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ROBUSTNESS AND CONSISTENCY OF POTENTIALLY-STIFF MULTI-WAY PRESSURE COUPLINGS IN COMPRESSIBLE MULTI-FLUID MODELS

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Eulerian models of multi-fluid flows consist in dividing the probability density function (PDF) of the flow in several groups (called fluids) which undergo separated but coupled transport and evolution. These models involve many features which challenge numerical simulation schemes. Notably, non-standard multi-modal PDF, compressibility with contrasted equations of state (EOS), and multi-way couplings at large volume fractions strain the schemes in terms of PDF resolution, entropy consistency, and coupling stiffness.

Stiff couplings can appear notably in mass and momentum exchanges and in pressure works. For instance, velocity relaxation (momentum exchange) can be stiff due to large drag forces. Stiffness in the pressure work can appear in energy equations when fluids are of highly contrasted compressibility or volume fractions: global volume changes of the mixture then impact fluids very unevenly. An extreme example of high practical impact is the case of air bubbles in water with small volume fraction.

To preserve robustness, numerical schemes generally involve implicit or explicit discretizations for respectively positive or negative stiff terms: for instance relaxation terms such as stiff drag require implicit schemes. Now, the sign of pressure work in the internal energy equation may change depending on expansion and compression phases. In numerous published studies, this constraint is mollified by introducing a finite-time relaxation equation of pressure imbalance [1]. This comes at the price of some serious detrimental and well-known side-effects. For a stiff pressure equilibration (or instantaneous relaxation), schemes on implicit pressure (possibly exponential) appear much more convenient in order to preserve robustness in all conditions and with thermodynamic consistency (for instance forbidding negative densities): high contrasts of volume fractions, densities, and EOS become accessible. This is one of the critical ingredients in situations of appearance or disappearance of highly contrasted fluids.

We illustrate this by successfully simulating not only the most strenuous mixed water–air and air–water shock tubes published in the literature (with their cranked up versions at lower volume fractions), but also the theoretical extremes of expansion to vacuum and shock from vanishing pressure. The simulations are carried out with inter-fluid pressure equilibrated embedded in a previously developed Euler–Euler explicit compressible scheme [2] (also presented by the authors in this conference) without complex multi-dimensional Newton-Raphson iterations and under normal CFL conditions [3].

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