Numerical modeling of supercritical flows: Progress, Challenges, and outstanding Issues

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Over recent years, significant progress has been made towards the computational modeling of high-pressure supercritical flows, pertaining to rockets, gas turbines, and internal combustion engines. However, several issues regarding the accurate representation of thermodynamic states, the formulation of reliable numerical algorithms, and the development of predictive physical models remain. This presentation will provide an overview of advances and remaining challenges spanning the fundamental thermodynamic understanding, computational modeling, and applications.

Beginning with a general description of supercritical flows, we will discuss challenges in accurately representing fluids at high-pressure conditions that involve strong density gradients, highly localized transition regions, and large variations in transport properties. Recent algorithmic developments in reliably describing these conditions are presented and numerical analysis is performed to highlight the impact of resolution requirements on the mixing, dispersion, and thermodynamic state-space representation.

The second part of this presentation provides an overview of recent developments of numerical algorithms and modeling tools for the prediction of supercritical mixing and combustion. The need for entropy-stable numerical schemes and relaxation techniques to deal with spurious pressure oscillations and underresolved flow-field representations is highlighted for preserving the physical realizability of numerical solutions across large density gradients.

The last part of this presentation discusses the application of these numerical methods to problems including large-eddy simulations of high-pressure diesel fuel injections, scalar mixing in supercritical shear-layers, and rocket combustion. Of particular interest is to evaluate the accuracy and limitations of existing modeling tools in predicting supercritical flows. The presentation closes by identifying open research issues and further research directions.

Bio-sketch: Matthias Ihme is Associate Professor in the Department of Mechanical Engineering at Stanford University. He holds a BSc. degree in Mechanical Engineering and a MSc. degree in Computational Engineering. In 2008, he received his Ph.D. in Mechanical Engineering from Stanford. After being on the faculty of the Aerospace Engineering Department at the University of Michigan for five years, he returned to Stanford in 2013. He is a recipient of the NSF CAREER Award (2009), the ONR Young Investigator Award (2010), the AFOSR Young Investigator Award (2010), the NASA Early Career Faculty Award (2015), and the Hiroshi Tsuji Early Career Research Award (2017). His research interests are broadly on the computational modeling of reacting flows, the development of numerical methods, and the investigation of advanced combustion concepts.