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Mean Flow Compressibility Effects in Transonic Turbulence Modeling

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ABSTRACT

The mean flow compressibility effects greatly influence the behavior of turbulent flows, as long as the flow is compressible. The fact is even though Favre average has taken into account the variation of the density, less accurate CFD results are always obtained when the flow is compressible. Thus, many compressibility corrections are made for high Mach number flows. As for the transonic turbulence flow, the mean flow compressibility effects are not mentioned. In this paper, it is demonstrated that the mean flow compressibility effects are not ignorable in transonic flows on some flow features. The mean flow compressibility effects are taken into account by introducing a characteristic turbulence length scale. The key is a new definition of vorticity by the curl of momentum. A compressible von Kármán length scale is introduced to obtain a new turbulence model CKDO (Compressible Kinetic Dependent Only) for complex compressible flows on the basis of the KDO. The only two empirical coefficients in the KDO model are not changed, which were calibrated by a slice of the incompressible flat plate boundary layer flow. Numerical simulations of transonic flows around RAE2822 airfoil, axisymmetric bump pipe and ONERA-M6 wing show that compressibility is non-negligible, and the new length scale definition can improve the prediction accuracies of aerodynamic features, such as the onset locations of shock waves, skin friction and pressure coefficients.

Keywords: turbulence model; Reynolds stress; transonic flow; compressibility

1. Introduction*

The everlasting demands for higher speed, lower drag, lower cost and lower noise level make the aircraft geometry and the flight environment become increasingly complex. There are mean flow density variation, shock waves, vortices, separations and other complex flow structures due to the interactions among them. These complex flow interactions have had a significant impact on the aerodynamic characteristics of the aircraft [1]. In special, the sensitivity of shock onset location in transonic flows is crucial to the total aerodynamic features. The adaptability of traditional turbulence models to these complex flows is quite limited, and the values between model prediction and experimental test are sometimes considerably different. The research of transonic turbulence has become a hotspot with great difficulty in the field of CFD research and application.

S. Bourdet et al. [2] obtained the DNS data of the NACA 0012 airfoil and investigated the transonic flow characteristic of the wing under three dimensional situations. Lien and Kalitzin [3] used the v^2-f turbulence model to deal with transonic flow problems with the RAE2822 airfoil. The pressure coefficients of the CFD simulation agreed well with the experimental data, but the friction coefficients deviated from the experimental value. Wu et al. [4] simulated the flows passing over the NACA0012 airfoil and the ONERA-M6 wing under transonic conditions using the SA [5] and the SST [6] turbulence model. The results showed that both of the turbulence models yielded accurate predictions of pressure distributions. However, the airfoil surface friction coefficient distributions were not given. In this paper, the same wing models are used to perform the numerical simulations with the same turbulence model. It is found that there exist huge differences between the predicted and experimental skin friction distributions, which leads us to improve incompressible RANS models for more accurate skin friction predictions.

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