오픈폼 다중 기준 적응 격자 기법을 활용한 이중 연료 엔진의 수치해석 연구

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A numerical study of the dual-fuel engine with multi-criterion adaptive mesh refinement using OpenFOAM

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ABSTRACT

The OpenFOAM-based adaptive mesh refinement (AMR) approach provides increased resolution in localized regions based on user-defined criteria, resulting in a simulation that dynamically tracks dominant physical features and reduces computational cost compared to uniform and static mesh approaches. A new multi-criteria adaptive mesh refinement solver was applied for engine simulation, it incorporates dynamic meshing capabilities already available in OpenFOAM. We mainly outline details of the new solver and demonstrate its basic functionality, accuracy, and computational efficiency by a 3-D engine simulation test case.

Key Words : OpenFOAM, AMR, Multicriteria, Load balance, dual-fuel engine

OpenFOAM is based on a numerical technique called finite volume method (FVM) which is a mesh-based method where the computational domain is subdivided into several cells, together creating a mesh. However, a computation with a fine mesh require extensive computer time. Adaptive mesh refinement (AMR) is often applied to resolve the critical fields, and thus, can achieve comparable accuracy with uniform fine grid [1-6].

The critical fields are often selected as the criteria based on which mesh refinement is performed. Xue et al. [4] selected refinement criterion based on the total mass of liquid drops and fuel vapor in each cell for spray modeling in engine simulation. G. Hindi et al. [7] proposed and tested a criterion for adaptive mesh refinement based on the droplet Stokes number. Liu et al. [8] took the magnitude of density gradient of water as the refinement criterion for liquid jet primary breakup simulation.

Generally, there are several important fields that researchers would lay stress on, however there is no multiple refinement criteria solver that can be used in OpenFOAM internal combustion engine simulation. Recently, Daniel et al. [9] presented the first stable AMR combined with Dynamic Load Balancing (DLB) implementation for OpenFOAM. Based on their work, we further optimized the solver for internal combustion engines based on the OpenFOAM 5.0 version. Figure 1 shows the structure of our new solver.

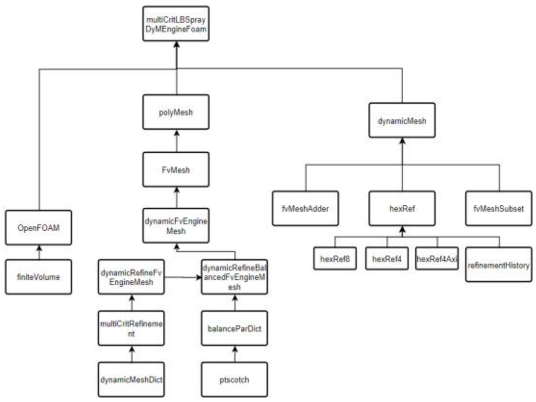

Fig. 1 Structure of solver and classes

The dynamicRefineFvEngineMesh class holds the mesh and is called to do mesh refinement. At first, this class is built by merging the fvMotionSolverEngineMesh class into dynamicRefineFvMesh class. Thus a 'move' function is added in dynamicRefineFvMesh

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member functions to achieve piston displacement.

dynamicRefineFvEngineMesh has been equipped with functions to handle polyhedral cells and to do finite volume discretization. This class provides the function 'update()' which executes an adaptive refinement on the mesh. The update function uses some other internal functions such as 'selectRefineCandidates()' for selecting candidate cells for refinement and 'refine()' for doing the refinement of some selected cells. To do the actual cutting of cells, dynamicRefineFvEngineMesh uses another class called hexRef stored in the variable meshCutter_. refinementHistory contains the history of the refinement (refinement-tree).

Some modifications are done in dynamicRefineFvEngineMesh class for calling multiCritRefinement class which reads all the criteria and their refinement levels from dynamicMeshDict file and passes these values by flags marked in multiCritRefinement fields.

The dynamicRefineBalancedFvEngineMesh applies PT-Scotch method specified in balancedParDict file in system directory to decompose domain in parallel computing, PT-Scotch provides efficient parallel tools to partition graphs, it extends the graph ordering capabilities of Scotch in the parallel domain [10]. Numerous codes were modified in the classes related to mapping such as fvMeshAdder, fvMeshSubset, and fvMeshDistribute to properly distribute the dimensioned fields.

A KSOE dual-fuel engine experiment data was used to validate our test case. Spray and flame are critical component to engine combustion and emissions simulations, which require fine computational mesh for better numerical resolutions, the criteria we adopted for AMR are *n*-dodecane ($C_{12}H_{26}$) mass fraction and temperature. single criterion (*n*-dodecane mass fraction/temperature) was adopted for comparison, the base grid size is 10mm, refinement level is 1 for both cases, a 2.5mm fine grid mesh is used as the reference case.

It is observed from Fig. 3 both single criterion and multi-criteria refined mesh based on n-dodecane field, the spray shapes are the same for both cases, however, the mesh near flame region cannot be refined by single criterion mesh refinement, which caused a higher flame propagation speed and a high temperature rise rate.

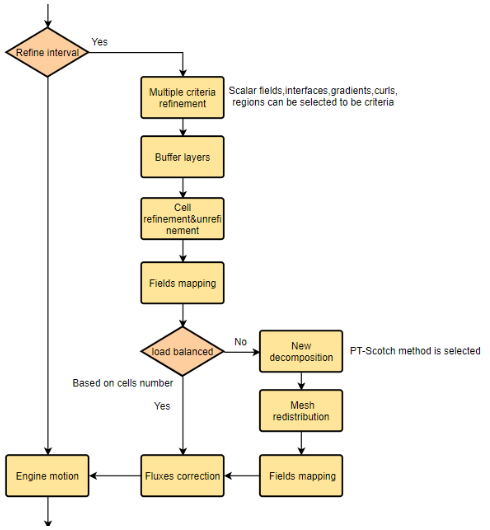

Fig. 2 Flow chart of DLB-AMR algorithm

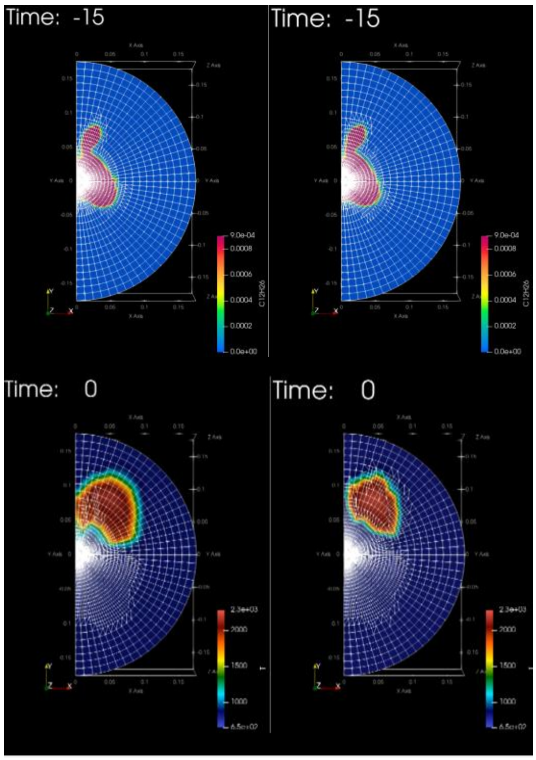

Fig. 3 Comparison between single criterion(left) and multi-criteria(right) mesh refinement on $C_{12}H_{26}$ field (above) and temperature field (below)

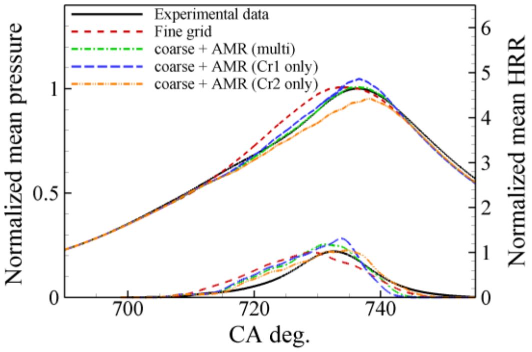

Fig. 4 Temporal evolutions of normalized mean pressure and mean HRR for different mesh strategies

Criterion 1 is selected as *n*-dodecane mass fraction, and criterion 2 is temperature. Figure 4 indicates that both single criterion and multi-criteria cases predict pressure correctly before TDC, which can be attributed to the fine resolution near spray region. For the criterion 1 case, peak pressure is higher than experiment data due to a higher HRR which is caused by the high flame propagation speed as is shown in figure 3. For the criterion 2 case, the ignition delay time increased and the peak pressure is lower than experiment result due to the low flame speed. Multi-criteria case generates good results which is comparable to the fine grid mesh.

A multi-criteria adaptive mesh refinement was implemented for engine simulation, dynamic load balance code was applied to reduce computational time, the multi-criteria AMR reproduced relatively good results compared to single criterion AMR, this work shows the capability of the new solver for engine simulation.

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