



instabilities are more severe when the condenser is in zero gravity (NASA project).

Undaunted, Narain developed a way to isolate the condenser from “noise” in the upstream and downstream flows and to create an active control for the inlet and exit conditions to achieve steady state. He and his research team have proposed a technology to achieve steady state and to identify the range of operations for any given heat flow. The research has led to the development of a state-of-the-art experimental laboratory and a direct computational simulation tool. Narain adds, “We believe we are the first to establish, both theoretically and experimentally, new exit condition categories for condensing flows within which one must identify the better known sub-categories of different flow regimes.” A recent journal article on the experimental support of simulation results has received nearly unanimous support from the reviewers and is in press for publication.

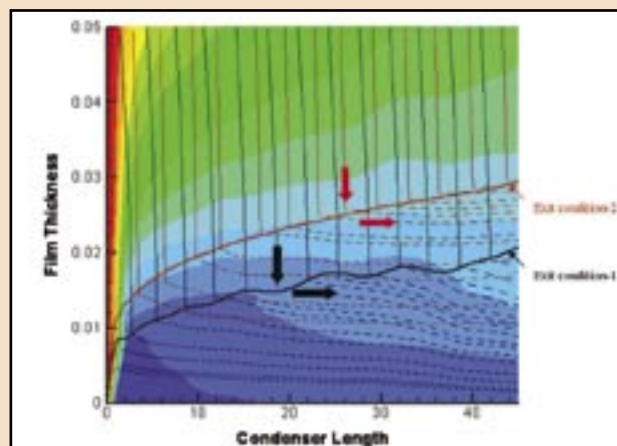
Developing Measurement Technologies

Equally satisfying, says Narain, was the development of a solution to a problem that stemmed from his two-phase flow research. In order to make accurate simulation predictions, it was necessary to make instantaneous thickness measurements of the liquid on the condensing surface without disturbing the flow. Faced with unsuitability of available instruments designed for this purpose, Narain invented a non-intrusive fiber-optic sensor that uses light beams and fluorescence to measure real-time thickness of a suitably doped dynamic liquid film. He and his students overcame obstacles of noise and signal processing, and submitted the invention report to NASA in September of 2006. Narain expresses gratitude for the generosity and support of leaders in other fields, saying, “Many professionals donated their time to guide us—and because we

were trying to invent something in a field that is not our own, that help was indispensable.” Michigan Tech, after informing NSF and NASA, is proceeding with the patenting process for this invention.

Funding for the fiber-optic sensor and the two-phase flow project has reached \$1,000,000 and includes a recent grant from NASA to extend the research until 2009. In the future, Narain expects to lead development of a more general purpose version of his interface tracking code for use in other applications. In the meantime, industry interest in Narain’s work is emerging; in early 2006, he acted as a consultant for Proctor & Gamble, modifying his code to predict temperature variations inside chemical films and gels that were moving on a conveyor and whose top surfaces were exposed to condensing steam. Dr. Narain has also successfully completed several other industry projects for Fernstrum Corp., EMP, Inc., General Motors, and Proctor and Gamble that involved fluid flow and heat transfer simulations for applications of interest to the sponsors.

As his research progresses, Narain continues to be active in the Michigan Tech community. He teaches *Fluid Mechanics* and *Heat Transfer*, and advises both graduate and undergraduate students. Narain challenges his students as he challenges himself, encouraging them to approach their understanding with a good mix of “How?” and “Why?” He cautions, “Always question what you know, and keep a sense of humility about the knowledge you *think* you have.”



With vapor moving from left to right, the streamline patterns and the interface locations are shown in the vicinity of the bottom condensing surface in a horizontal channel condenser. For different exit conditions, the results indicate different fluid physics and steady states. Simulations assist in assessing a condenser’s performance in a thermal system. The background contours indicate velocity magnitude (red for the fast vapor at the inlet and blue for the slowest liquid on the condensing surface).