HIGH-FIDELITY NUMERICAL SIMULATIONS OF THE REACTING FLOW FIELD OF AN ANNULAR COMBUSTOR MODEL OF AN AIRCRAFT ENGINE

Allocation: Director Discretionary/100 Knh
PI: Ahmed Taha[1]
Co-PIs: Seid Koric[1], Daniel Mira[2]
Collaborators: Oriol Lehmkuhl[2], Ricard Borrel[2], Albert Coca[2], Samuel Gómez[2], Mariano Vázquez[2], Guillaume Houzeaux[2], Madhu Vellakal[1]

[1]National Center for Supercomputing Applications
[2]Barcelona Supercomputing Center

EXECUTIVE SUMMARY

Our research is dedicated to performing high-fidelity numerical simulations of conditions representative of aeronautical combustors from turbofan engines using wall-resolved Large-Eddy Simulation (LES). The challenges associated with the modeling of these systems correspond to the full characterization of the reacting layers, the near-wall treatment, and the ability to predict pollutant emissions. This project is defined to show the aerospace and aeronautical community that high-performance computing (HPC) codes can be used to perform real-engine simulations, and can go one step beyond the state-of-the-art in modeling large-scale combustion systems for propulsion and power applications.

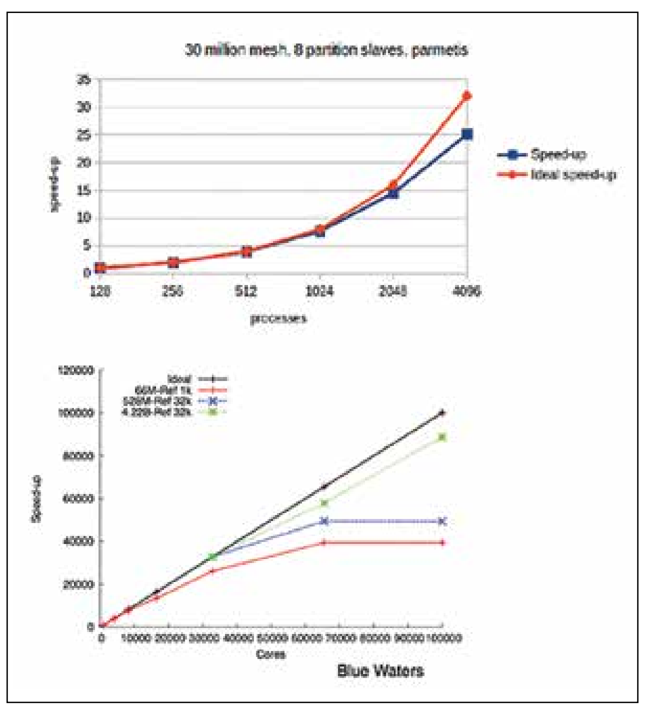

Figure 1: Scaling tests on MareNostrum (top) and Blue Waters (bottom).

RESEARCH CHALLENGE

The challenges associated with the modeling of these systems correspond to the full characterization of the reacting layers, the near-wall treatment, and the ability to predict pollutant emissions.

METHODS & CODES

The code used for the project is called Alya [1], which is a computational fluid dynamics code of the PRACE Benchmark Suite for HPC applications. It has been highly optimized and independently tested on most European supercomputing platforms. The Alya code was developed at the Barcelona Supercomputing Centre and is a parallel multiphysics software package using the finite element method to run applications on HPC facilities. For combustion problems, Alya showed excellent scalability on the Blue Waters supercomputer (Fig. 1—bottom) to 100,000 cores on meshes of up to 4.22 billion elements. The algorithms and models employed to solve the individual physical problems have been assessed and validated in previous research [1–4].

The governing equations describing the reacting flow field correspond to the low Mach number approximation of the Navier–Stokes equations with the energy equation represented by the total enthalpy. The chemical state is described by two controlling variables: the mixture fraction and the reaction progress [3]. The combustion process is assumed to take place in the flamelet regime for all computing cases, and we employ a turbulent combustion model based on presumed probability density function [3,4]. The modeling approach that we follow in this project is valid for partially premixed flames, as this approach can recover the structure of premixed flames in regions dominated by flame propagation, as well as the structure of diffusion flames in the postflame regions [3,4].

RESULTS & IMPACT

The main results of this project are manifold as shown below and in Fig. 2:

- Development of an efficient computational framework to perform large-scale simulations of reacting flows under aero-engine-like conditions.
- Numerical characterization of a technically premixed swirling flame.
- Numerical characterization of both a piloted and nonpiloted turbulent nonpremixed jet flame.

The primary impact of the project is the development of a computational framework that can be used to study complex combustion systems based on high-fidelity simulations of turbulent reactive flows.

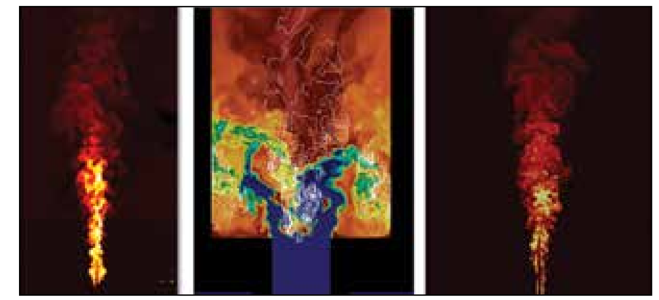

Figure 2: Snapshots of turbulent flames—(a) nonpremixed jet flame, (b) technically premixed jet flame, and (c) nonpremixed piloted jet flame.

WHY BLUE WATERS

The full characterization of the reacting layers needs a very fine mesh to capture all of the flow details. In addition, achieving convergence at reasonable timescales requires running the code at scale. Using Blue Waters makes conducting the parametric study with such large meshes and complex physical modeling possible in a timely manner.

PUBLICATIONS & DATA SETS

Borrell, R., et al., Parallel mesh partitioning based on space filling curves. *Computers & Fluids*, in press (2018), DOI:10.1016/j.compfluid.2018.01.040.
Sandia D flame (LES data)
DLR Jet flame A (LES data)
Swirling combustor with central axial jet injection (LES data)