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Massive parallel simulation of gas turbine combustion using a fully implicit unstructured solver on the heterogeneous Sunway Taihulight supercomputer

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Sunway Taihulight is a supercomputer that comprises of 40,000 SW26010 many-core processor chips. Different from CPU+accelerator architectures powered by hardware from vendors such as NVIDIA, AMD, and Intel., this processor features an on-chip heterogeneous design. Boasting a peak performance of 125 PFlops and a sustained Linpack performance of 93 PFlops, Sunway Taihulight held the No. 1 spot on the TOP500 list from June 2016 to November 2017 and it is recognized as the world's first peta-scale system. As for application, we do not only pay attention to the distributed parallelism, but also the many-core fine-grained parallelism which plays a key role in boost the simulation performance on this supercomputer. In this study, massive parallel simulations of a full annular aeroengine combustor chamber have been achieved on the on-chip heterogeneous Sunway Taihulight supercomputer. A billion-size unstructured mesh is generated through grid replication and rotation, accompanied by the development of an efficient geometric matching algorithm to address the conformal interface issue. We developed graph-based and tree-based loop fusion approaches for implicit solving procedure of the momentum equation, it is found that the strategic utilization of data reuse and separation of vector computation significantly enhances the performance on many-core processor. For linear system, a finer-grained parallelization based on sparse matrix-vector multiplication and vector computation is validated. Massive parallel tests utilizing 16K processes with 1M cores are successfully conducted to simulate the turbulent non-premixed combustion in an aeroengine combustor with nearly one billion cells. Compared to the pre-optimization version, this fully accelerated code achieves an impressive 5.48 times speedup in overall performance, with a parallel efficiency of up to 59%. After conducting an extensive series of studies, we have developed a comprehensive solution for the massive parallel simulation of gas turbine combustion using unstructured grids and implicit solver on heterogeneous Sunway Taihulight supercomputer. This simulation allows for the observation of instantaneous flame interaction between sectors, providing a level of detail and realism that cannot be achieved through single-sector RANS simulations.