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Computational Fluid Dynamic Investigation of Loss Mechanisms in a Pulse-Tube Refrigerator

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In predicting Pulse-Tube Refrigerator (PTR) performance, One-Dimensional design and analysis tools such as Gedeon Associates SAGE® typically include models for performance degradation due to thermodynamically irreversible processes. SAGE®, in particular, accounts for convective loss, turbulent conductive loss and numerical diffusion "loss"via correlation functions based on analysis and empirical testing.
While the simplicity of 1-D simulation tools facilitates PTR design and analysis, this convenience comes at the cost of modeling detail. An investigator wanting to drill-down into the constitutive relationships or governing principles can be shielded from low-level physical details that may otherwise lead to design insights. In these types of investigations, a higher-order Computational Fluid Dynamics (CFD) simulation complements a 1-D simulation. Whereas 1-D simulation is a sufficient starting point for PTR design, Two-Dimensional and Three-Dimensional CFD models enable an investigator to refine the design—to explore and visualize "real" physical heat-transfer and fluid flow behavior that has been condensed, simplified or omitted in 1-D modeling tools. In a 2-D or 3-D CFD model, the system dynamics and complexity between the input and output of a particular PTR component are not hidden. In this regard, higher order CFD is also a means of validating 1-D models, or of tuning lower-order design tools to new performance spaces before physical functional validation or prototyping.
In this study, we compare CFD and SAGE® estimates of PTR refrigeration performance for four distinct pulse-tube lengths. Performance predictions from PTR CFD models are compared to SAGE® predictions for all four cases, and also compared to select published analytical and empirical models. Then, to further demonstrate the benefits of higher-fidelity and multidimensional CFD simulation, the PTR loss mechanisms are characterized in terms of their spatial and temporal locations.

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