

## *McMaster University – Marilyn Lightstone CRD*

NSERC/UNENE Collaborative Research and Development Grant  
on Mathematical Modelling of Intersubchannel Mixing



### Overview

This research is concerned with modelling fluid flow and heat transfer in subchannel geometries. Computational fluid dynamics (CFD) is being used to model the flow pulsations that occur in the gap region of nuclear fuel bundles. Simulations are validated against experiments to assess the validity of the models used, in particular the turbulence models. The long term of the research is to develop an improved understanding of the underlying physics of the flow pulsations. This will then allow for development of simple models which capture the important physical phenomena and can be incorporated into industrial safety analysis codes such as ASSERT-PV. The benefit to industry will be more accurate predictions of fuel sheath temperatures as well as development of highly qualified personnel for potential employment in the nuclear industry.

For the period April 2007 to September 2009, two graduate students (George Arvanitis and Deep Home) worked on this UNENE supported research. Their work was computational in nature and the research facilities required were high speed computers as well as the commercial CFD code ANSYS-CFX. The simulations were performed using the quad computers in the Mechanical Engineering CFD Lab as well as the high performance cluster in Dr. John Luxat's laboratory. George and Deep's activities over the period April 2007 to September 2009 are summarised below.

### Research Program

George Arvanitis started his Masters degree in September 2006 on numerical modelling of subchannel flow pulsations using unsteady Reynolds Averaged Navier-Stokes (RANS). George was very productive over the period covered by this progress report. He completed the research for the thesis, the thesis writing, and he successfully defended his thesis in the fall of 2008. His work in unsteady RANS was successful in capturing the experimental results for pulsation frequency with an error of about 15%. He has a number of conference papers (listed below) as well as a recently published journal paper in *Nuclear Engineering and Design*. Although George Arvanitis has Canadian citizenship, he is from Greece and returned to Greece after defending his thesis to complete a mandatory term in the Greek army. He has now completed that term and returned to Canada in November 2009. He is currently in talks with Nuclear Safety Solutions regarding potential employment with them.

Deep Home began his Ph.D. in September 2004. During the period April 2007 to September 2009, Deep focused his research on the simulation of the flow pulsations

using Detached Eddy Simulation (DES) and on writing up the work prior to 2007. DES is a hybrid RANS modelling approach that uses Large Eddy Simulation in the flow regions away from walls, while unsteady RANS is used in the near wall region. Careful modelling is required at the interface between the two regions. He had previously used DES to predict a channel flow problem to allow him to become familiar with DES as well as to validate the method against published Direct Numerical Simulation results. The channel simulations have now been published in the journal *Numerical Heat Transfer*. He has completed the simulation of gap pulsations in subchannel geometries and has validated against experimental data. He has completed a first draft of his thesis and I expect him to defend his Ph.D. in early 2010. Deep has numerous conference papers (including papers at NURETH and the American Nuclear Society meeting in 2009) as well as two journal papers. He will write at least one more journal paper detailing the results of the DES simulations for subchannel flows.

Deep has recently started working at Nuclear Safety Solutions. In many ways, Deep Home is an example of a UNENE success story! He has done great research (with excellent publications) and is now working in the nuclear industry. I expect the same of George.

Meetings were held with the UNENE research advisory committee as the work progressed. These meetings were held at the Bruce Power offices in Toronto in October 2007 and July 2008. We received positive feedback and constructive comments from the RAC.

#### *Journal Publications*

- Home, D., Arvanitis, G., Lightstone, M.F., and Hamed, M.S., 'Simulation of flow pulsations in a twin rectangular sub-channel geometry using unsteady Reynolds Averaged Navier-Stokes modelling', *Nuclear Engineering and Design*, Vol. 239, pp. 2964-2980, 2009.
- Home, D., Lightstone, M.F., and Hamed, M.S., 'Validation of DES-SST based turbulence model for a fully developed turbulent channel flow problem', *Numerical Heat Transfer Part A: Applications*, Vol. 55, pp. 337-361, 2009.

#### **Conference Publications**

- Home, D., Lightstone, M.F., Hamed, M.S., 'Numerical Investigation of Flow Pulsation Phenomena Using DES-SST Approach', *2009 American Nuclear Society Annual Meeting*, Atlanta, Georgia, U.S.A., June 14-18, 2009
- Home, D., Lightstone, M.F., and Hamed, M.S., 'Numerical Investigation of the Flow Pulsation Phenomena in a Twin Rectangular Sub-channel Geometry', *CFD2009*, Ottawa, ON May 3-5, 2009
- Home, D., Lightstone, M.F., and Hamed, M.S., 'Numerical Investigation of Turbulent Flow in a Twin Rectangular Subchannel Geometry', *Proceedings of 29<sup>th</sup> Annual Conference of the Canadian Nuclear Society and 32<sup>nd</sup> CNS/CNA Student Conference*, Toronto, ON, June 1-4, 2008.

- Arvanitis, G., Home, D., Lightstone, M.F., and Hamed, M.S., 'Unsteady Reynolds Averaged Navier-Stokes (URANS) Modelling of Turbulent Flow in a Twin Rectangular Sub-Channel Geometry', *Proceedings of 29<sup>th</sup> Annual Conference of the Canadian Nuclear Society and 32<sup>nd</sup> CNS/CAN Student Conference*, Toronto, ON, June 1-4, 2008.
- Home, D., Lightstone, M.F., and Hamed, M.S., 'Applicability of DES-SST based Turbulence Model for Turbulent Channel Flow Problem', *Proceedings of 15<sup>th</sup> Annual Conference of the CFD Society of Canada*, Toronto, May 27-31, 2007.
- Home, D., Lightstone, M.F., and Hamed, M.S., 'Detached Eddy Simulation based turbulence modeling approach for inter sub-channel thermal mixing', *Proceedings of International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-12)*, Pittsburgh, Pennsylvania, U.S.A., Sept 30-Oct 4, 2007