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Modeling of Viscous Shock Tube Using ES-BGK Model Kinetic Equations

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The viscous effects on unsteady shock wave propagation are investigated by numerical solution of the Boltzmann model kinetic equations. The kinetic equations are solved for two unsteady non-equilibrium flow problems, namely, the one-dimensional Riemann problem and a two-dimensional viscous shock-tube. The numerical method comprises the discrete velocity method in the velocity space and the finite volume discretization in physical space using various flux schemes. The discrete version of H-theorem is applied for analysis of accuracy of the numerical solution as well as of the onset of non-equilibrium. Simulations show that the maximum entropy generation rate in viscous shock tube occurs in the boundary layer / shock wave interaction region. The entropy generation rate is used to determine the time-variation of the speed of propagation of shock, contact discontinuity and rarefaction waves.

I. Introduction

Shock wave propagation in microscale geometries has been a subject of renewed interest recently due to challenges and opportunities arising with advances in microsystems. Many macroscale sensors and devices such as pumps, valves and engines have been implemented in mesoscale and microscale versions using the Micro-Electro-Mechanical Systems (MEMS) fabrication techniques for silicon and, more recently, metallic materials. To date, most of such microsystems involving a gas as the working fluid are based on low-speed flow phenomena. Exploitation of compressible flow mechanisms can potentially increase performance of microdevices. For example, micro wave rotor concept has been suggested in Ref.[1] as a higher compression-efficiency alternative to spool microcompressors. Microscale pulsed detonation engine[2] has been recently demonstrated and may be used to provide power densities higher than the combustion-based microthrusters.Additionally, a break-down of chip-level vacuum packaging for MEMS components involves the propagation of an initial pressure discontinuity through a planar micron-sized enclosure. Such applications of unsteady, high-speed flows in microsystems requires improved understanding of supersonic flows at microscale.

The problem of shock wave propagation in low pressure gas is dynamically similar to that at microscales if the surface roughness effects are negligible. The low-pressure shock tubes have been investigated starting as early as 1950s. The early experiments on shock wave propagation in low-pressure gases have demonstrated several important aspects of such flows, i.e. shock speed attenuation that becomes more prominent as the pressure decreases. A model was proposed by Duff[3] to account for the lower shock strength achievable for a given diaphragm pressure. Duff's model assumes that the flow between the contact discontinuity and shock wave is isentropic and, thus, does not include viscous effects explicitly and predicts the shock strength that is independent of the size of the tube (or Knudsen number). Recently Brouillette[4] revisited the shock wave propagation in viscous regime and developed a quasi one-dimensional theory for the shock attenuation including the effects of friction. Based on this model, the speed of propagation of flow perturbations is scale dependent and can be slower than the isentropic speed of sound. Zeitoun *et al*[5] studied the shock wave propagation in low-pressure shock tubes based on kinetic and continuum approaches. The

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