Waves in Fluids III

IMPA, Rio de Janeiro, Brasil, June 5-11, 2011

Book of Abstracts

A hydrostatic model for atmospheric convection

Esteban Tabak, Courant Institute, NYU, NY, USA
Paul Milewski, University of Wisconsin, Madison, WI, USA

From a global perspective, the core of the atmosphere is a very shallow fluid layer: a few tens of kilometers of air surrounding a planet with a circumference of 40 thousand kilometers. Hence its long waves can be modeled as hydrostatic. Yet the atmosphere is to a large extent heated from below, giving rise to convective instabilities –our storms– which rule much of its dynamics. Therefore, in order to build simple conceptual models for the global structure of the atmosphere, one needs to find a way to represent the effect of convective instabilities within a hydrostatic framework. This talk will describe one such conceptual model, where one or more layers of fluid representing the troposphere excite convective activity in a thin boundary layer, leading to storms and mixing, represented in this hydrostatic model through breaking waves. The model will be applied to validate a novel theory that accounts for the meridional extent of the tropics in terms of the waves excited by the diurnal cycle of solar radiation.

Internal waves and wave-induced mean flows in the ocean

Oliver Buhler, Courant Institute, NYU, NY, USA

The ocean contains significant energy in the form of internal waves and these waves interact in complicated ways with the topography of the sea floor. This talk will focus on internal waves that are generated by the lunar tides and how these "internal tides" interact with topography. In addition to predictions from linear wave theory, recent results on the nonlinear mean flow generated by the internal waves will be presented.

Bifurcation from minimal wave-speed

Paul Milewski, UW Madison, USA

There has been many studies on the bifurcation of nonlinear solitary surface waves in two- and three-dimensions about the minimum of the phase-speed at a finite wavelength. This minimum can occur in various physical instances such as in capillary-gravity or in flexural-gravity waves. We shall give a more complete picture of the bifurcations and show how newly found dark solitons play a role.

Bifurcation and resonance in standing water waves

Jon Wilkening, UC Berkeley, USA

We develop a trust-region shooting algorithm for solving two-point boundary value problems governed by nonlinear PDE. We use our method to compute families of space-time periodic solutions of the gravity-driven water wave in two and three dimensions, focusing on questions of stability, resonance and the effect of small divisors. To evolve the interface in time, we use a spectrally accurate boundary integral collocation method in 2d, and a 5th order finite element method in 3d. The calculations are performed in double and quadruple precision using a workstation with a 448 core GPU. We also answer negatively a long-standing conjecture of Penney and Price about the existence of a limiting standing wave of maximum amplitude that forms a sharp, 90 degree interior crest angle each time the fluid comes to rest. The work in 3d is joint with Chris Rycroft.

Multi-Scale Interactions and the Diurnal Cycle in the Tropics

Carlos F. M. Raupp, Dept. of Atmospheric Sciences, USP, São Paulo, Brazil.

In the large-scale atmospheric dynamics are two basic kinds of wave motions, namely the low-frequency Rossby waves that are characterized by an approximate geostrophic balance and the high frequency inertio-gravity waves (also called Poincaré waves), which depart considerably from geostrophic equilibrium and are thus mostly related to deep convective cells. Due to the large time-scale separation between these two wave types, these modes have been treated of completely different ways in numerical weather forecast models. While the Rossby modes are responsible for the evolution of synoptic scale weather disturbances, the Poincaré modes are in principle irrelevant for synoptic-scale weather forecast, being essentially considered as a noise in atmospheric general circulation models. In the midlatitude dynamics where baroclinic instability is the main energy source for large-scale atmospheric disturbances, this approach has shown to be reasonable and justifies the good skill of weather forecasts in the extratropics.

Nevertheless, in the tropical region the meridional temperature gradient associated with the solar forcing is weak and, consequently, the main energy source for synoptic and planetary scale wave disturbances is associated with clouds and moist convection through scale interactions. As a consequence, the atmospheric general circulation numerical models generally poorly represent either the diurnal cycle of tropical convection and the large to planetary scale convectively coupled tropical disturbances. In this context, in the present talk I will discuss about the possibility of an inertio-gravity mode to excite a Rossby mode in view of the wave interaction mechanisms and present a linear wave interaction theory involving equatorially trapped Rossby and Poincaré modes through the diurnal cycle of the background moisture field in the context of deep convection parameterization. The difficulty of atmospheric general circulation models in representing planetary scale wave disturbances in the tropics will also be discussed in view of the present theory.

Raupp, C. F. M.; Silva Dias, P. L. Interaction of equatorial waves through resonance with the diurnal cycle of tropical heating. Tellus, 62A, 706-718, 2010.

Financial Support: FAPESP

The stability of large-amplitude shallow interfacial non-Boussinesq flows

Anakewit Boonkasame, University of Wisconsin, Madison, USA.

Nonlinear stability – or long-time well-posedness – of two-layer flows under the shallow-water assumption and with the Boussinesq approximation has been studied in a number of previous works, e.g. [2] and [3]. In the current work, we examine nonlinear stability of two-layer flows under the shallow-water assumption but without the Boussinesq approximation. (Our formulation also lends itself to taking the Boussinesq approximation in a systematic manner.) We use simple waves to give a priori bounds to solutions of the resulting system of equations and we construct a region in the phase space within which solutions evolving from hyperbolic initial data remain hyperbolic up to breaking.

References:

1. A. Boonkasame, P. A. Milewski, "The stability of large-amplitude shallow interfacial non-Boussinesq flows", to appear in Stud. App. Math.
2. L. Chumakova, F. E. Menzaque, P. A. Milewski, R. R. Rosales, E. G. Tabak, and C. V. Turner, "Stability properties and nonlinear mappings of two and three-layer stratified flows", Stud. Appl. Math. (2009), 123-137.
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Stabilized edge-based finite element computation of gravity currents in lock-exchange configurations

Alvaro Coutinho, Center for Parallel Computations and Department of Civil Engineering, UFRJ, Rio de Janeiro, Brazil.

Modeling of gravity current flows is important in many problems of science and engineering. Gravity currents are primarily horizontal flows driven by a density difference of few per cents. This phenomenon occurs in many scales in nature, such as ocean and marine flows, sea breeze formation, avalanches, turbidite flows, etc. Most of the gravity current simulations employ structured grid or spectral methods. In this work, we simulate gravity-driven flows by a parallel stabilized edge-based finite element code with particular emphasis on the simulation of the lock-exchange problem for planar and cylindrical configurations. Our results are validated against other highly resolved numerical simulations and experiments.

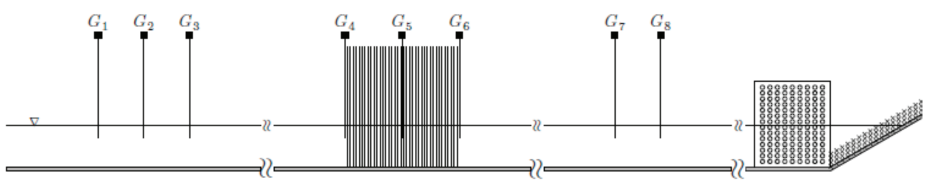
Long Waves through a Submarine Forest

Chiang C. Mei, Civil and Environmental Engineering, MIT.

Motivated by the observed effectiveness of wave damping by mangroves, there have been suggestions of planting a strip of forest (Green Belt) along the coast for protection against tsunami. As an initial step in mathematical modeling, we study the effects of emergent coastal forests on the propagation of long surface waves of small amplitudes. The forest is idealized by a tight array of vertical cylinders. Simple models are employed to represent bed friction and to simulate turbulence generated by flow through the tree trunks. A multi-scale (homogenization) analysis similar to that for seepage flows is carried out to deduce the effective equation on the macro-scale by proper averaging over the periodic cells on the microscale. The effective coefficients are calculated by numerically solving the micro-scale problem in a unit cell surrounding one or several cylinders. Analytical and numerical solutions for wave attenuation on the macro-scale for different bathymetries are presented. For a transient incident wave, analytical results are discussed for the damping of a leading tsunami. For comparison a series of laboratory data for periodic waves simulating long-period infragravity waves, as well as transient incident waves simulating tsunamis, are also presented. Good agreement is found between data and predictions even though some of the measured waves are short or quite nonlinear.

The asymptotic technique of homogenization can be extended to solute dispersion in waves through vegetated waters.

This work is a collaboration between P.L-F Liu and I. C. Chan of Cornell University , Z.H. Huang and W. B. Zhang of Nanyang Technological University of Singapore.



Ocean wave energy: an asset and a threat

Freédéric Dias, Department of Mathematics, University College Dublin.

This talk will present some surprising results related to freak waves and discuss the mathematical and numerical challenges facing the research on wave energy conversion.

Stability of finite amplitude capillary waves

Wooyoung Choi, NJIT, Newark, NJ, USA.

We study the linear stability of the exact deep water capillary wave solution of Crapper (1957) subject to two-dimensional perturbations (both subharmonic and superharmonic). By linearizing a set of exact one-dimensional nonlocal evolution equations, a stability analysis is performed with the aid of Floquet theory. To validate our results, the exact evolution equations are integrated numerically in time and the numerical solutions are compared with the time evolution of linear normal modes.

Flow Around a Slender Cylinder: The Ginzburg-Landau Equation

J. A. P. Aranha, NDF-EPUSP, São Paulo, Brazil.

The complex Ginzburg-Landau Equation (GLE) has been used as a phenomenological model to describe some qualitative features of a class of problems related to a distributed supercritical Hopf bifurcation; in this context, Monkewitz and collaborators described with GLE some neat observed behaviors of the flow around a slender circular cylinder in the range $60 \leq Re \leq 140$. The phenomenological extension to the range above $Re \approx 188$, where the 2D solution becomes unstable with respect to 3D perturbation (Benjamin-Feir instability) and the actual flow becomes chaotic, is impaired by the difficulty to recognize experimentally the Re-dependence of the GLE coefficients in this hostile environment. The purpose of the present research is to extend this analysis far beyond $Re \approx 188$ once it has been shown (see Aranha (2004)) that GLE is an asymptotic solution of the full 3D Navier-Stokes equation: by solving numerically the 2D well behaved problem, where the solution is periodic in a large range of Reynolds numbers (roughly for $Re \leq 105$), one can infer asymptotically the 3D correction by means of an amplitude function that satisfies the GLE, with coefficients that can be determined from the solution of a linear equation defined in the cross section plane. The final goal is to obtain a reduced Navier-Stokes equation defined along the cylinders span, that coupled to the elastic equation allows one to estimate the fatigue life of a riser in an offshore production system. This is a work in progress and in present talk three points will be explored: first, to present the practical and conceptual context of the research; second, to show the qualitative ability that GLE has to describe the main features of the actual 3D problem, including some strong chaotic behavior; third, to give an overview of the asymptotic approximation that leads to the reduced Navier-Stokes equation.

Holmboe instability in non-Boussinesq fluids

Ricardo Barros, IMPA, Rio de Janeiro, Brazil

We perform the stability analysis for stratified shear flows whose density transition layer is much thinner than, and, possibly, displaced with respect to, the velocity shear layer for which Holmboe instability along with the well-known Kelvin-Helmholtz instability is known to be present. Here, we provide a more complete picture of stability characteristics of stratified shear flows with taking into account the effects of non-negligible density increment for which the classical Boussinesq approximation is no longer valid. We corroborate some of the experimental results by Lawrence et al. (1991) and reveal some interesting predictions as a result of the approach.

Internal Wave Models

Ailín Ruiz de Zárate, S.P. Oliveira, Department of Mathematics, UFPR, Curitiba, Brazil
A. Nachbin, IMPA, Rio de Janeiro, RJ, Brazil
D. G. Alfaro Vigo, UFRJ, Rio de Janeiro, RJ, Brazil
W. Choi Department of Mathematical Sciences, NJIT, USA

In the context of ocean and atmosphere dynamics, we present a reduced strongly nonlinear one-dimensional model for the evolution of internal waves over an arbitrary topography. This model is a generalization of the one proposed in Choi and Camassa (JFM 1999). The reduced model aims at obtaining an efficient numerical method for a two-dimensional problem with two layers containing inviscid, immiscible, incompressible and irrotational fluids of different densities. The upper layer is shallow compared with the characteristic wavelength at the interface of the two-fluid system, while the bottom region's depth is comparable to the characteristic wavelength. The non-linear evolution equations describe the behaviour of η (the internal wave elevation at the interface) and u (the mean upper-velocity) for this water configuration. Some important aspects will be discussed such as: dispersion relations, the nonlocal effect of the Hilbert Transform on the strip and the use of a conformal mapping to handle general topography profiles which introduces terrain following coordinates and a variable coefficient accompanying each spatial derivative.
To solve our model approximately we implemented a numerical scheme based on the method of lines. Two particularities of the model deserve special attention: the dispersive term with a singular integral operator and the variable coefficient accounting for the topography information, which could be in a rapid scale. To deal numerically with a dispersive term an auxiliary variable V is introduced. The evolution in time is made on η and V. We implemented a fourth order Runge-Kutta time-integration scheme, which was also the choice of Choi and Camassa, and a fourth order approximation using a centered five point formula for the spatial derivative. This is our best choice in terms of stability, up to now. When the nonlinearity is weak and the bottom is flat, we recover u from η and V (after each time step) by going to Fourier space via FFT. In the presence of rough bottom (variable coefficients) or strong nonlinearity, this efficient strategy does not work and we must solve a linear algebraic system involving spectral matrices. By using a spectral matrix instead of an FFT, we are paying a price in complexity but not in accuracy. This is an ongoing research. This approach may not be the best for multiple scale problems, and we are currently investigating the use of the alternate trapezoidal quadrature method instead. Some preliminary results from the Matlab implementations will be shown, including periodic topography experiments and solitary waves solutions.

Active Fluids

Mike Shelley, Courant Institute, NYU, NY, USA

Active fluids are suspensions internally driven by a dynamic microstructure, such as many immersed microswimmers, or by motor proteins that pull on structures immersed in a cell's cytoplasm. I will discuss recent progress on understanding the dynamics of active motile suspensions, such as bacterial baths, using simulations of many discrete swimming particles and a first-principles continuum kinetic theory. Extensions include coupling the hydrodynamic theory to a chemotactic response of the microswimmers.

Wave Turbulence: A story far from over

Alan Newell, Department of Mathematics, University of Arizona.

Wave turbulence is about understanding the long time statistical behavior of a sea of weakly nonlinear, random, interacting wavetrains. The facts that it has a natural asymptotic closure and a kinetic equation whose solutions capture not only the thermodynamic states of isolated systems but also the Kolmogorov solutions of nonisolated ones tends to be seen as suggesting that wave turbulence is a solved problem. Nothing could be further from the truth. In this lecture, I will briefly discuss why this is so and what some of the outstanding challenges are.

Two and a half problems

André Nachbin, IMPA, Rio de Janeiro, Brazil

In this talk I will present recent results on two problems. First, in collaboration with A.M. Luz, we consider an amplitude modulation theory for waves over a highly disordered topography. An effective nonlinear Schrodinger equation arises and the topography has an impact on the stability of Stokes waves. The analysis follows that by Mei and Hancock (JFM, 2003). Second, in collaboration with T. Fokas, we revisit the non-local water wave formulation by Ablowitz, Fokas and Musslimani (JFM, 2006) and include the presence of a topography.

Principal Component Analysis (Dimensionality Reduction) of the Water Wave Problem

Nathan Kutz, Department of Applied Mathematics, University of Washington, USA

One of the most important uses of computational methods and techniques is in its applications to modeling of physical, engineering, or biological systems that demonstrate spatio-temporal dynamics and patterns. For instance, the field of fluid dynamics fundamentally revolves around being able to predict the time and space dynamics of a fluid through some, potentially complicated geometry. Understanding the interplay of spatial patterns in time indeed is often the central focus of the field of partial differential equations. In systems where the underlying spatial patterns exhibit low-dimensional (pattern forming) dynamics, then the application of the proper orthogonal decomposition can play a critical role in predicting the resulting low-dimensional dynamics. We consider the dynamics and stability of time-periodic standing surface gravity waves using a dimensionality reduction technique based on the Proper Orthogonal Decomposition (POD). The reduced model qualitatively reproduces the entire solution branch, from the low-amplitude sinusoidal solutions to the high-amplitude solutions with sharply peaked crests, thus demonstrating that the timeperiodic standing wave solutions, along with their bifurcations structure and stability, can be considered in a low-dimensional framework when the proper basis is selected.

Resonantly Forced KdV Equations

David Amundsen, Carleton University, Canada

The periodically forced KdV equation and its variants provide a model of nonlinear wave phenomena in a wide range of physical contexts. Such models capture the balance between dispersive and nonlinear effects in the presence of strong periodic forcing. This in turn gives rise to a rich array of solutions when the frequency is at or near resonance. I will provide a survey of the key characteristics of these systems and their solutions. In particular I will discuss an analytic framework for characterizing and approximating solutions in the limit that dispersive effects are weak. Various forms of nonlinearity will be considered and the effects of weak dissipation will also be included. In particular I will draw connections between the well known quadratic (KdV), and cubic (mKdV) cases. While the primary focus will be on steady solutions, I will also briefly discuss transient effects and stability characteristics.

Self sustaining traffic shocks

Ruben Rosales , Department of Mathematics, MIT, Cambridge, USA.

An analogy between traffic flow continuum models and reacting gas dynamics is exploited to obtain a theory for fully developed phantom jams. Phantom jams arise without apparent cause in many roadways for high enough traffic densities. For inviscid second order traffic flow continuum models, this phenomena is associated with a (linear) instability of the uniform density state. This instability saturates into a self-sustaining upstream traveling wave with an embedded shock: the jamiton. These waves are mathematically analogous to Chapman-Jouguet Detonations in combustion theory: a shock with an attached exothermic reaction zone, isolated from the rest of the flow by a sonic point. Numerical calculations show that these nonlinear waves are attracting solutions, with the time evolution of the system converging towards a jamiton dominated configuration.

Some issues on the numerical approximation of nonlocal operators

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A. Nachbin, IMPA, Rio de Janeiro, Brazil

In the context of modeling internal water waves, some strongly nonlinear reduced models exhibit a nonlocal term involving a Hilbert transform on the strip. To perform a careful stability analysis and detect whether numerical solutions are reliable or spurious, it is necessary to adapt the classical von Neumann analysis to account for nonlocal dispersive terms. We address this issue by a fully-discrete analysis of the one-dimensional linear model, in the flat bottom case. We found a formula for the amplification factor that provides estimates concerned with numerical stability and dispersion (namely phase errors). We contrast the numerical properties of the original dispersive problem with that of the underlying non-dispersive case, namely a linear hyperbolic system and verify that the physical regularization provided by a nonlocal (singular integral) dispersive term allows for less restrictive stability conditions. We also discuss the spectral properties of a numerical integration of the nonlocal term by the alternate trapezoidal rule. For some convolution-type integral kernels, such a quadrature method always yields eigenvalues with double multiplicity.

Instability of solitary waves on the surface of a shallow channel

Juan Carlos Muñoz, Universidade del Valle, Cali, Colombia.

The first experimental observation of solitary waves performed by Scott Russell (1844) suggested that these waveforms appear to be highly stable states of motion, which propagate without changing their shape over time. In the literature, several dispersive-type models, such as the Korteweg-de Vries equation and Boussinesq-type systems has been used to describe this phenomenon, but physical derivations of these models neglect surface tension effects. In this talk we consider the generalized Benney-Luke equation

$$\Phi_{tt} - \Phi_{xx} + a\Phi_{xxxx} - b\Phi_{xxtt} + n\Phi_t(\Phi_x)^{n-1}\Phi_{xx} + 2(\Phi_x)^n\Phi_{xt} = 0, \tag{1}$$

which is a model (if $n = 1$) for the propagation of water waves on the surface of a channel with shallow depth, taking into account surface tension effects. Here $\Phi = \Phi(x,t)$ denotes the fluid's velocity potential at position x and time $t > 0$, a, b are positive numbers such that $a - b = \sigma - 1/3$, and σ is named the Bond number, which captures the effects of surface tension and gravity force. We present analytical and numerical results concerning existence and orbital stability/instability of travelling-wave solutions of equation (1) for some ranges of the model's parameters and wave speed. The instability mechanism of these standing-wave solutions is illustrated by means of numerical simulation.

Dynamics of Nonlinear Gravity-Capillary Waves

Zhan Wang, University of Wisconsin, Madison, USA.

We consider the evolution of free surface water waves on an ideal fluid in deep water under the influence of both gravity and capillarity. In two-dimensions the fully nonlinear time dependent problem is solved by parametrized conformal mapping technique. The stability properties for elevation and depression solitary waves, previously predicted by several model equations, are confirmed by the full Euler equation. Both Head-on and overtaking collisions are studied numerically.

In three-dimensions a cubic model equation motivated by the work of Craig and Sulem is presented. We show that the model equation precisely agrees with the full Euler equation near the bifurcation point for line solitary waves. For lump or fully localized three dimensional solitary waves we show evidence that current computations of the full Euler equations are not sufficiently resolved. The stability properties and the focussing phenomena of these waves are investigated via numerical time evolution of the equation.

A macroscopic type of wave-particle duality: from chaotic individual trajectories to probabilities

Yves Couder & E. Fort, Matière et Systèmes Complexes, Université Paris Diderot, France.

A droplet bouncing on a vertically vibrated liquid interface can become dynamically coupled to the surface waves it excites. The droplet and its associated wave thus become spontaneously propagative and form a "walker". Through several experiments we will address one central question. How can a continuous and spatially extended wave have a common dynamics with a localized and discrete droplet? Does a form wave-particle duality emerge?

We will first describe the complex structure of the wave-field (1) and show that it results from the superposition of waves generated in the points visited by the droplet in the recent past. Its interference structure thus contains what we have called a "wave mediated path-memory". The situation is simple when the walker has a rectilinear motion. However in all other situations this spatial and temporal non-locality generates interesting effects.

Two situations will be specifically discussed:
- The orbital motion of a walker when the droplet is submitted to a transverse force (2). We will show that in the presence of path memory the measured orbit radius, instead of varying continuously with the force, can only take quantized values.
- The reaction to attempts of spatial confinement. We find that in this situation the trajectory of an individual walker (3) becomes disordered. However statistical analyses show that deterministic mean behaviours have been maintained, giving rise to well determined probabilities. The limits in which these results can be compared to those at quantum scale will be discussed.

(1) A. Eddi, E. Sultan, J. Moukhtar, E. Fort, M. Rossi, and Y. Couder. J. Fluid Mech .674, 433-464, (2011).

(2) E. Fort, A. Eddi, A. Boudaoud, J. Moukhtar, and Y. Couder, PNAS 107, 17515-17520, (2010).

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Bouncing droplets (and the nature of reality)

John Bush, Department of Mathematics, MIT, Cambridge, USA.

Yves Couder and coworkers have recently reported the results of a startling series of experiments in which droplets bouncing on a fluid surface exhibit wave-particle duality and, as a consequence, several dynamical features previously thought to be peculiar to the microscopic realm. We explore this fluid system in light of the Madelung transformation, whereby Schrodinger's equation is recast in a hydrodynamic form. Doing so reveals a correspondence between bouncing droplets and subatomic particles, and provides some rationale for the observed macroscopic quantum behaviour. New experiments are presented, and indicate the potential value of this hydrodynamic approach to both visualizing and understanding quantum mechanics.

First steps towards a better understanding of animal schooling and flocking

Jun Zhang, Department of Physics and Courant Institute, NYU, New York, USA.

Flying birds and swimming fish are familiar to everyone though their remarkable locomotion abilities remain poorly understood. Even less understood is their group behavior – birds form flocks and fish form schools. Do they benefit energetically from such groups? Do individuals compete for advantageous positions within a group? Are these groups formed due to physical interactions through the surrounding fluid, or by social or behavioral decisions?

Puzzled by these questions, we have performed two recent laboratory experiments on interactions between unsteady flows and dynamic boundaries (here flapping wings or flexible membranes). In the first experiment, we investigate the dynamics of a minimal group of two "passive swimmers" (two flapping flags) and study the drag forces they experience in a high-Reynolds-number flow. Unlike the well-known hydrodynamic drafting of rigid objects placed in tandem, flexible structures like flags show inverted drafting where the leading body enjoys a reduced drag while the follower suffers a drag increase. In the second experiment, we replace the second passive flag with an active flapper that performs a prescribed "swimming motion." We found that the leading flexible body can be synchronized from downstream and the drag can be reduced to a surprising amount – about one third of the drag experienced in isolation.

Shape optimization for tumor location

Cristina Turner, FAMAF, Córdoba, Argentina

In non-invasive thermal diagnostics for the location of a tumor, accurate correlations between the thermal image on skin surface and interior human physiology are often desired, which require general solutions for the bioheat equation. In this paper we use sensitivity analysis in order to compute the shape derivative of the functional that provides the minimum (the geometrical position of the tumor). We minimize a functional that depends on the temperature of the body in a domain and on the temperature on the boundary of the domain obtained from the experimental data.

2D incompressible ideal flows around a small obstacle

Huy Hoang Nguyen, Universidade Estadual de Campinas, Campinas, SP, Brazil.

This talk is devoted to some mathematical questions related to the asymptotic behavior of incompressible, ideal, time-dependent two dimensional flow in the exterior of a single smooth obstacle when the size of the obstacle becomes very small. We have two different cases concerning the behavior of velocity field at infinity: the flow is rest or past at infinity. In this talk, we are interested in considering the second case. This is a joint work with Milton C. Lopes Filho, Helena J. Nussenzveig Lopes.
