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Further developments of an interface-aware subscale dynamics closure model for multimaterial cells

Andrew J. Barlow[1], Ryan Hill[2] and Mikhail Shashkov[3]

[1] Computational Physics Group, AWE Aldermaston, Reading, Berkshire, RG7 4PR, UK, andy.barlow@awe.co.uk
[2] X-Computational Physics, XCP-4, Los Alamos National Laboratory, Los Alamos, NM 87545, USA
[3] X-Computational Physics, XCP-4, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

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Multimaterial cells are often used in Arbitrary Lagrangian Eulerian (ALE) methods to represent material interfaces that undergo high deformation and cannot be modelled robustly with a Lagrangian treatment. A separate set of material properties is normally maintained for all the materials in each multimaterial cell along with the volume fractions that define the proportion of the cells volume occupied by each material. A closure model is then required to close the governing equations, which are otherwise underdetermined, that is, to define how the volume fractions and states of the individual material components evolve during the Lagrangian step. The challenge in developing closure models is how to accurately update the thermodynamic states of the individual material components in the multimaterial cell, and determine the nodal forces that such a zone generates - despite the lack of information about the velocity distribution within multimaterial cells.

The interface-aware sub-scale-dynamics (IA-SSD) closure model [1,2] consists of two stages. During the first, bulk stage, the well known equal compressibility model is used. During the second stage, sub-scale interactions of the materials inside the multimaterial cell are taken into account. At this stage, information about the topology of the materials inside the multimaterial cell is utilised, which allows the inclusion of the orientations of internal interfaces in the model. Each material interacts in a pair-wise fashion with the materials with which it has a common boundary. The interactions are based on the solution of the acoustic Riemann problem between each pair of materials and is limited using physically justifiable constraints: positivity of volume, positivity of internal energy and controlled rate of pressure relaxation. To determine values for the limiting coefficients in the flux terms used, a constrained-optimization framework is employed using a quadratic objective function with linear constraints. The algorithm guarantees the positivity of the material volume and internal energy as well as the smooth relaxation of the pressure - this provides a significant increase in robustness for the overall algorithm.

This paper considers some further developments and simplifications of the IA-SSD algorithm. In [2] the full constrained optimization problem is solved, this introduces some complexity and reliance on third party software. A new simpler method has been developed that avoids

the reliance on third party software. The new method makes use of the analytic expressions for the two material case that were presented in [2]. It is shown that the general n material problem can be solved approximately avoiding the need to solve the general optimization problem by applying the two material problem at each interface in turn and updating the solution by exchanging the limited fluxes at the interface to produce an intermediate solution. This intermediate solution is then used to define the constraints for the next interface material pair, the interface fluxes are again exchanged and the solution updated and so on until all the two material interface pairs have been updated.

A further simplification of the IA-SSD algorithm that has also been made is to avoid the need to interpolate velocities from the nodes to the centroids of the material components. This has been achieved by modifying the acoustic Riemann solver used to calculate p* at each material interface by replacing the velocity jump term with an artificial viscocity like term calculated from the nodal velocities and the state variables for the pair of materials either side of the interface.

The bulk phase has also been improved by introducing multiphase artificial viscocities and multiphase subzonal pressures. This provides a much better starting point for the subcell dynamics step, as it improves the initial distribution of shock heating amongst the material components. The new multiphase artificial viscocities are defined using the local material component densities, mass fraction weighted average sound speeds and nodal velocities. This leaves the volume fraction weighted average used in the momentum step unchanged from the value that would be calculated if the single material method was applied to the average cell values, but makes the shock heating of the material components more appropriate for the component densities. A similar approach has also been taken in introducing the multiphase subzonal pressures. In this case density differences are obtained for each material component in each of the four corner volumes. These are converted into pressure perturbations using the average cell sound speed for each material in each of the four corner volumes. These are then used to generate forces for each material component which are used to update the internal energies of the material components. A volume fraction average is then again used to define consistent average pressure perturbations for the forces required for the momentum solve.

Results will be presented for both idealised test problems and applications to enable the performance of the algorithm modifications to be assessed by comparison with results presented in [2] for the original IASSD method and results obtained with other closure models.

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