meshed view of the model shown below.

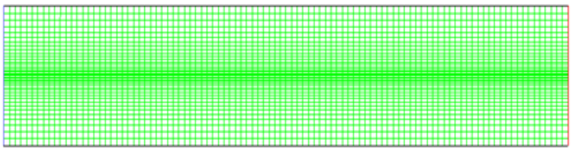

Figure.1. Meshed view of the model

Cases Studied: Using the model that has been designed and meshed for the problem, some special cases are analysed. The cases analysed are as follows,

Case I: Both the upper and lower zones having same velocity and same direction flows

Case II: The upper and lower zones having same direction but different velocity in the ratio of 2:1

Case III: Both the upper and lower zones having different velocities and opposite direction in the ratio of 2:1

Turbulence Model: A two dimensional model is sufficient for analysis for this case. Since, mixing is the main parameter to be studied here, models based on eddy viscosity would give better results. SST $k - \omega$ is an eddy viscosity based model that can be used for two dimensional analysis. SST $k - \omega$ is a combination of two well used formulations. Here, a $k - \omega$ model is used for the inner region of the boundary layer and hence it can be used throughout the viscous sub layer up to the wall. Whereas, when a freestream is encountered, the formulation changes over to a $k - \varepsilon$ model to avoid the problems encountered in using $k - \omega$ model for the freestream conditions.

SST $k - \omega$ is very good in the prediction of flows involving adverse pressure gradients and separation.

2. RESULTS

Case I (Same Velocity and Same Direction): The turbulence intensity contour shows that turbulence is not much predominant. The turbulence levels are very low in this case.

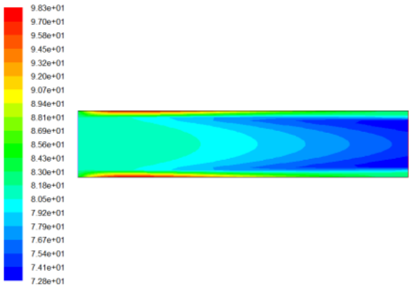

Figure.2. Turbulence Intensity Contour for Case I

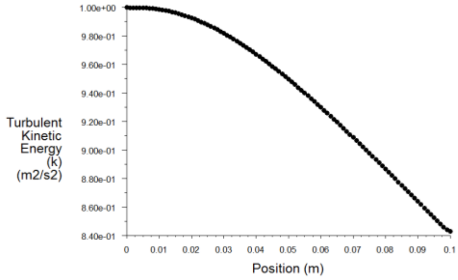

Figure.3. Turbulence Kinetic Energy Plot for Case I

It is clearly seen that the interaction at the beginning produces high turbulent kinetic energy but as the length increases the turbulent kinetic energy decreases due to dilution of the flow.

Case II (Different Velocity and Same Direction): Here both the upper and the lower streams flow in the same direction but at different velocities in the ratio of 2:1. Due to the difference in velocities, we can assume appreciable mixing in the duct.

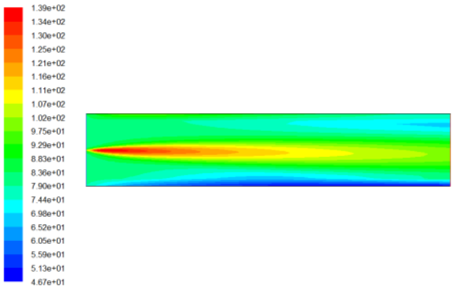

Figure.4. Turbulence Intensity Contour for Case II

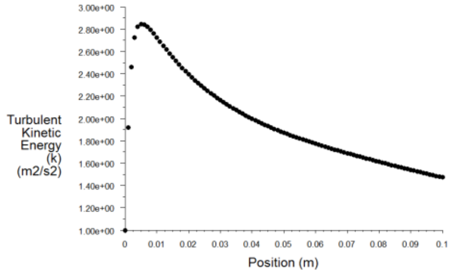

Figure.5. Turbulence Kinetic Energy Plot for Case II

The high kinetic energy at the beginning of the flow suggests the rapid interaction of the two flows near the inlet and their progressive reaction as the flow continues in the duct.

Case III (Different Velocity and Different Direction): There is high amount of mixing and shear. This is mainly due to the direction of the flows.

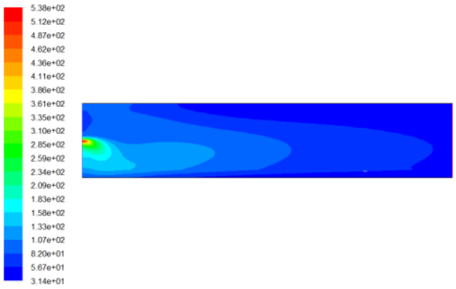

Figure.6. Turbulence Intensity Contour for Case III

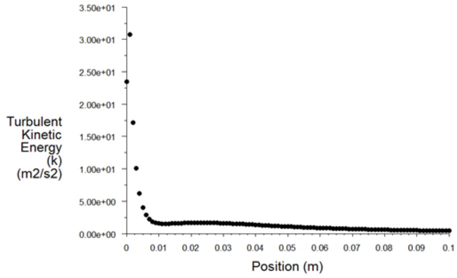

Figure.7. Turbulence Kinetic Energy Plot for Case III

3. CONCLUSION

Different types of models were analyzed before selecting a particular model for the problem. It was found out that the SST K-Omega gives better results for compared to the others in terms of quality, accuracy and speed. Analysing the different cases of the problem, gave us an insight to the magnitude of mixing under different boundary conditions.

Under the case I, the case where both the upper and lower streams have same velocity and flow in the same direction, the mixing was quite inappropriate with very less amount of mixing and no free shear layers which would be inappropriate for high mixing ratios. In case II, where the upper and lower streams flowed in the same direction but have different velocities of the ratio of 2:1. This case showed better mixing compared to case I, as the streams flowed at different velocities which gave better chances of mixing with higher turbulent intensity and turbulent kinetic energy with appreciable mixing compared to case I.

In case III, where the upper and lower streams flow in opposite directions and at different velocities in the ratio of 2:1. This case showed the best mixing of all the cases. It showed the highest values of turbulence intensities and turbulent kinetic energy values and highest mixing for the flow in the duct.

It is concluded that for high efficient mixing case III is the good option out of the three cases and if moderate mixing is required then case II can be implied.

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