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论文

Navier-Stokes方程二阶速度滑移边界条件的检验

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摘要 对微尺度气体流动，Navier-Stokes方程和一阶速度滑移边界条件的结果与实验数据相比，在滑移区相互符合，在过渡领域则显著偏离. 为改善Navier-Stokes方程在过渡领域的表现，有些研究者尝试引入二阶速度滑移边界条件，如Cercignani模型, Deissler模型和 Beskok-Karniadakis模型. 以微槽道气体流动为例，将Navier-Stokes方程在不同的二阶速度滑移模型下的结果与动理论的直接模拟Monte Carlo(DSMC)方法和信息保存(IP)方法以及实验数据进行比较. 在所考察的3种具有代表性的二阶速度滑移模型中，Cercignani模型表现最好，其所给出的质量流率在Knudsen 数为0.4时仍与DSMC和IP结果相符；然而，细致比较表明，Cercignani模型给出的物面滑移速度及其附近的速度分布在滑流区和过渡领域的分界处(Kn= 0.1)已明显偏离DSMC和IP的结果.

关键词 二阶速度滑移模型 微槽道流动 DSMC方法 IP方法

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Assessment of second-order velocity-slip boundary conditions of the navier-stokes equations

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Abstract

For micro-scale gas flows, the Navier-Stokes equations with first-order velocity slip boundary conditions give results that agree with experimental data in the slip regime, but differ obviously in the transitional regime. Second-order velocity-slip boundary conditions were introduced to improve the performance of the Navier-Stokes equations in the transitional regime. This paper considers two-dimensional gas flows through microchannels for which the Navier-Stokes solutions based on different second-order velocity-slip boundary conditions suggested by Cercignani, Deissler, Beskok and Karniadakis, respectively, are compared with the kinetic results given by the information preservation (IP) method, the direct simulation Monte Carlo (DSMC) method, and experimental data. It is shown that the Cerciganani model performs best among the three second-order models we examined, and its mass flow rate agrees with the DSMC and IP results even at the Knudsen number of 0.4. However, a careful examination of the slip velocities and velocity distributions at and around the channel surfaces given by the Cercignani model demonstrates that they considerately deviate from those given by the DSMC and IP methods at the Knudsen number of 0.1, that is generally regarded as a critical value to divide the slip and transitional regimes.

Key words microflow velocity slip DSMC IP

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