ALPACA - a Versatile Multiresolution Compressible Flow Framework for highresolution Simulations

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Computational Fluid Dynamics of compressible flow phenomena has become an important tool in research and industry. Improvements in numerical model development for multi-physics problems has enabled the research in fluid mechanics nowadays to consider very complex problems by highperformance computation. Such problems are characterized by nonlinear mechanisms that generate multiple temporal and spatial scales. Whereas turbulence is a broad-band phenomenon whose largest scales are determined by flow boundaries and exterior forcing, and whose smallest scales are determined by viscous dissipation length scales, singularities such as shocks and interfaces do not possess inherent length and time scales if considered in a continuum description. They generate small scales by instabilities, driven through their mutual interaction, and interact with broad-band flow structures, creating a scenario which is extremely complex for numerical flow modeling: high-resolution requirement of broad-band scales and instabilities, monotonic capturing of shocks and interface, tracking of interfaces without artificial diffusion and mass loss. Unfortunately, as increased computational power to handle extreme resolutions does not come “for free” anymore [1], large-scale simulations of compressible flows need to exploit multiple levels of parallelism [2] in order to benefit from current and future high-performance computing hardware.

In this talk, we present the open-source multi-phase compressible flow simulation framework ALPACA [3], developed at the TUM Chair of Aerodynamics and Fluid Mechanics. ALPACA provides a full compressible Navier-Stokes finite-volume solver for large-scale distributed memory architectures. Multiphase problems can be considered via a level-set formulation with conservative interface interactions. Temporal and spatial discretization schemes follow state-of-the-art methods including strongly-stable adaptive time-stepping [4], high-order WENO reconstruction and various approximate Riemann solver. The full range of spatial scales in the simulations is compressed by a block-based multiresolution (MR) scheme [5,6] that allows for SIMD optimization [7]. Furthermore, Message Passing Interface (MPI) is used to run ALPACA on large distributed-memory machines like the SuperMUC-NG at LRZ. Written in C+ +17, the modular structure of the framework allows to exchange the compute kernels for the spatial and temporal discretization freely without impact on the parallel performance [6,7]. Based on classical compressible benchmark problems (Sod shock tube, Air-Helium bubble collapse), we will present the concept behind ALPACA and demonstrate its parallel performance. Moreover, the modularity and versatility is illustrated with examples of solidification simulations [8] and fluid-structure interactions for cavitation effects in soft tissues.

We hope that by presenting this state-of-the-art simulation environment to the community we stimulate cooperation on further code development and interest to employ the tool for own research.

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