Department of Mechanical Engineering Seminar

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A Physics-driven Statistical Surrogate of Scalar Turbulence

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ABSTRACT

New system-level codes are being developed for advanced reactors for safety analysis and licensing purposes. Thermal-hydraulics of advanced reactors is a challenging problem due to complex flow scenarios assisted by free jets and stratified flows that lead to turbulent mixing. For these reasons, the 0D or 1D models used for reactor plena in traditional safety analysis codes like RELAP cannot capture the physics accurately and introduce a large degree of modeling uncertainty. System-level calculation codes based on the advection-diffusion equation neglect turbulent fluctuations. These fluctuations are extremely important as they introduce higher-order moments, which are responsible for vortex stretching and the passage of energy to smaller scales. Komolgorov hypothesized that the flow velocity field follows a -5/3 scaling in the inertial region where Markovian characteristics can be invoked to model the interaction between eddies of adjacent sizes. This law holds true in the inertial region where the flow is Markovian. For scalar turbulence, the scaling laws are affected by thermal diffusion. If a fluid has a Prandtl number close to one, the thermal behavior is dominated by momentum, so the spectra for velocity and temperature are similar. For small Prandtl number fluids, such as liquid metals, the thermal diffusion dominates the lower scales and the slope of the spectrum shifts from the -5/3 slope to a -3 slope, also called the Batchelor region. System-level thermal hydraulics codes need to be able to capture these behaviors for a range of Prandtl number fluids.

Direct numerical simulations (DNS) are capable of capturing these scale interactions in scalar turbulence, but are computationally expensive for simple geometries and impossible at the system level. An alternative way to model the turbulent fluctuations can be described through a reduced-order model using the principles of statistical mechanics. Statistical mechanics-based methods provide a method for extracting statistics from data and modeling that data using easily represented differential equations. The Kramers-Moyal (KM) expansion method can be used either as a subgrid-scale (SGS) closure for solving the momentum equation or to model velocity and temperature fluctuations directly. This method can be used as a statistical surrogate for use in large-scale systems that captures the scale interactions accurately while being computationally efficient.

BIO

Molly Ross is a thermofluidic system engineer at Oak Ridge National Laboratory. She obtained her bachelor's degree in mechanical engineering from Kansas State University in 2017, and will obtain her PhD in nuclear engineering from Purdue University in May, 2024. Her primary research area focuses on developing stochastic closures to turbulent flows and heat transfer models with specific applications in thermal-hydraulic safety analysis. She has also investigated other keynote issues in nuclear engineering. This has included developing a neutron radiography system to provide high resolution void fraction measurements to investigate debris bed coolability as well as developing machine learning algorithms to predict and classify material thermal properties. In her future research career, she plans to extend both stochastic methods and machine learning algorithms to characterize physics in advanced reactors, improve grid-scale planning, and provide a framework to allow better-informed decision making from available sensor information.