11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20–25, 2014, Barcelona, Spain

THE INITIAL–BOUNDARY RIEMANN PROBLEM FOR THE SOLUTION OF THE COMPRESSIBLE GAS FLOW

Martin Kyncl[1] and Jaroslav Pelant[2]

[1] Aerospace Research and Test Establishment,
VZLÚ, Beranových 130, 199 05 Praha - Letňany, Czech Republic, kyncl@vzlu.cz
[2] Aerospace Research and Test Establishment,
VZLÚ, Beranových 130, 199 05 Praha - Letňany, Czech Republic, pelant@vzlu.cz

Key words: *Compressible Gas Flow, the Riemann problem, Boundary Conditions.*

Undoubtedly, the boundary conditions plays important role in the computational fluid dynamics (CFD). We work with the system of equations describing non-stationary compressible turbulent fluid flow, i.e. the Reynolds-Averaged Navier-Stokes (RANS) equations in 2D and 3D. We focus on the numerical solution of these equations, and on the boundary conditions. We suggest the original approach to the boundary conditions. The aim is to satisfy the conservation laws in the close vicinity of the boundary. Usually, the boundary problem is being linearized, or roughly aproximated. The inaccuracies implied by these simplifications may be small, but it has a huge impact on the solution in the whole studied area, especially for the non-stationary flow. In our approach we try to be as exact as possible. Therefore we use the analysis of the so-called Riemann problem for the 2D/3D split Euler equations in order to construct the boundary values (for the density, velocity, pressure). We solve the boundary modifications of this initial-value problem. We show the analysis leading to our results using the well-known finite volume method (FVM) to discretize the analytical problem, represented by the system of the equations in generalized (integral) form. To apply this method we split the area of the interest into the elements, and we construct a piecewise constant solution in time. The crucial problem of this method lies in the evaluation of the so-called fluxes through the edges/faces Γ_{ij} of the particular elements. The state values in the vicinity of the edge Γ_{ij} are known at time instant t_k, and these values form the initial conditions (LIC - left-hand side, and RIC - right-hand side) for the so-called Riemann problem for the 2D/3D split Euler equations. The exact (entropy weak) solution of this problem cannot be expressed in a closed form, and has to be computed by an iterative process (to given accuracy). Therefore various approximations of this solution are usually analyzed. At the boundary faces we deal with the local modified Riemann problem, where the LIC is given, while the RIC is not known. In some cases (far field boundary) it is wise to choose the RIC here as the solution of the local Riemann problem with given far field values, which gives better results than the solution of the linearized Riemann problem, see [1]. Another boundary condition based on the exact Riemann problem solution, simulating the impermeable wall on move, was shown in [3, pages 221-225], where the RIC is constructed in a special way, in order to obtain the desired solution. Using the analysis of the Riemann problem we show, that the RIC for the local problem can be partially replaced by the suitable complementary condition. Some of the suggested boundary conditions were shown in [2] (by preference of pressure, temperature, velocity,...). Here we focus on the inlet boundary condition conserving the total quantities and the direction of the velocity. We complement the boundary problem suitably, and we show the analysis of the resulting uniquely-solvable modified Riemann problem. We construct own algorithm for the solution of this boundary problem. It can be used within various methods in CFD. The algorithm was coded and used within our own developed code for the solution of the compressible gas flow (the Euler, NS, and RANS equations). Numerical examples show superior behavior of the suggested boundary conditions. In the presented example we show the boundary condition conserving the total pressure, the total temperature, and the direction of the velocity. The part of the inlet flow is supersonic. It can be seen in figure 1. (left), that the used inlet boundary condition does not reflect the shock waves into the computational area. Right picture shows that this boundary condition can be used on the shortened computational domain with the similar result. Constructed boundary conditions are robust and accelerate the convergence of the method. This is the original result of our work.

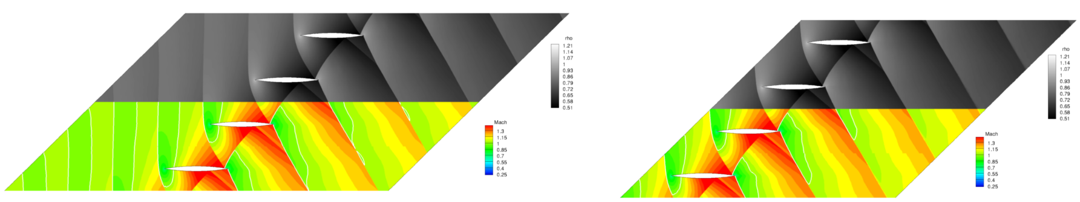

Figure 1: The compressible gas flow, transonic regime. Two computations with the same boundary data. The right picture shows the computation with the shortened inlet part. Inlet located left. Pressure isolines, density and Mach number isolines, highlighted Mach number 1.

REFERENCES

[1] V. Dolejší: Discontinuous Galerkin method for the numerical simulation of unsteady compressible flow. *WSEAS Transactions on Systems,* **5(5)**,1083–1090, 2006.

[2] M. Kyncl: Numerical solution of the three-dimensional compressible flow. Doctoral Thesis, Charles University, Prague, 2011.

[3] E. F. Toro: *Riemann Solvers and Numerical Methods for Fluid Dynamics.* Springer, Berlin, 1997.