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Flow investigations

Enabling new thermal system designs

A very significant knowledge and technology gap exists between modern-day refrigeration and air-conditioning systems and the ones required for extreme thermal applications like space exploration. Amitabh Narain's cutting edge research is expected to enable development of new technologies and systems of interest to NASA, the US Air Force, and the electronics/avionics cooling industry.

Vapor compression cycles employing boilers and condensers work reliably in traditional refrigeration and air-conditioning applications but fail to work reliably under shear/pressure driven and high heat-flux conditions. Yet shear/pressure driven miniaturized vapor compression cycles remain a system of choice for modern, densely packed electronics applications. These applications demand removal of heat-flux in excess of 1kW/cm^2 from a compact heat source location to a compact heat rejection location.

Nothing short of trailblazing, Narain has developed experimental and computational simulation capabilities in order to close this knowledge and technology gap. One of the world's leading experts on film condensation and two-phase flows, Narain measures flow with modern sensors, flow visualization, and real time data acquisition and processing. By modeling the complicated processes in condensing flows, Narain's contributions have led to a better understanding of the basic convective transport mechanisms. In fact, little fundamental progress has been made in this industrially important research since the classical solutions of Wilhelm Nusselt in 1911.

"Our three independent computational simulation capabilities have yielded results that are consistent with one another and relevant experiments," notes Narain. "These supportive simulations resolve the physics at the interface. They also locate the dynamic liquid-vapor interface in the annular wavy regime, and make detailed predictions of the flow and heat-transfer rates."

Future thermal systems will need to employ condensing/evaporating flows driven by shear and pressure forces alone. "These flows behave quite differently from flows that are influenced by gravitational forces," adds Narain. The prediction and control of such flows are important for the development of new miniature cooling technologies for electronics and avionics, the kind that employ µm-mm scale condensers/evaporators, as well as new space-based thermal management systems and space-based Rankine cycle power generation systems being considered for long-duration manned space missions to the moon and Mars.

Narain and his research team have recently found an important new result that identifies a unique feature of boundary condition sensitivities in condensing/evaporating flows. "The value of the mean flow variables depend on ever-present fluctuations, thermal conditions at the heat-exchange surface, upstream inlet conditions, and, also, downstream exit conditions," he explains. "Non-natural impositions of exit pressure values rearrange the distribution of energy consumption rates in the interior of the fluids and at their interface. This alters the mean interfacial mass-transfer rates, wall heat transfer rates, and often triggers long and vexing thermal transients in the metal walls of the condenser."

The team's ongoing research focuses on the fundamental characterization of condensing and boiling flows and developing the kind of better predictive and flow control capabilities that will enable new system designs.