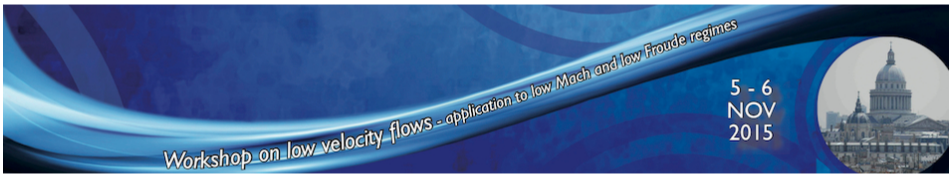

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A Low-Mach solver for the Euler equations allowing for gravity source terms

The Euler equations of inviscid hydrodynamics in the presence of a gravity g admit static non-vanishing solutions (called hydrostatic equilibria) and for $g = 0$ they converge towards an incompressible flow for $M \longrightarrow 0$, $t > 0$.

The inability of many solvers, initially devised to capture shocks and other supersonic features, to capture the low Mach regime is a challenging problem. Apart from the explicit time integration inforcing time steps $\in O(M)$ for stability and thus making simulations time-expensive, it has been found that the schemes'diffusion grows typically as $O(1/M)$. Therefore even an implicit integration M
in time has to overcome this additional problem. The issue has been so far addressed in a variety of different manners.

The focus of this work lies on Roe-type schemes, which, given the physical flux function f(q) define the interface flux as
$f(i+1/2) := 1/2(f(q(i+1)) + f(q(i))) - 1/2D(q(i+1) - q(i))$
Given the Jacobian $A = f'$, the usual Roe scheme is obtained by setting $D = |A|$, evaluated in a suitable mean state between q(i) and q(i+1).

The artificially high diffusion in the low Mach regime coming from the matrix D, modifications have been found (Weiss & Smith 1995, Turkel 1999) that lead to schemes able to resolve the low Mach limit for homogeneous Euler equations. They replace D by $P{-}1|PA|$ for suitable invertible matrices P, and are called preconditioned schemes mainly for historical reasons.

We show that when gravity source terms are included, these schemes are not asymptotic preserv- ing, and thus are unable to display their low Mach properties when applied to a gas in hydrostatic equilibrium. We suggest a different low Mach modification of the diffusion matrix (Miczek+ 2015, Barsukow+ in prep.), such that its scaling now does not violate the conditions of such equilibria.

In order to compare with earlier low Mach schemes we study its properties in the case of homoge- neous Euler equations. In the limit $M \longrightarrow 0$ we obtain a discretization of the incompressible system. We study von Neumann stability of this scheme and show experimentally that it is able to resolve features of low Mach flow even for $M \sim 10^{-10}$. For the limit system the kinetic energy emerges as an additional conserved quantity. Its evolution over time is a measure of the diffusion of the numerical scheme and is verified to be independent of M.

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