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A Multiscale-Domain Decomposition Method for High Reynolds Number Flows

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Abstract

The high Reynolds number flow contains a wide range of length and time scales, and the flow domain can be divided into several sub-domains with different characteristic scales. In some sub-domains, the viscosity dissipation scale can only be considered in a certain direction; in some sub-domains, the viscosity dissipation scales need to be considered in all directions; in some sub-domains, the viscosity dissipation scales are unnecessary to be considered at all.

For laminar boundary layer region, the characteristic length scales in the streamwise and normal directions are L and $L\,\mathrm{Re}^{-1/2}$, respectively. The characteristic length scale and the velocity scale in the outer region of the boundary layer are L and U, respectively. In the neighborhood region of the separated point, the length scale $l << L$, the velocity scale $u << U$, and $ul/n = O(1)$. In the light of this reason there exists a great disparity of the grid Reynolds numbers $R_{\Delta x_i}$ between different cells in Navier-Stokes (NS) equations computations for high Reynolds number flows, an idea of solving the conservation equations for discrete cells was proposed and named the discrete fluid dynamics (DFD) algorithm. Analysis shows that the basic conservative equations for discrete cells are the Euler equations, NS- and diffusion parabolized (DP) NS equations.

In this paper, a new multiscale-domain decomposition method is developed for the high Reynolds number flow. First, the whole domain is decomposed to different sub-domains with the different characteristic scales. Then the different dominant equation of all sub-domains is defined according to the diffusion parabolized (DP) theory of viscous flow. Finally these different equations are solved simultaneously in whole computational region.

For numerical tests of high Reynolds numerical flows, two-dimensional supersonic flows over rearward and frontward steps as well as an interaction flow between shock wave and boundary layer were solved numerically. The pressure distributions and local coefficients of skin friction on the wall are given. The numerical results obtained by the multiscale-domain decomposition algorithm are well agreement with those by NS equations. Comparing with the usual method of solving the Navier-Stokes equations in the whole flow, under the same numerical accuracy, the present multiscale domain decomposition method decreases CPU consuming about 20% and reflects the physical mechanism of practical flow more accurately.

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