EXPERIMENTAL INVESTIGATIONS of **JET ARRAY IMPINGEMENT HEAT TRANSFER** and **FULL-COVERAGE FILM COOLING**

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ABSTRACT

Experimental results are presented for investigations of jet-array impingement heat transfer, and full-coverage film cooling.

For the impingement array investigation, limited available data suggest a substantial impact of Mach number on the heat transfer from an array of jets impinging on a surface at fixed Reynolds number. Many jet array heat transfer correlations currently in use are based upon tests in which the jet Reynolds number was varied by varying the jet Mach number. Hence, this data may be inaccurate for high Mach numbers. Results from the present study are new and innovative because they separate the effects of jet Reynolds number and jet Mach number for the purposes of validating and improving correlations which are currently in use. The present study provides new data on the separate effects of Reynolds number and Mach number for an array of impinging jets in the form of discharge coefficients, local and spatially-averaged Nusselt numbers, and local and spatially-averaged recovery factors. The data are unique because data are given for impingement jet Mach numbers as high as 0.60 and impingement jet Reynolds numbers as high as 60,000, and because the effects of Reynolds number and Mach number are separated by providing data at constant Reynolds number as the Mach number is varied, and data at constant Mach number as the Reynolds number is varied. As such, the present data are given for experimental conditions not previously examined, which are outside the range of applicability of current correlations.

For the full coverage film cooling study, experimental results are presented for an arrangement which simulates a portion of a gas turbine engine, with appropriate streamwise static pressure gradient and varying blowing ratio along the length of the contraction passage which contains the cooling hole arrangement. Film cooling holes are sharp-edged, streamwise inclined at 20^{o} with respect to the liner surface, and are arranged with a length to diameter ratio of 8.35. The film cooling holes in adjacent streamwise rows are staggered with respect to each other. Data are provided for turbulent film cooling, contraction ratios of 1 and 4, blowing ratios (at the test section entrance) of 2.0, 5.0, and 10.0, coolant Reynolds numbers Re_{fc} from 10,000 to 12,000, freestream temperatures from 75ºC to 115ºC, a film hole diameter of 7 mm, and density ratios from 1.15 to 1.25. Changes to *X/D* and *Y/D*, non-dimensional streamwise and spanwise film cooling hole spacings, with *Y/D* of 3, 5, and 7, and with *X/D* of 6 and 18, are considered. For all *X/D*=6 hole spacings, only a slight increase in effectiveness (local, line-averaged, and spatially-averaged) values are present as the blowing ratio increases from 2.0 to 5.0, with no significant differences when the blowing ratio increases from 5.0 to 10.0. This lack of dependence on blowing ratio indicates a condition where excess coolant is injected into the mainstream flow, a situation not evidenced by data obtained with the *X/D*=18 hole spacing arrangement. With this sparse array configuration, local and spatially-averaged effectiveness generally increase continually as the blowing ratio becomes larger. Line-averaged and spatially-averaged heat transfer coefficients are generally higher at each streamwise location, also with larger variations with streamwise development, with the *X/D*=6 hole array, compared to the *X/D*=18 array.

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Dr. Phil Ligrani is currently the Oliver L. Parks Endowed Chair, and Director of Graduate Programs at Parks College of Saint Louis University. His previous academic position was as the Donald Schultz Professor of Turbomachinery in the Department of Engineering Science at the University of Oxford. There, from 2006 to 2009, he was also Director of Oxford University's Rolls-Royce UTC (University Technology Centre) in Heat Transfer and Aerodynamics. From 1994 to 2006, he was a Professor of Mechanical

Engineering, Adjunct Professor in the Department of Bioengineering, Director of the Convective Heat Transfer Laboratory, and Associate Department Chair in the Department of Mechanical Engineering at the University of Utah. As of January 2012, Dr. Ligrani is author or co-author of more than 140 publications in archival journals, 7 book chapters, as well as approximately 92 conference publications and presentations. From 1995 to 2011, he also presented approximately 74 lectures at different institutions and establishments, including many invited lectures. He has been primary advisor for a total of 79 graduate students completing Ph.D., M.E., M.S. degrees, and Turbomachinery Diplomas. Some of his recent honors, awards, and academic recognitions include:

- Distinguished Advisory Professor, Inje University, South Korea, 2010 to 2012.
- Distinguished Lecture Award, 2011, CEAS Distinguished Lecture Series, College of Engineering, University of Wisconsin, Milwaukee, Wisconsin, USA.
- Distinguished Editorial Review Board membership for Springer Publishing Corporation (2006-present).
- Carl E. and Jessie W. Menneken Faculty Award for Excellence in Scientific Research.
- Invited Keynote Lecture to the Fifth International Symposium on Turbulence, Heat, and Mass Transfer, Dubrovnik, Croatia (2006).
- Associate Editorships for the ASME Transactions-Journal of Fluids Engineering (2005-2008), and the ASME Transactions-Journal of Heat Transfer (2003-2007 and 2010-2013).
- NASA Space Act Tech Brief Award for "Development of Subminiature Multi-Sensor Hot-Wire Probes".
- November 2011, Invited Keynote Paper, 11th Asian International Conference on Fluid Machinery, and 3rd Fluid Power Technology Exhibition, Indian Institute of Technology Madras, Chennai, India.
- November 2011, Invited Keynote Paper, IGTC’11 Osaka, International Gas Turbine Congress 2011 Osaka, Japan.
- June 2011, Silver Winner – Annual 26th Educational Advertising Awards, Higher Ed Marketing, Higher Education Marketing Report.
- May 2011, Invited Lecture, 15th International Symposium on Field- and Flow-Based Separations (FFF2011), CASSS – International Separation Science Society, South San Francisco, California, USA. Research interests include turbomachinery, convective heat transfer, and fluid mechanics, as well as micro-fluidics, fractionation, and separation science, including SPLITT Fractionation.