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PARALLEL AND DYNAMIC MESH ADAPTATION OF TETRAHEDRAL-BASED MESHES FOR PROPAGATING FRONTS AND INTERFACES: APPLICATION TO PREMIXED COMBUSTION.

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Abstract. To reduce CO2 emissions and specific consumption, aeronautical engine manufacturers have to increase the Overall Pressure Ratio (OPR) of the turbines. This OPR increase leads to an direct increase NOx emissions. Lean-premixed combustion is an appealing technology to mitigate this effect. The modeling of lean-premixed flames in industrial combustors is very challenging as combustion takes place at very small scales. In this context, parallel mesh adaptation as proposed by Benard et al. [1] based on the MMG library [2, 3, 4] is an enabling technology, which has the potential to reduce dramatically the cost of flame front capturing simulations in an industrial context. The application case proposed in the present paper is a lean-premixed semi-industrial burner named PRECCINSTA. This burner has already been used as a benchmark case in many studies. Here, static and dynamic mesh simulations are performed and compared to demonstrate that the flow dynamics in the simulations are mainly dependent to the flame front resolution. Thus, the dynamic mesh simulations enable to get the same results as significantly heavier and more costly static grid simulations.

1 INTRODUCTION

During the past two decades, the steady power increase of parallel super-computers participated heavily in developing 3D unsteady CFD modeling approaches. Turbulent combustion modeling based on Large-Eddy Simulation (LES) has strongly benefited from this evolution as it enabled to increase the flame front resolution and to include more physics. In combustion LES of realistic systems, mixing and reactions mainly occur in thin regions at the sub-grid scale. However, an increase of the mesh resolution at the flame location enables to capture more flame/turbulent interactions responsible for the main flow dynamics. Adaptive mesh refinement (AMR) is an appealing technique to improve the mesh resolution in the flame and to reduce the modeling errors at a lower

CPU cost. AMR has been originally designed for Cartesian grids [5] and used since then for many types of flows. The major challenge for its use on distributed memory machines is its parallelization. The local mesh refinement indeed creates load imbalance that needs frequent repartitioning and balancing.

The strategy, which is presented in this paper, relies on dynamic adaptation of tetrahedron-based unstructured grids. This strategy has several advantages: i) complex geometries are easily meshed, ii) the mesh is locally isotropic, iii) it enables to use conformal grids without hanging nodes, which minimizes modifications to the flow solver. The proposed methodology [1] consists of frequent sequential calls to the MMG remeshing library [2, 3, 4], which adapts the mesh inside each MPI rank without modifying the interface shared with the other ranks. Then, repartitioning and transfer of cell groups is performed to ensure an optimal load balance and to modify the cells at the interface. All the underlying algorithms have been optimized to reach good performances with grids of several billion cells on more than 10'000 cores. This dynamic mesh adaptation strategy has been implemented in the YALES2 code [7, 8] and applied to the modeling of the so-called PRECCINSTA burner, a turbulent lean-premixed swirl combustor. In this application, AMR enabled using analytical finite-rate chemistry at a reasonable cost. The flame front structure, dilution by burnt gases and quenching as well as CO mass fraction are noticeably well reproduced showing the potential of this approach for pollutant emission prediction.

2 LES OF THE PRECCINSTA LEAN-PREMIXED BURNER

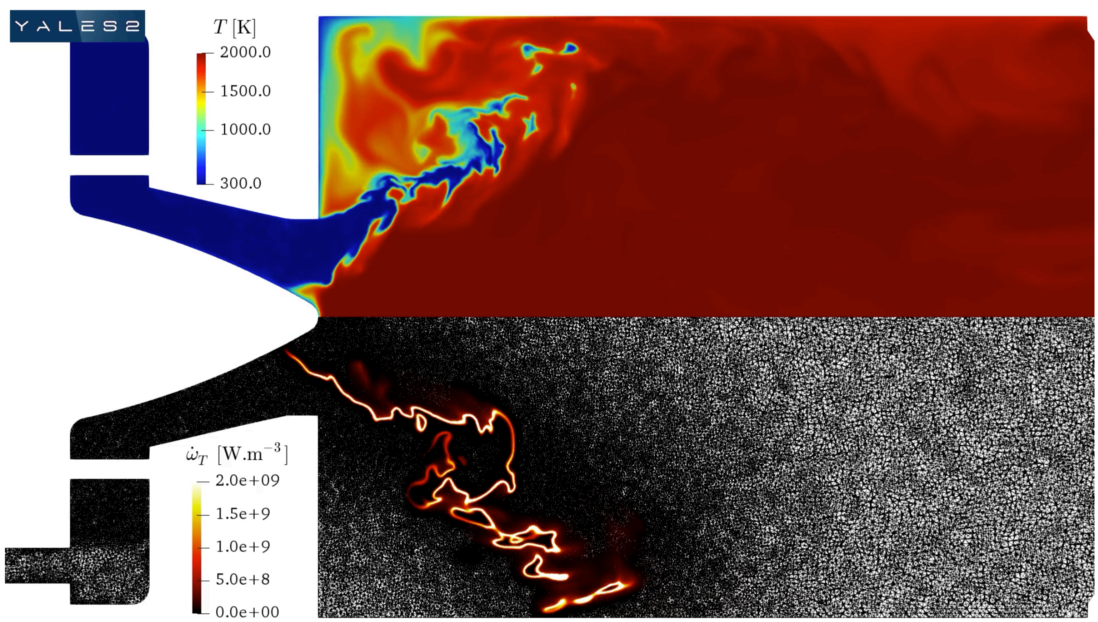

Figure 1: Mesh topology for the dynamic case with instantaneous temperature (top) and heat release rate (bottom).

The present study extends the work of Benard et al. [9], who investigated the impact of heat loss on the flame topology and on the pollutant emissions. The same setup is considered here with the same static meshes NAD3 and NAD4, which count 110M and 880M elements each and with mesh resolutions in the flame region of 300 and 150 microns, respectively. An additional simulation with a dynamic mesh refined only at the flame front location is performed. This simulation, which is illustrated in Fig. 1, counts 260M cells and costs approximately three times less than the static NAD4 case, which has the same resolution in the flame front.

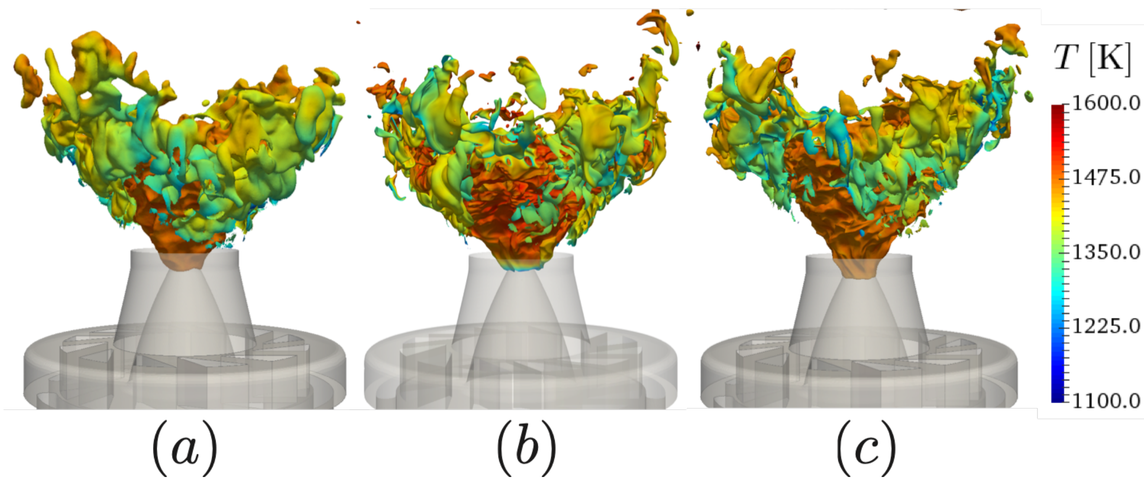

Figure 2: Comparison of instantaneous progress variable iso-surfaces for different meshes (a) static mesh of 110M cells and $\Delta x = 300\mu m$ (NAD3), (b) dynamic mesh of 260M cells and $\Delta x = 150\mu m$, (c) static mesh of 880M cells and $\Delta x = 150\mu m$ (NAD4).

Figure 2 presents instantaneous progress variable iso-surfaces for the three selected cases. It shows that the small-scale wrinkling is similar between the dynamic and static NAD4 cases as they have the same resolution in the flame front. This observation is confirmed in Fig. 3, which gives the PDF of the curvature on the progress variable iso-surface. The two finer cases have the same curvature PDF, which is different from the coarser NAD3 case.

Details comparisons of the flow statistics for the temperature and the major species have been performed (not shown here), which also prove that the dynamic mesh case, while being cheaper, provides a similar accuracy to the finest static case.

3 CONCLUSIONS

This paper shows that dynamic mesh refinement of lean-premixed flames is now tractable. This is a major step forward for the computation of realistic industrial burners with finite-rate chemistry.

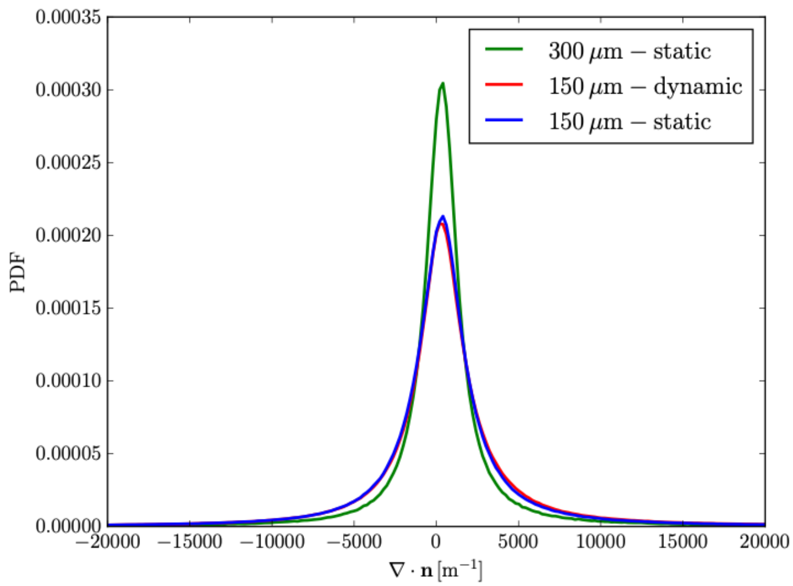

Figure 3: Comparison of curvature statistics for the different mesh resolutions.

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