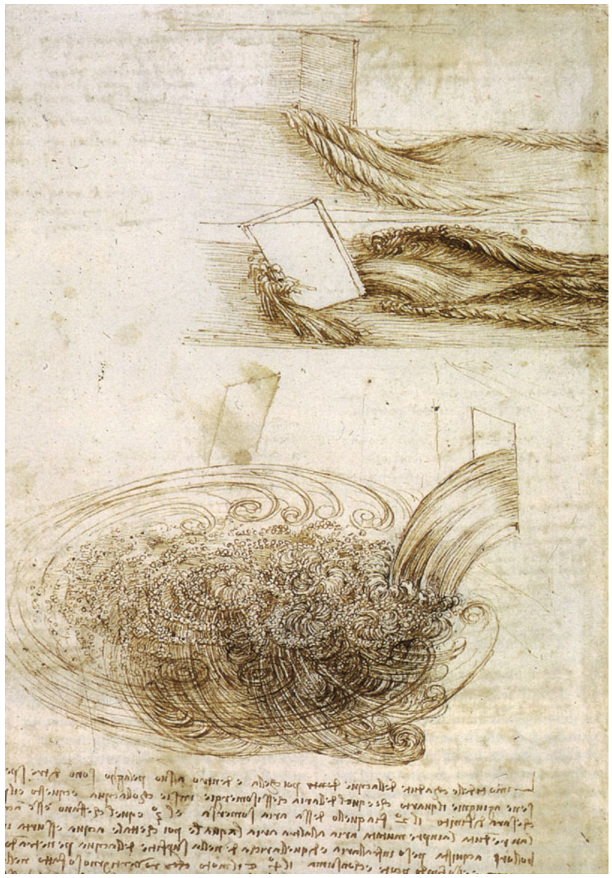
Workshop on

Fluid-Structure Interaction

Dipartimento di Matematica - Politecnico di Milano

March 18-20, 2019



La Turbolenza - Leonardo da Vinci

ORGANIZERS

Denis Bonheure - denis.bonheure@ulb.ac.be
Département de Mathématique, Université Libre de Bruxelles (Belgium)

Filippo Gazzola - filippo.gazzola@polimi.it
Dipartimento di Matematica, Politecnico di Milano (Italy)

SPONSORS

Dipartimento di Matematica - Politecnico di Milano

FNRS (Belgium) - PDR T.1110.14 (FNRS) - Existence and asymptotic behavior of solutions to systems of semilinear elliptic partial differential equations

PRIN 2015 Equazioni alle derivate parziali di tipo ellittico e parabolico: aspetti geometrici, disuguaglianze collegate, e applicazioni

Fonds Thelam de la fondation Roi Baudouin (Belgium) - Mathematical study of the stability of suspended bridges: focus on the fluid-structure interactions

SPEAKERS

Muriel Boulakia - boulakia@ann.jussieu.fr
Laboratoire Jacques-Louis Lions, Université Pierre et Marie Curie, Paris (France)

Marco Bravin - Marco.Bravin@math.u-bordeaux.fr
Institut de Mathématiques de Bordeaux, Université de Bordeaux (France)

Dominic Breit - d.breit@hw.ac.uk
School of Mathematical and Computer Sciences, Mathematics Heriot-Watt University Edinburgh (UK)

Giovanni Paolo Galdi - galdi@pitt.edu
Department of Mechanical Engineering and Materials Science, University of Pittsburgh (US)

David Gérard-Varet - david.gerard-varet@imj-prg.fr
UFR de Mathématiques, Université Paris Diderot (France)

Emmanuel Grenier - emmanuel.grenier@ens-lyon.fr
Unité de Mathématiques Pures et Appliquées, ENS de Lyon (France)

Angelo Iollo - angelo.iollo@math.u-bordeaux.fr
Institut de Mathématiques de Bordeaux and Memphis Team, Université and Inria Bordeaux (France)

Christophe Lacave - Christophe.Lacave@univ-grenoble-alpes.fr
Institut Fourier, Université Grenoble Alpes (France)

Walter Lacarbonara - walter.lacarbonara@uniroma1.it
Dipartimento di Ingegneria Strutturale e Geotecnica, Università la Sapienza di Roma (Italy)

Irena Lasiecka - lasiecka@memphis.edu
Department of Mathematical Sciences, University of Memphis (US)

Boris Muha - borism@math.hr
Department of Mathematics, Faculty of Science, University of Zagreb (Croatia)

Daniele Rocchi - daniele.rocchi@polimi.it
Dipartimento di Meccanica, Politecnico di Milano (Italy)

Sebastian Schwarzacher - schwarz@karlin.mff.cuni.cz
Department of Mathematical Analysis, Karlovy University, Prague (Czech Republic)

Marius Tucsnak - marius.tucsnak@u-bordeaux.fr
Institut de Mathématiques, Université de Bordeaux (France)

Christian Vergara - christian.vergara@polimi.it
Dipartimento di Matematica, Politecnico di Milano (Italy)

Justin Webster - websterj@umbc.edu
Department of Mathematics and Statistics, University of Maryland, Baltimore (US)

	Monday, March 18	Tuesday, March 19	Wednesday, March 20
09:10		**I. Lasiecka**	**J. Webster**
10:00		**D. Breit**	**M. Tucsnak**
10:50		*coffee break*	*coffee break*
11:20		**B. Muha**	**E. Grenier**
12:10		**C. Lacave**	**G.P. Galdi**
13:00		*lunch*	*lunch*
14:00	*welcome*		
14:30	**D. Gérard-Varet**	**A. Iollo**	
15:20	**S. Schwarzacher**	**W. Lacarbonara**	
16:10	*coffee break*	*coffee break*	
16:40	**M. Boulakia**	**D. Rocchi**	
17:30	**M. Bravin**	**C. Vergara**	

TITLES AND ABSTRACTS

Muriel Boulakia: Well-posedness for the coupling between a viscous incompressible fluid and an elastic structure

Abstract: In this talk, we consider a system modeling the interaction between a viscous incompressible fluid and an elastic structure. The fluid motion is represented by the Navier-Stokes equations while the elastic displacement is described by the linearized elasticity equation. The elastic structure is immersed in the fluid and the whole system is confined into a general bounded smooth domain. Our main result is the local in time existence and uniqueness of a strong solution of the corresponding system. This work is a joint work with Sergio Guerrero and Takeo Takahashi.

Marco Bravin: Energy equality and uniqueness for weak solutions of a "fluid+rigid body" interaction problem

Abstract: This talk will focus on the uniqueness of weak solutions for a fluid-structure interaction problem. The system of equations describe the motion of a rigid body which is moving in a bounded two dimensional domain fulfilled by an incompressible viscous fluid and on the boundaries are prescribed Navier-slip conditions. The goal of this talk is to present some tools to solve this types of problem. During the talk I will present the main ideas to prove the energy equality, the continuity in time for the solutions, a duality paring for time dependent domains and finally a perturbation argument to prove existence of strong solutions for fluid-structure problems based on $\mathcal{R}$-boundedness. All these steps permit us to prove uniqueness.

Dominic Breit: Compressible fluids interacting with a linear-elastic shell

Abstract: We study the Navier–Stokes equations governing the motion of an isentropic compressible fluid in three dimensions interacting with a flexible shell of Koiter type. The latter one constitutes a moving part of the boundary of the physical domain. Its deformation is modeled by a linearized version of Koiter's elastic energy.We show the existence of weak solutions to the corresponding system of PDEs provided the adiabatic exponent satisfies $\gamma > \frac{12}{7}$ ($\gamma > 1$ in two dimensions). The solution exists until the moving boundary approaches a self-intersection.

Giovanni Paolo Galdi: On the Phenomenon of Self-Oscillations of a Navier-Stokes Liquid past a Cylinder

Abstract: We provide sufficient conditions for branching out of time-periodic solutions from steady-state solutions to the two-dimensional Navier-Stokes equations in the exterior of a cylinder. The main difficulty consists in the fact that the relevant linearized operator presents a continuum spectrum that includes 0, for any value of the Reynolds number. This circumstance makes all available theories inapplicable to the case at hand. We also furnish detailed results on the asymptotic spatial behavior of the flow that shows, in particular, that the purely oscillatory motion occurs downstream, essentially only in a neighborhood of the cylinder, whose size increases with the Reynolds number.

David Gérard-Varet: Recent results on the Prandtl equations

Abstract: We will discuss the stability properties of the Prandtl equation, which is a celebrated model of the so called boundary layer, that develops in high Reynolds number flows near rigid boundaries. We shall notably discuss a recent well-posedness result obtained with H. Dietert.

Emmanuel Grenier: Instability of viscous shear layer

Abstract: This talk is a review of recent progresses in the study of the linear and nonlinear instability of shear layers near a boundary for Navier Stokes equations when the viscosity vanishes.

Angelo Iollo: Multimaterial Numerical Models

Abstract: The study of multimaterial phenomena requires advanced numerical modeling. These problems are difficult to handle by traditional theoretical approaches, challanging or hazardous to study in the laboratory or time-consuming and expensive to solve by classical numerical means. Our objective is to simplify the numerical modeling of problems involving several materials such as hyper elastic-plastic solids, water or air, evolving in regimes going from high to low mach. Rather than using extremely optimized but non-scalable methods, we adopt eulerian numerical models that bypass certain modeling difficulties when the boundaries are moving and the topology is complex and unsteady. The main elements of this approach are an implicit representation of the material interfaces and ad hoc models for the equilibrium interface conditions. In this talk we will focus on compressible hyper-elastic materials and their incompressible limits. We will present numerical illustrations of the evolution of fluid/fluid, solid/fluid and solid/solid interfaces in several mach regimes. Work in collaboration with E. Abbate, M. Bergmann, F. Bernard, A. Fondanĉhe, G. Puppo

Christophe Lacave: Long time and small obstacle problem for the 2D Navier-Stokes equations

Abstract: We consider rigid bodies moving under the influence of a viscous fluid and we study the asymptotic as the size of the solids tends to zero. In a bounded domain, if the solids shrink to “massive” pointwise particles, we obtain a convergence to the solution of the Navier-Stokes equations independently to any possible collision of the bodies with the exterior boundary. In the case of “massless” pointwise particles, the energy equality is not sufficient anymore to derive a uniform estimate for the velocity of the solid. Our basic remark is that the small obstacle limit is related to the long-time behavior though the scaling property of the Navier-Stokes equations $u^{\epsilon}(t,x) = \epsilon^{-1}u^{1}(\epsilon^{-2}t, \epsilon^{-1}x)$. Hence, we derive $L^p - L^q$ decay estimates for the linearized equations in the exterior of a unit disk. We then apply these estimates to treat the massless pointwise particle. These works are in collaboration with S. Ervedoza, M. Hillairet and T. Takahashi.

Walter Lacarbonara: Flutter control of long-span bridges

Abstract: Long-span suspension bridges exhibit a high bending-torsional slenderness. The high compliance together with the high width-to-depth ratio of the typical boxed, sharp-edge, deck cross sections emphasize the dynamic effects of the aerodynamic loads ensuing from wind-structure interaction. Thus, a variety of dynamic instability phenomena, including flutter, galloping, buffeting, affect these structures and represent the most serious limit state. We first show that aerodynamic phenomena can be unfolded effectively in the framework of a nonlinear parametric bridge modeling approach accounting for the geometric nonlinearities of the suspension cables and of the deck-girder. Such modeling relies on a geometrically exact theory which puts together originally the kinematics of the different parts of the system and the balance of linear and angular momentum. We then discuss new flutter control strategies based on the use of nonlinear vibration absorbers that improve the aerodynamic stability of these bridges. The control system consists of clusters of pairs of vibration absorbers whose restoring forces exhibit properly tailored hysteresis whose dissipation grows at larger rates than the negative damping of the self-excited aerodynamic forces past the flutter condition. It is shown that such control architecture has the ability to shift the flutter and to mitigate the limit cycle oscillations occurring in the post-flutter regime.

Irena Lasiecka: Stabilization and Control of a 3-D fluid-structure interaction

Abstract: We consider an interface problem consisting of a 3D-fluid equation interacting with a 3-D dynamic elasticity. The interface is moving according to the speed of the fluid. The PDE system is modeled by system of partial differential equations describing motion of an elastic body inside an incompressible fluid. The fluid is governed by Navier-Stokes equation while the structure is represented by the system of dynamic elasticity with weak dissipation. The interface between the two environments undergoes oscillations which lead to moving frame configuration, the latter giving rise to a quasilinear system. It is shown that under small disturbance hypothesis solution exist globally in time. Stability [in time] of such solutions is also considered. The obtained results depend on topological properties of the spaces under consideration. Control problem corresponding to minimization of vorticity or hydrodynamic pressure subject to constraints is discussed. The problem is motivated by applications arising in bio-mechanics, aeroelasticity and industrial processes. In the presence of weak damping affecting the solid the control-to-observation map is proved global-so that the size of the data can be chosen uniformly in time. This allows consideration of an infinite time horizon control problem. The latter depends on the global existence results obtained recently with M. Ignatova, I. Kukavica and A. Tuffaha.

Boris Muha: Analysis of a Fluid-Structure Interaction Problem Arising in Hemodynamics

Abstract: Fluid-structure interaction (FSI) problems describe the dynamics of multi-physics systems that involve fluid and solid components. These are everyday phenomena in nature, and arise in various applications ranging from biomedicine to engineering. Mathematically, FSI problems are typically non-linear systems of partial differential equations (PDEs) of mixed hyperbolic-parabolic type, defined on time-changing domains (i.e., moving boundaries). In this talk I will formulate an FSI problem describing blood flow through a compliant vessel treated with biomedical device called a stent. I will illustrate the main features of the FSI problem, as well as main challenges arising in the PDE analysis of such FSI problems. I will also describe a numerical method for a class of FSI problems that, in this case, leads to a proof of existence of weak solutions to the PDE system. This is joined work with S. Čanić, M. Galić, M. Lulj, J. Tambača and Y. Wang.

Daniele Rocchi: Aerodynamic non-linearities in modelling bridge aeroelasticity

Abstract: Numerical modelling of wind-bridge interaction has to take into account the non linear dependency of aerodynamic forces on different parameters: reduced velocity, wind-bridge angle of attack, motion amplitude. Usually, linearized models are used to design long span bridges due to the complexity to develop fully non linear models but some of the non linear aerodynamic effects are dominant when very long span bridges are considered and multi-box deck sections are adopted or when vortex induced vibrations have to be modelled. An overview of some wind tunnel experimental procedures to highlight aerodynamic non-linear effects and on their numerical modelling will be presented.

Sebastian Schwarzacher: Existence and regularity for a non-linear Koiter shell interacting with an incompressible fluid

Abstract: We study the unsteady Navier Stokes equations in two and three dimensions interacting with a non-linear flexible shell of Koiter Type. The latter one constitutes a moving part of the boundary of the physical domain of the fluid. This leads to a coupled system of PDES. The fluid-structure interactions is captured in form of a weak momentum equation, where the space of testfunctions is part of the concept of solutions. We introduce new methods that allow to prove higher regularity estimates for the shell and (in case of two dimensions) the fluid. Due to the improved regularity estimates it is then possible to extend the known existence theory to weak solutions for non-linear Koiter shell models. This is a work that was achieved in collaboration with B. Muha (Univ. of Zagreb).

Marius Tucsnak: THE PISTON PROBLEM: WELL-POSEDNESS, STABILITY AND CONTROLLABILITY

Abstract: We consider the coupled PDEs/ODEs system modelling the motion of a solid in a viscous heat conducting gas. We first develop a systematic approach to obtain local well-posedness and asymptotic stability results. We next show that in the one dimensional case (the piston problem) some of our results are global. We also discuss the so called "adiabatic piston" problem, which is still of big interest in statistical physics. Finally, we show that for a simplified problem we obtain finite time controllability.

Christian Vergara: CONVERGENCE AND STABILITY OF PARTITIONED ALGORITHMS FOR THE FLUID-STRUCTURE INTERACTION PROBLEM

Abstract: The numerical solution of the fluid-structure interaction problem is a challenging issue. To exploit existent fluid and structure numerical methods and codes, partitioned algorithms, based on the successive solution of the two subproblems, have been studied and applied in many contexts. However, when the fluid and structure densities are similar (large *added mass effect*), partitioned explicit schemes may fail to be stable, whereas partitioned implicit schemes require a very small relaxation to converge.
In this talk, we discuss the stability and convergence of partitioned schemes based on Robin transmission conditions. In particular, a suitable choice of the parameters in the Robin conditions could improve the stability and convergence properties of partitioned schemes in presence of large added mass effect. Accordingly, we show and discuss several convergence analysis and optimization of the interface parameters for implicit schemes obtained for different geometric configurations of the fluid-structure interface (flat, cylindrical, spherical). Moreover, we theoretically investigate the stability of explicit schemes as a function of the interface parameters. For all these theoretical findings, we will show correspondingly three-dimensional numerical results taken from hemodynamics, a field where the added mass effect is relevant.

Justin Webster: MODELING AND ANALYSIS OF AXIAL FLOW CANTILEVER FLUTTER

Abstract: Flutter is a self-excitation instability of an elastic structure in a surrounding fluid flow. Much can be said at the qualitative level about panel, flag, and airfoil flutter, as these phenomena are of great interest in engineering. On the other hand, rigorous well-posedness and long-time behavior analyses are comparatively few. Beyond clear applications in aerospace engineering, flutter arises in the biomedical realm and also in sustainable energies. Motivated by interest in *piezoelectric energy harvesting*, we consider large deflection PDE models of an elastic cantilever driven by non-conservative terms. We briefly describe results for a *panel flutter* model, a simpler situation involving a fully clamped plate in an inviscid potential flow. We then discuss the ways in which the modeling and analysis break down if a portion of the structural boundary is free. For the flow, we must consider a mixed boundary value hyperbolic problem involving the *Kutta-Joukowsky condition*; for the cantilever, an *inextensibility* constraint leads to nonlinear (and nonlocal) inertia terms and quasilinear stiffness terms. The associated analytical challenges reflect the difficulty in modeling the physics of the problem. Recent well-posedness and stability results for the inextensible cantilever will be given, corroborated by modal simulations (in both 1 and 2-D) driven by non-conservative terms.