Assessment of Flux Evaluation Methods and Turbulence Models for Viscous Hypersonic Flows.

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Keywords: Hypersonic, Turbulence, Computational Fluid Dynamics.

ABSTRACT

Efficient and accurate computation of aerodynamics and thermal environment of hypersonic vehicle is essential in their design and development of hypersonic vehicles. Computational fluid dynamics methods have gain significant prominence in recent years and have been used in hypersonic vehicle design; however, a number of challenges remain, including the prediction of the laminar to turbulent transition as well as the turbulent flow field development are active areas of research at present. Furthermore, substantial challenges exist in devising accurate and robust numerical schemes for the convective flux computation of Navier-Stokes solvers. Popular approximate Riemann solvers for transonic and supersonic flow simulation, e.g. the Roe scheme [6], have shown deficiencies, such as over-expansions and oscillations around the sonic line, fig. 1. For this reason, improved schemes have been developed.
In recent years the AUSM family has been widely used in hypersonic CFD. The original AUSM scheme has been introduced for the first time by M.-S. Liou in [2] and then improved in [3] to obtain the AUSM+. Recently Liou [4] extended the AUSM-family schemes to solve flows at all speed regimes with the AUSM+up family of schemes. One of the key points of the AUSM+up scheme is the choice of the interface speed of sound.
The present work involves a systematic analysis of the Roe and AUSM+up family of schemes for a range of generic hypersonic test cases. The work focuses on two main aspects. The first is the behaviour of these scheme in the laminar and turbulent flow regimes. The second part of the work involves the analysis of different compressibility corrections to the two-equation $k - \omega$ [9], SST [5] turbulence model as well as the one-equation Spalart-Allmaras model [8]. Turbulence modelling remains a great challenge in the hypersonic flow simulation, as a major source of errors in the prediction of aerodynamic forces and heat transfer. Turbulence models are commonly used for incompressible flows but for high Mach flows compressibility corrections are needed. From the review paper of Roy [7] it is clear that a lot of work has been done in order to validate the different turbulence models for simple hypersonic flows but studies are still needed to validate these models for more complex cases such as Edney Types shock/shock iterations [1] and boundary layer iterations.
Figures 2, 3, 4 and 5 show examples of results obtained for an infinite cylinder ($R = 1$). The results show that for cases with even a week expansion, the use of the entropy satisfying interface speed of sound it is needed. Results are presented with the AUSM+up scheme, for inviscid and laminar flow ($Re = 25000$), and 4-stage Runge-Kutta method in time with a CFL of 0.25 was used. Further investigations include more complex flow fields such as Edney types shock/shock interaction and shock/boundary layer interaction and these are discussed a the full paper.

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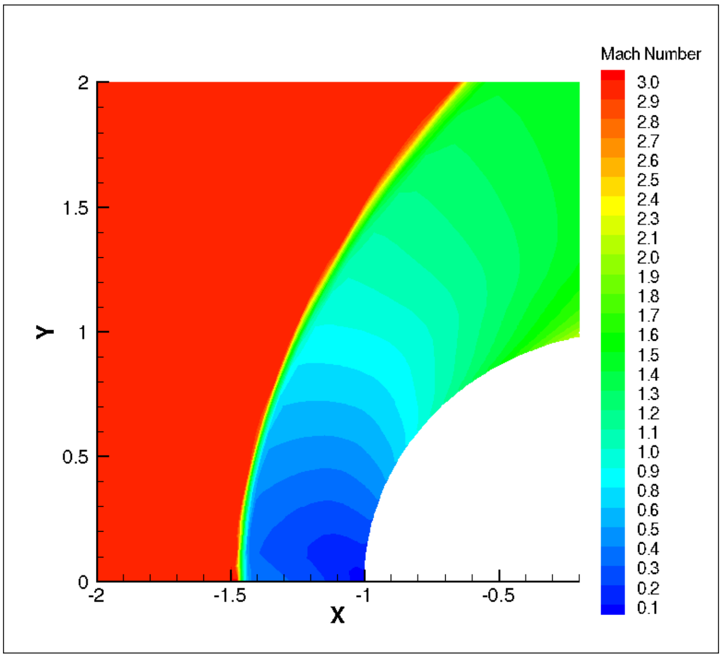

Figure 1: Infinite cylinder inviscid case. The flow was computed using the Roe scheme, 4-stages Runge-Kutta, $CFL = 0.05$ and $M = 3$.

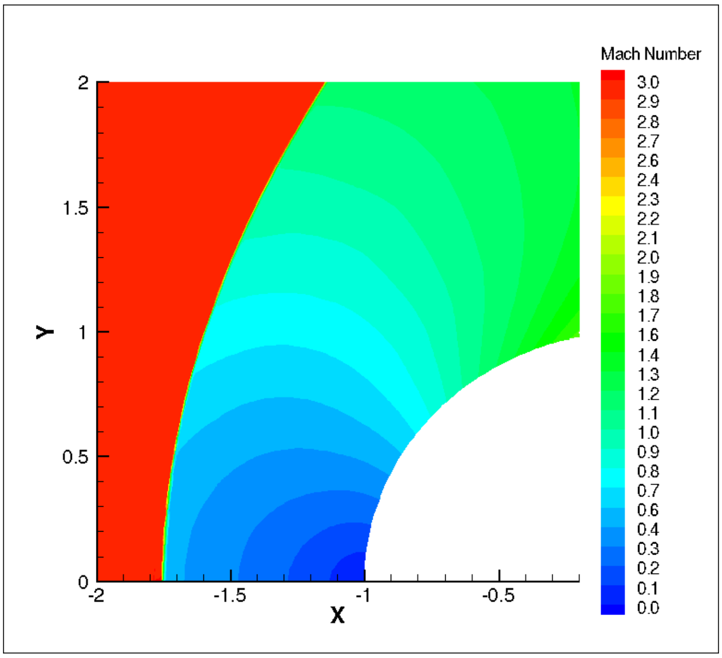

Figure 2: Infinite cylinder inviscid case. The flow was computed using the AUSM+up with entropy satisfying $a_{1/2}$, 4-stages Runge-Kutta, $CFL = 0.5$ and $M = 3$.

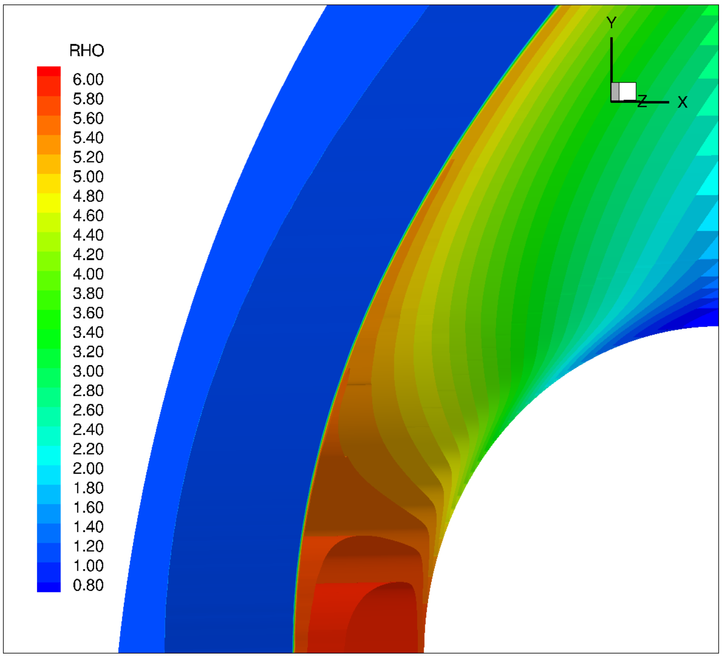

Figure 3: Infinite cylinder laminar case. The flow was computed using the AUSM+up with entropy satisfying $a_{1/2}$, 4-stages Runge-Kutta, $CFL = 0.25$ and $M = 10$. RHO is the dimensionless density $(\frac{\rho}{\rho_\infty})$.

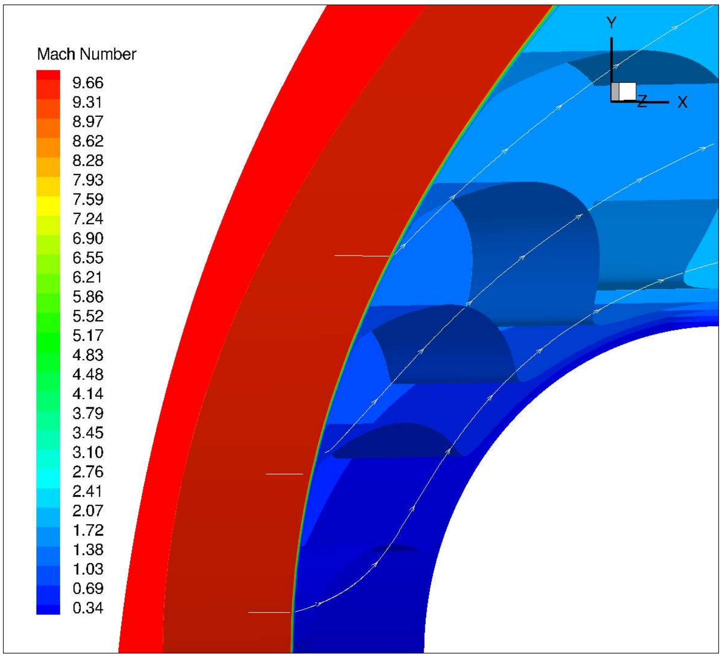

Figure 4: Infinite cylinder laminar case. The flow was computed using the AUSM+up with entropy satisfying $a_{1/2}$, 4-stages Runge-Kutta, $CFL = 0.25$ and $M = 10$. Mach iso-surfaces.

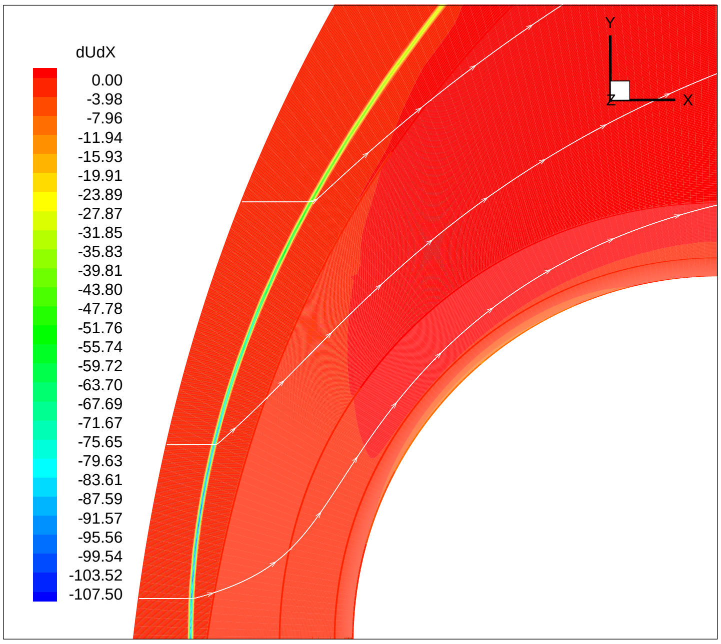

Figure 5: Infinite cylinder laminar case. The flow was computed using the AUSM+up with entropy satisfying $a_{1/2}$, 4-stages Runge-Kutta, $CFL = 0.25$ and $M = 10$.

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