Master Thesis Research Project Proposal

AI-assisted turbulence modeling in dense gas flows
Ecole Centrale de Lyon / LMFA

Context

Dense gases are characterized by their unusual thermodynamic behavior when their pressure, temperature and density are close to the saturation curve in the vicinity of the critical point. In this region, the fundamental derivative defined as $\Gamma = 1 + \frac{\rho}{c}\frac{\partial c}{\partial \rho}|_s$,with ρ the density, c the speed of sound and s the entropy, is lower than unity for dense gases. Dense gases, are used as working fluids in Organic Rankine Cycle (ORC) engineering systems harvesting thermodynamic cycles for the recovery of fatal heat. These ORC systems experience an accelerated development under the combined effect of the increase of the energy price and of the public awareness of climate issues (see Figure 1). Companies developing such systems face numerous challenges among which some come from a lack of basic

FIGURE 1 – Concentration solar panel Organic Rankine Cycle (Crédit STG international)

knowledge regarding the turbulent flows of dense gases in expanders.

In 2018, a Young Researcher Project has been granted to our group at LMFA by Agence Nationale de la Recherche (ANR) to analyze the fundamental behavior of compressible turbulence in dense gas (DG) flows and to transfer this knowledge to the field of ORC turbine flow modeling. Since then, Direct Numerical Simulation (DNS) has been used to build an extensive database of turbulent DG flows. The database comprises decaying Homogeneous Isotropic Turbulence (HIT) (Giauque, 2017), forced HIT (Giauque, 2020, see Figure 2), mixing layer (Vadrot, 2020) and supersonic channel flow. Using this database and following Vreman's (Vreman, 1995) methodology, our research team currently concentrates its efforts on providing turbulence closure models to the dense gas flow community in general and to the ORC designer community in particular.

Objectives and Methodology

The Master student will be part of this modeling research effort dedicated to turbulence closure for LES and RANS in the context of dense gas flows. The strategy that will be followed in this Master will largely rely on the notions of Optimal Estimator (Balarac, 2008) and of Uncertainty Quantification (Sudret, 2008). Given the large choice of possible combinations for the model variables, modern techniques such as **artificial neural networks (ANN) or Generative adversarial networks (GAN)** will be used with profit during the course of the Master in order to identify the precise formula to be used for each **statistical (RANS) or subgrid-scale (LES) model.**

The Master student will also tackle the issue of robustness of the turbulence model. This can be done using the notion of polynomial chaos expansion (Congedo, 2011) for the turbulent kinetic energy (or any other macroscopic quantity of interest), adding variance (treated as uncertainties) to the coefficients of the model.

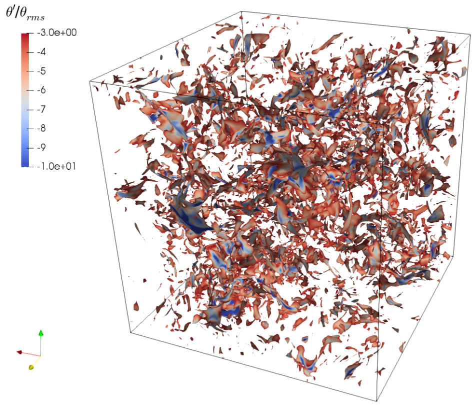

FIGURE 2 – Shocklets in turbulence colored by the divergence of the velocity field

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Master thesis advisors

Christophe Corre (Full Professor ECL) :

Christophe Corre joined Ecole Centrale de Lyon and the Fluid Mechanics and Acoustics Laboratory (LMFA) in 2014 within the Turbulence and Stability research group. His teaching activities address the numerical simulation of flows and engineering optimization. His research activities cover three main areas : (1) the development of efficient methods for the simulation of hydrodynamic or aerodynamic flows, (2) the robust simulation of complex (two-phase, non-Newtonian, dense gases) flows, and (3) the analysis and optimization of flows including uncertainties.

Alexis Giauque (Assistant Professor ECL) :

Since 2013, Alexis Giauque holds an assistant professor position at Ecole Centrale de Lyon. He is part of the LMFA turbomachinery research team and focuses his research on Large Eddy Simulation of secondary flows in realistic geometries. Since 2016, he has also started a new research initiative aiming at the precise modeling of turbulence in the context of turbulent dense gas flows for ORC turbomachinery applications.

Profile

This Master thesis research project (starting date April 2022) will be carried out in the Fluid Mechanics and Acoustics Laboratory (LMFA) at Ecole Centrale de Lyon (ECL). Since it involves both physical modeling of turbulence and numerical developments in machine learning, technical skills in fluid mechanics and applied mathematics are expected from the applicant. A marked taste for modeling and physical analysis in fluids will be an asset. Depending mostly on the academic performance of the candidate, a PhD thesis in the research group on the same topic will be considered.
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