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NAVIER-STOKES SIMULATIONS OF SHOCK WAVE REFLECTION FROM THE AXIS OF SYMMETRY

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ABSTRACT

Axisymmetrical supersonic internal and external flows are found in many aerospace applications, including the intake, nozzle, and jet flows of air-breathing propulsion systems. Such flows typically feature shock waves that converge towards the axis of symmetry and reflect from it. It is well-established that under the inviscid flow model (shocks are treated as discontinuities), shock reflection from the axis of symmetry is always of a Mach (three-shock) type consisting of the incident and reflected shocks and a nearly normal shock (Mach disk) at the axis of symmetry. Regular (two-shock) reflection cannot occur. However, in some experiments and numerical simulations, seemingly regular reflection from the axis of symmetry was observed. This may happen for various reasons. One of them is the influence of viscous effects when the size of Mach disk becomes comparable with shock wave thickness.

The present study is aimed at the investigation of the influence of shock thickness on the shock reflection from the axis of symmetry. The main research tool is numerical simulations using the Navier-Stokes equations. Since in the literature there are various, somewhat different, versions of the axisymmetrical Navier-Stokes equations, the governing equations were re-derived in an integral form particularly suitable for finite-volume numerical methods. The computational domain was discretized with an adaptive unstructured grid composed of triangular elements. Finite volumes were established around grid nodes. The inviscid fluxes were calculated using the MUSCL-Hancock TVD scheme with an exact Riemann solver and central differences were used for the viscous fluxes. A predictor-corrector approach is used for numerical integration in time. The developed code was validated with a few test problems. For example, a standing normal shock was simulated to demonstrate, via comparison with the analytical solution, that the shock profile is correctly reproduced by the code when grid convergence is achieved.

The developed flow solver was then used to simulate an axisymmetric wedge-generated supersonic internal flow. Since the main interest was in the reflection of the generated shock from the axis of symmetry, the boundary layer on the wedge was not considered (slip boundary condition was used). The numerical results were compared with the numerical simulations using the Euler (inviscid) equations. It was demonstrated that in some cases, depending on the Reynolds number, the Navier-Stokes solver produces the flow structure resembling a regular reflection, while the Euler model results in a Mach reflection.