ERCIM "Alain Bensoussan" Fellowship Scientific Report

Fellow:	**Marek Gayer**
Visited Location :	**Norwegian University of Science and Technology (NTNU), Trondheim, Norway**
Duration of Visit:	**12 months**

I - Scientific activity

During my fellowship, I collaborated with prof. Ole Morten Aamo and his PhD student Milan Milovanovic. Our project dealt with finding strategies for vortex shedding control around cylinders in 2D space domain. My research and responsibility was to make software analysis and implementation of optimal software codes for the solved problems (by means of performance, maintainability and extendibility) in C++ and MATLAB, to allow us to simulate and verify using Computational Fluid Dynamics (CFD) solvers our control strategy proposals.

I made the reengineering, analysis and development of a software framework and application dedicated for simulation and control of incompressible fluid flows. The simulation is based on the Navier-Stokes model with possible control actuation from a customizable control module. Components of the simulation framework are: Computational Fluid Dynamics (CFD) code VISTA featuring a Navier-Stokes solver, Utility library with shared functionality for customizable Flow control modules and the configuration system, which allow defining separate simulation cases. Flow control modules are responsible for performing control calculations and actuation, reading values in flow fields, storing results for post-processing in each time step. By creating eventual new Flow control modules, we can simulate different flow control behaviour and strategies. I realized the simulation solution and it's components in C++ with using VISTA and Diffpack API. The mesh is generated using GRIDDLER by SINTEF ICT Applied Mathematics.

I also developed codes for a case study based on this framework, where the objective is to suppress vortex shedding around cylinders in the 2D space domain by feedback control based module with kernel coefficients pre-calculated in MATLAB using Ginzburg-Landau model.

I have simulated a case study based on the software simulation environment allowing control of vortex shedding in flows around cylinders with a state feedback controller, removing vortex shedding for the Reynolds number = 60. The simulations can be potentially repeated for higher Reynolds numbers, under the condition of providing recomputed kernels for state feedback controller. This contribution resulted in timely submission and acceptance of our article "Model-based Stabilization of Vortex Shedding with CFD Verification" to a prestigious control conference, the 48th IEEE International Conference on Decision and Control.

The characteristics from the computed flow field in whole time and space domain are stored in the VTF format using GLview Express Writer API, embedded in VISTA and also some files

are produced by the Utility library in plain text files, which can be imported in MATLAB. We can post-process these results by using both the MATLAB and GLview Inova. During and after finishing of the simulation, we can monitor in the MATLAB various parameters: applied control values on the slots, force drag and lift, velocities and pressures in the flow field, pressures on the surface of the cylinder and many other parameters for 2D and 3D plots. I developed MATLAB scripts for processing the stored data sets and monitoring the results. My proposal and implementation of file storage system allow performance optimal visualization and monitoring of these results as well as managing and storing of many data sets for both the developers and users.

To run the simulations, our primary focus are installations on remote multiprocessor Linux servers, so that we can eventually compute general, usually complex 3D simulations flow control cases and in future with parallel processing. While this option offers advantages over local installations, namely in terms of performance, I also found this option on the other hand often impractical namely due to lack of development tools on our server, where the simulations were performed, and certain problems with queuing system and performance of transferring simulated data sets over the network. Therefore I had proposed a portable version, which is able to run on local computers with various operating systems. To overcome the portability limitation, as well as difficult installation of Diffpack and VISTA CFD code (which currently runs only on Linux), I have created a solution based on using VmWare virtual machines with Debian Etch Linux as the guest operating system as the base for our local installations.

II- Publication(s) during your fellowship

[1] A Simulation Framework for Testing Flow Control Strategies
M. Gayer, M. Milovanovic, and O. M. Aamo, "A simulation framework for testing flow control strategies," in The 18th International Conference on Applied Simulation and Modelling, (Palma, Spain), pp. 69–76, IASTED, Acta Press, 2009.

[2] Software Platform for Nanoscale Device Simulation and Visualization
M. Gayer and G. Iannaccone, "A software platform for nanoscale device simulation and visualization," in IEEE International Conference on Advances in Computational Tools for Engineering Applications, (Zouk Mosbeh, Lebanon), pp. 432-437, Notre Dame University, Lebanon, July 2009.

[3] Model-based Stabilization of Vortex Shedding with CFD Verification
M. Milovanovic, M. Gayer, and O. M. Aamo, „Model-based stabilization of vortex shedding with CFD, Verification," in 48th IEEE International Conference on Decision and Control, (Shanghai, China), IEEE, 2009.

III -Attended Seminars, Workshops, and Conferences

- The 18th International Conference on Applied Simulation and Modelling (active participance with paper [1])
- IEEE International Conference on Advances in Computational Tools for Engineering Applications (active participance with paper [2]).

IV – Research Exchange Programme (12 month scheme)

1. **SpaRCIM, Spain 14. - 18. September 2009 with Prof. Francisco Marques,** Professor of Applied Physics, Departament de Física Aplicada, Modul B5 Campus Nord, Universitat Politècnica de Catalunya, 8034 Barcelona – Spain, (Tel.) 34-93-401-6897, (Fax) 34-93-401-6090

I was pleased to meet and exchange ideas and presentations with Prof. Francisco Marques and his team. This team is focused on researching problems related to computational fluid dynamics. I have presented my recent work related to software development based on numerical methods and also in environment of computational fluid dynamics control. I appreciate quality of publications and research profile of Prof. Marques as well as his kindness and hospitality. Prof. Marques presented to me various projects solving incompressible flow, often based on spectral methods, and spectral elements, including some strategies for control problems, such as Taylor-Couette flow with problems of control in rotating cylinder.

Perhaps most interesting were projects related to various simulation of offshore and beach shape development by Albert Falqués Serra (such as coastal morfodynamics, evolution of shore-oblique/transverse sand bars, dynamics of sandy coastlines), caused by sea water and transport of sand. Simulations of these problems were based on solving governing partial equations using finite difference method and spectral methods.

My presentations with slides of my work described in above mentioned publications [1, 2 and 3] were accepted with genuine interest. Presentation of DOLFIN/FEniCS, a finite element solver, which is suitable also for incompressible flow resulted in particular interest in using as well on UPC, because this LGPL software package provides framework for creating a basic incompressible Navier-Stokes solver in around 50 lines of code.

2. INRIA, Bordeaux, France, 21. - 25. September 2009 with Prof. Thierry Colin
Institut Universitaire de France, HdR, 351 cours de la Libération, 33405 Talence cedex, France, Tel : (33/0) 5 40 00 21 20, Fax : (33/0) 5 40 00 26 26

I have made presentations for our works and projects described namely in [1, 3] and discussed with team MC2 headed by Prof. Thierry Colin. I have exchanged the ideas namely with prof. Charles-Henri Bruneau and Dr. Iraj Mortazavi. They presented me several interested projects of control around cylinders and pipes using both active and passive strategies, such as for transitional backward-facing step flows, using pulsed inlinet velocities, using porous devices for square back Ahmed body, and using a porous sheath around a pipe.