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NUMERICAL SIMULATIONS OF SHOCK WAVE REFLECTION FROM THE STRAIGHT WEDGE WITH A CONCAVE TIP

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ABSTRACT

Shock wave reflection from obstacles is an important research area because of its relevance to a wide range of applications. Regular reflection (a two-shock configuration) and Mach reflection (a three-shock configuration) lead to significantly different dynamic and thermal loads, and, therefore, it is important to predict the transition between them. In the case of shock reflection from a straight wedge the transition from regular to Mach reflection happens close to the sonic/detachment angle. However, if a concave cylindrical tip is attached to the straight wedge, the transition is delayed and occurs closer to the von Neumann angle. This effect was first discovered via inviscid numerical simulations, followed by experimental confirmation in shock tube experiments with optical visualization for the concave tip radii as small as a few millimeters. However, the experiments did not fully agree with the inviscid numerical modeling. It may be conjectured that these disagreements may be related to viscous effects, which manifest themselves in the finite shock front thickness and the growth of boundary layers on solid surfaces.

The present paper is the first step toward the numerical investigation of the influence of viscous effects on the shock reflection from straight wedges with concave tips. The governing equations are the Navier-Stokes equations for flows of an ideal gas with constant specific heats. The computational domain is discretized with an unstructured grid composed of triangular elements. Finite volumes are established around grid nodes. The inviscid fluxes are calculated using the MUSCL-Hancock TVD scheme with an exact Riemann solver, and central differences are used for the viscous fluxes. A predictor-corrector approach is used for numerical integration in time. The scheme is of the second order in space and time. During computations, transient refinement-coarsening (h-refinement) is used at shock wave fronts, contact and tangential discontinuities, and boundary layers. The developed code was validated with a few test problems with analytical solutions, such as a standing normal shock and a boundary layer on a flat plate.

The described Navier-Stokes flow solver and its Euler (inviscid) version were used to simulate shock reflection from wedges with concave tips for the conditions corresponding to available experimental data. The Navier-Stokes simulations were performed both with the non-slip and slip boundary conditions. The comparison of experimental schlieren images and numerical results for these physical models allows us to shed new light on the influence of viscous effects on the shock wave reflection process under study.