Paul Sabatier University

March 2008

Scientific magazine issue n° 1

Headlines

Molecular Biology

Fluid Mechanics

Université Paul Sabatier TOULOUSE III

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CNRS CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

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New: Our scientific magazine now available in English!

Since 2004, The Paul Sabatier University (UPS, Toulouse, France) magazine has appeared quarterly. It contains news and features about life at the university, including short reports about research activities from different departments and research laboratories.
Its success in French speaking countries has encouraged us to create an international edition in English, which launches this month. So, the March 2008 issue you have in hand is number one, corresponding to number 12 of the French version. This, and future issues will contain a selection of the best articles that appear in the French Edition.
In the headlines of this issue, you will find two scientific reports featuring activity in two very important research domains developed at our university.

The first, devoted to **molecular biology**, provides an outline of relevant research efforts developed within six CNRS/University laboratories. All these laboratories are dealing with the most fundamental aspects of life sciences.
As you will see in these articles, the surge in the number of direct applications from molecular biology to medical research has motivated a number of stimulating collaborations, helped along by the fact that medical research is also a priority at our university.

The second report focuses on research activities in **fluid mechanics**, a field that lies at the interface of physics and mathematics. Here, multiple and even unexpected applications of this basic science can be foreseen, thanks to a long tradition of stimulating collaborations between Paul Sabatier University and the National Polytechnic Institute of Toulouse.

I hope you enjoy the new edition.

Jean-François SAUTEREAU
President of Paul Sabatier University

Currently used abbreviations

UPS: University Paul Sabatier (Toulouse, France)
CNRS: French National Center for Scientific Research
INSERM: French National Institute for Health and Medical Research
INSA: National Institute of Applied Science
INRA: National Institute for Agricultural Research
INPT: National Polytechnic Institute of Toulouse

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Revealing the Pax6 transcription factor in neural stem cells of a chicken embryo

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Headline

From molecular biology to integrated systems

Research in molecular biology is forging ahead. After having successfully described the building blocks of life, it is now addressing how life itself works. With numerous applications on the horizon...

>>> François AMALRIC, professor at UPS, Director of the IPBS; Marc HAENLIN, CNRS senior scientist, Director of the CBD

Biology has made great progress over the last fifty years, going from observation to analysis and from description to explanation. Following the discovery of the fundamental principles of living organisms, unearthed from structure-function studies of fundamental macromolecules like DNA, RNA, proteins, lipids and glycoconjuguates, research in biology has undergone huge change in recent times thanks to new approaches to research and important technological advances. Large-scale studies have been made, with the most important being the sequencing of numerous genomes, including the human genome.

It is now possible to study individual molecules and how they are assembled as well as cells and tissues and individuals and groups of individuals in an integrated manner. As a result, it has become obvious that the complexity seen in animals is not a result of the number of genes they contain (which is only slightly larger than those in drosophila) but comes instead from a combination of factors whose description requires diverse methodology, in vitro, in vivo, in situ and new technological protocols, going from experimentation to theoretical modelling. This is also why single disciplines have given way to more multidisciplinary research teams and collaborations in recent times.

Macromolecules

At Paul Sabatier University, six joint laboratories CNRS-UPS (1) have been set up, making this collaboration -- which integrates research, teaching and knowledge transfer -- one of the most successful outside Paris. The team focuses on three major areas: individual molecules and multimolecular complexes; cells and complex bodies; and the individual and groups of individuals (populations). Based on competitive fundamental research, the domains of biotechnology and health have been developed, together with as general science and information techniques.

The study of life-supporting molecules -- macromolecules -- has been made possible by exceptional developments in molecular biology that combine genetics and biochemistry. At Paul Sabatier, several internationally recognised research groups are involved in structure-function studies of such molecules. For example, an important collaboration (LBME, IPBS and LMGM) is working on RNAs. The researchers routinely use highly sophisticated NMR, crystallography and proteomic platforms, which they also develop and maintain to the highest standards. Proteomics, a field that has developed quickly over the last five years, is crucial for research in biology and allows researchers to access the composition of multimolecular complexes. In addition, a strong imaging platform (CBD, LBME, IPBS) allows further studies on the dynamics of these molecules. These platforms are open to the entire university community and also support numerous collaborations in industry. They have strong connections with physics and chemistry, notably in the field of membrane biophysics, membrane proteins and nucleic-acid/protein complexes. Such a regrouping of skills allows new concepts and novel biological research tools to be developed.

Cells

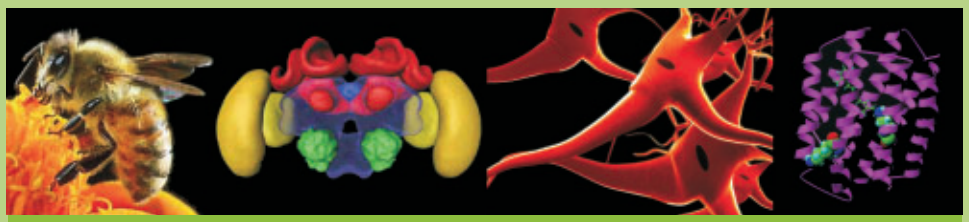
Most of the research teams at Paul Sabatier are focusing on cells, using bacteria and nucleated cell models. This community is interested in how bacteria function and studies genome stability and replication, biochemistry of membranes and walls and the pathogenicity

>>>

Technological Platforms

In a sustained collective effort, the IFR 109 laboratories and IPBS have established and share powerful technological platforms, some of which have received the national IbiSA label. They are open to research and development partners in both the private and public domains. They include proteomic, bio-crystallography, biological NMR, imaging, animal experimentation and transgenesis, allowing the study of individual molecules up to the whole animal. A description of these platforms can be seen on the following websites
http://www.ipbs.fr/ and http://www.iefg.biotoul.fr

Headline



>>> FROM MOLECULES TO INDIVIDUALS AND VICE VERSA from left to right: rhodopsine molecule, neurons, insect brain, honey bee.

of mycobacteria that cause diseases like tuberculosis (LMGM and IPBS). These biochemists and microbiologists also belong to a wider community that includes research groups at INSA and INRA who study eukaryotic cells as models for complex systems. Molecular and cellular biology methodologies coupled with concepts and tools from biophysics, such as high-resolution imaging (LBME, IPBS, CBD), are employed in this field too. The researchers analyse fundamental process functioning in cells, differentiation processes and the malfunctioning of pathological cells -- more particularly that of cancerous cells (LBME, IPBS, CBD).

Individuals and populations

Understanding how the molecular and cellular mechanisms that dominate development, reproduction and, more broadly, physiological and higher cognitive functions in animals, requires experimental systems on the scale of the individual and populations. Many research units use a variety of animal models, which allow genetic (drosophila, zebrafish and mouse), embryological (xenopus and chicken) and behavioural and cognitive methodologies (drosophila, honey bee and mouse). Sequencing the genome of the majority of these models has already been realised or is underway.
One of the most striking findings to come from modern biology concerns not only the extraordinary evolutionary conservation of proteins coded by genomes but also the conservation of the biological processes in which they participate. Indeed, a variety of model systems, in both invertebrates and vertebrates, have considerably increased our understanding of how living organisms function. Mechanisms studied concern reproduction, embryonic development, organogenesis (neurogenesis, myogenesis, haematopoiesis and angiogenesis), oncogenesis and metabolism (CBD, IPBS, MPM). Research on cognition focuses on cue-based, spatial and contextual learning and memory, as well as on collective behaviour in animal societies supporting distributed cognition phenomena. The establishment of a technological platform for imagining provides an ideal environment for studying molecular and cellular mechanisms at the single-molecule level right up to the scale of the entire organism.

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(1): Microbiology and Molecular Genetics Laboratory (LMGM), Eucaryote Molecular Biology Laboratory (LBME), Institute of Pharmacology and Structural Biology (IPBS), Centre for Developmental Biology (CBD), Animal Cognition Research Centre (CRCA), Metabolism, Plasticity and Mitochondria (MPM). Four laboratories, LMGM, LBME, CBD and MPM are part of the Federative Institute of Functional Investigation of Genomes (IFR 109).

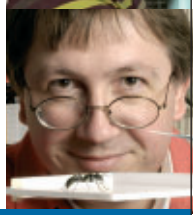
A New Research Federation

These six laboratories belong to the ***Research Federation*** located on the Paul Sabatier University campus. This Federation will eventually include approximately 150 CNRS and Inserm researchers, 90 university researchers, 150 technicians, 60 post-docs and 140 graduate students. Currently, the Federation publishes more than 200 papers a year in international journals, including in high-impact non-specialized journals (Nature, PNAS and Science). It will also help to improve knowledge transfer in the domains of biotechnologies and health (cancer, neurosciences and infectious diseases).

Headline

The systems biology approach to understanding the dynamics of interaction networks in genome and insect societies

How do ants organise their work in a colony? How do particular genes influence genome dynamics as a whole? Systems biology has now started to answer these and other questions.



>>> Olivier GADAL, CNRS scientist, Institute for Exploratory Functional Genomics (joint laboratory UPS/CNRS)
Guy THERAULAZ, CNRS senior scientist, Research Centre on Animal Cognition, (joint laboratory UPS/CNRS).

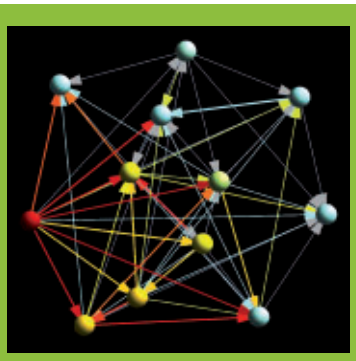
Systems biology is a whole new way of studying and understanding how living systems work. The main goal of this burgeoning field is to understand how properties observed at a given level of biological organisation (genome, cell, brain and societies) emerge from the complex networks of interactions that exist among its components (genes, proteins, neurons, individuals). Interactions among these elements are highly non-linear and give rise to self-organised properties at the collective level.

Gene movements

To understand these phenomena, systems biology combines experimental and theoretical approaches in which mathematical modelling and computer simulations play a key role. Understanding the expression of genetic information in the eukaryotic genome requires a precise description of the laws that govern the movement and the spatial organisation of genes in the nucleus. In fact, eukaryotic genomes are not randomly distributed in the nuclear volume, and the way genetic units are positioned relative to specific nuclear sub-domains affect how accessible they are. The spatial organisation of chromatin structures must also be described by statistical quantities, such as the probability distribution of positions within a population, or average chromatin compaction levels, because of the stochastic nature of gene motion. Similarly, gene motion must be described by parameters such as diffusion coefficients and confinement radii. Such descriptions are crucial for accessing the laws underlying chromatin motion - an approach that allows us to understand how gene movement allows complex genetic programs.

Swarm intelligence

Understanding collective behaviour in social insects -- such as how the division of labour is regulated, how nest-building activities are coordinated, or explaining the processes responsible for collective decisions -- requires mathematical models that can describe interactions among individuals and how these interactions give rise to the properties observed at the collective level. Such models are built on statistical laws describing individual behaviour. Numerical simulations are then used to precisely evaluate the quantitative and qualitative impact of each model's parameters on the resulting spatial and temporal collective dynamics. Simulations are also used to make testable predictions. Following step-by-step methodology provided by the theory of complex systems, we can now understand a large number of collective behaviours at different levels of organisation. In this integrated approach, all the processes implemented in the models represent real biological phenomena and the models themselves become more realistic.



>>> The network of hierarchical wasp interactions in a Polistes dominulus colony with 13 individuals. In these colonies, self-organisation processes reinforce successful individuals in such a way that the link weight distribution of the interaction network follows a power law.

Book: CAMAZINE, S., DENEUBOURG, J.L., FRANKS, N., SNEYD, J., THERAULAZ, G. & BONABEAU, E. 2001. *Self-Organization in Biological Systems*. Princeton University Press.

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Cancer: therapeutic targets for tomorrow

Transcription regulation and protein synthesis are modified in tumour cells. A better understanding of the mechanisms involved in deregulation and abnormal protein production compared to normal cells is crucial for developing new therapies.

>>> Jean-Philippe GIRARD, Senior scientist Inserm ,(IPBS, joint laboratory UPS/CNRS) and Kerstin BYSTRICKY, assistant professor at UPS, (LBME. Joint laboratory UPS/CNRS).

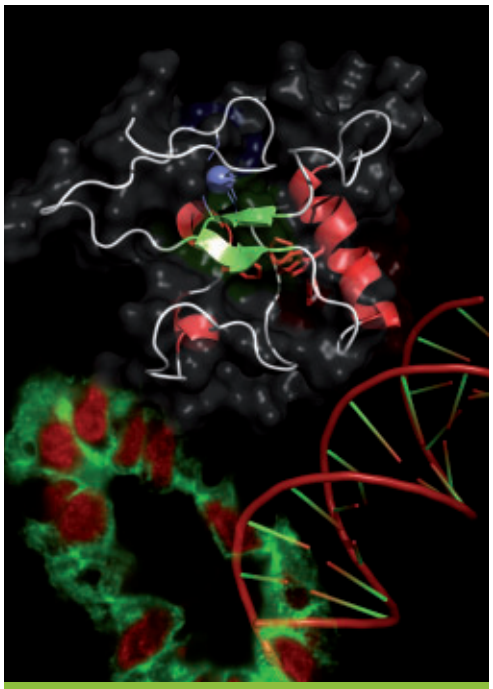
The main objective of the Biology Federation research teams at Paul Sabatier University is to better understand the fundamental mechanisms of life with a view to applying the knowledge gained to develop new anti-cancer therapies. The research combines both new technologies and models that go from the scale of molecules (DNA, RNA, proteins) to cells (yeast and vertebrate) and all the way to entire organisms (mice, flies, fish). Such a multidimensional approach is in line with the strategic objectives of the biggest cancer research centres in Europe and the US.

Functional genomics and proteomics

With the entire sequence of the human genome, and many other organisms' genomes, now complete, the challenge is to understand how genomes are decoded, how gene expression is regulated and how their products – proteins -- are integrated into cellular networks and signalling. An important area of research at Paul Sabatier University is to study genetic and epigenetic control of gene expression in normal and tumour cells, particularly in breast cancers and leukaemia. Current research activities aim at determining the role of cellular architecture, nuclear dynamics and chromatin organisation (DNA and structural proteins) in the regulation of gene expression as well as the analysis of DNA replication, recombination and repair mechanisms. Several teams specialise in analysing ribonucleic particles and RNA-mediated post-transcriptional regulation. The study of large multiprotein complexes involved in these processes requires approaches that involve "proteomics", which allows the state of all the proteins in a tissue or cell under specific conditions to be determined. This allows normal and tumour cells to be compared and changes in the precise composition of functional multi-protein complexes and their posttranslational modifications can be determined.

Genetics and imaging techniques

Anti-cancer strategies are based on the functional characterisation of genes and proteins in a wide variety of original animal models being developed by the Biology Federation. Potential new pharmacological targets can be tested and confirmed



>>> 3D structure of the THAP domain.

in vivo using site-directed mutagenesis (drosophila, yeast) or gene invalidation techniques (mice). Innovative approaches also include characterising the interactions between cells and their micro-environment.
Visualising many different biological phenomena is possible thanks to the RIO Imaging Platform at Toulouse. Highly sophisticated microscopes (confocal and multi-photon as well as electron microscopes) allow in situ and in vivo studies ranging from single molecules to cells and animals.
The goal is to transfer discoveries made in basic research to the patient, so collaborating with clinicians and industrial partners is a priority. The Biology Federation has plans to establish links with the Canceropole at Langlade (Toulouse Cancer Campus) and with members of the Canceropole Grand-Sud-Ouest.

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Head line

Molecular machines control cellular growth

Many human diseases are caused by defects in the molecular machines responsible for expressing the genome and for maintaining its integrity.

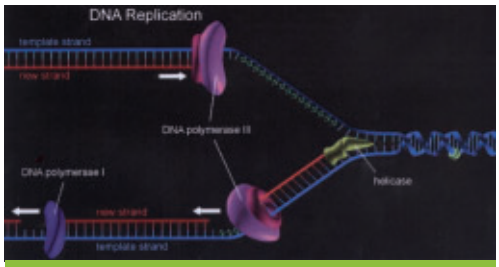
>>> Yves HENRY, CNRS senior scientist, head of the Ribosomes and Telomeres team at the Eukaryote Molecular Biology Laboratory (LBME, joint laboratory UPS/CNRS) and Patrice POLARD, CNRS senior scientist, at the Microbiology and Molecular Genetics Laboratory (LMGM, joint laboratory UPS/CNRS).

In order to grow and divide in a controlled fashion, the cell – be it of bacterial or human origin -- must express and duplicate its genome in an appropriate way. This depends on detecting any damage the cell sustains and repairing it. Correct expression, duplication and repair of the genome relies on numerous chemical reactions that rely on specific biological catalysts. Several of these catalysts are made from an assembly of macromolecules, mainly proteins and RNA. When these molecular machines become less reliable or when their production becomes defective or uncontrolled, diseases, including cancer, can develop.

Genome expression

The Research Federation teams at Paul Sabatier University study the composition, structure, mode of assembly and function of these molecular machines under normal and pathological conditions. These studies employ several model systems (bacterial cells, yeast, *drosophila,* mice and human cells in culture) and experimental methods combining genetics, biochemistry and structure determination. Work is carried out at the proteomic, NMR and cell imaging labs at Paul Sabatier.

The expression of the genome, which is made of DNA, refers to the production of copies of certain portions of this genome in the form of RNA and the further processing and fate of these RNA copies. These RNA replicas are produced in a process known as “transcription” and require several molecular machines that interact with genomic DNA and which can be grouped into three main classes. Machines in the first class (the “activators”) trigger the transcription process, while machines in the second class (the “RNA polymerases) are responsible for actually synthesising the RNA replica. Finally, machines in the third class (“mediator complexes”) connect the activators with the RNA polymerases. The research teams work on all three types of machines. The RNA replicas can be used as made, or can be “scanned” by huge molecular machines called ribosomes to produce proteins. The researchers study the assembly of these ribosomes and also work on Diamond-Blackfan anaemia, which is caused by defects in ribosome assembly and function.



>>> molecular machines in the process of duplicating the DNA of a cell.

Faithful duplication

Correct genome expression depends on strictly controlling genome integrity and repairing any damage the genome suffers when necessary. It also depends upon faithful duplication of the genome prior to cell division. Molecular machines (such as the “DNA recombination complexes”, “DNA polymerases” and “telomerase complexes”) repair DNA damage or participate in genome duplication. Defects in genome duplication and repair can have highly deleterious consequences, in particular chromosomal instability that can induce cell death (“apoptosis”), numerous cancers and certain syndromes such as “dyskeratosis congenita”. These defects can also, in some cases, be advantageous in that they provide genetic changes that confer a selective advantage. For example, some processes utilising specific molecular machines seem to produce genetic variability, such as DNA transposition and natural transformation. We are working on the modes of synthesis and function of all these machines and on the molecular defects responsible for certain cancers or for dyskeratosis congenita. The production and destruction of these molecular machines are themselves catalysed by other machines, termed molecular chaperones and proteasomes, whose structure and function are being studied by some of our research groups. The ensemble of our research aims to understand how molecular machines function in a coordinated fashion relative to each another.

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Neurogenesis and pathologies of the nervous system

Understanding how neurons are born and differentiate will help in developing strategies to cure neurodegenerative disorders, such as Alzheimer's.

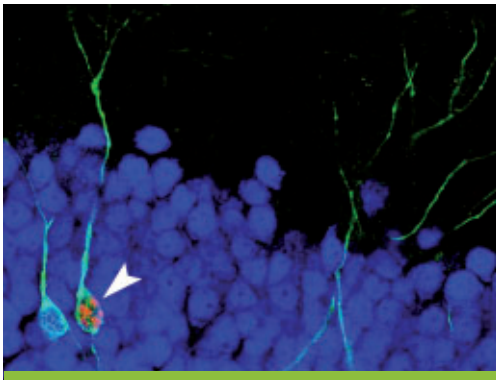
>>> (from left to right) : Claire RAMPON, CNRS scientist at CRCA, (joint laboratory UPS/CNRS), Marie-Lise MADDELEIN, CNRS scientist at IPBS (joint laboratory UPS/CNRS), Philippe COCHARD, CNRS Senior scientist at CBD (joint laboratory UPS/CNRS) and Pascale BELENGUER, Professor UPS at MPM (joint laboratory UPS/CNRS).

The brain -- the most complex organ in the human body -- is made up of 100 billion neurons, as many as the number of stars in our galaxy! And it contains ten times more glia, cells that are crucial for proper neuronal function. How do these countless forms of neurons and glial cells develop? Using model systems adapted to each type of species (fly, fish, frog, chick, rodent), researchers in our laboratories are now beginning to answer this basic question -- an essential prerequisite for defining therapeutic strategies for neurodegenerative diseases.

A problem of choice !

Development is the main topic of research at the CBD. One area concerns the crucial role that calcium plays in the initial phases of brain construction -- crucial because blocking calcium movements very early on in the embryo produces an animal virtually devoid of a nervous system. Once neural stem cells are generated, they must actively proliferate: in humans, more than 250,000 neurons are generated every minute.
The mechanisms that control such an active proliferation are under study and we have shown that, contrary to the established dogma, a cell that is forced to divide can nevertheless become a neuron.

Another research domain deals with the dialogue between neighbouring stem cells, to understand how specific signals dictate the choice a neural stem cell makes -- either to keep proliferating and maintain itself or to stop dividing and undergo terminal neuronal differentiation. Through a series of decisions, neural stem cells will then give rise, at the right time and place, to specific types of neuron and glial cell.
Genetic analysis shows us how the specific information encoded in each group of neural precursors is interpreted, leading the cell towards a fate unique among the large variety of neuronal phenotypes possible. Another major choice for a stem cell is to either become a neuron or a glial cell.
We made the surprising discovery that a diffusible signal responsible for the genesis of particular sets of neurons is also required for glial cell formation.
We have provided evidence for a gene that could explain how this signal controls the formation of these two totally different cell types.



>>> Birth of new neurons in the adult brain of a mouse model in Alzheimer's disease. Specific fluorescent markers and confocal microscopy allow us to visualise a newborn neuron (arrowhead, orange-stained cell nucleus) together with immature neurons, labelled in green.

New neurons in the adult brain

The belief that neurons are never generated in the adult brain was shattered a few years ago: new neurons are continuously generated in some brain regions and can take part in mnesic function. This major finding means that the dramatic neuronal losses associated with neurodegenerative diseases could be compensated for. Teams at CRCA, IPBS and MPM are working in this new field and have shown that new neurons are indeed produced in the brain of a mouse model in Alzheimer's disease, but that these neurons are unable to survive in the long term.
It is therefore critical to understand what prevents them from further developing into mature neurons.
Alzheimer's is caused in part by aggregation of a peptide, A, amyloid, into senile plaques.
We characterise this aggregation at the molecular level by studying plaque formation *in vivo* with fluorescence microscopy in model organisms (yeast) and in neurons.
We have also discovered that a gene responsible for neurodegenerative retinopathy controls the dynamics of mitochondria -- a process involved in mitochondrion morphology and which regulates its function.
This has led us to explore the impact of mitochondrial dynamics on neurogenesis, and neuronal differentiation and function.

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Pathogenic Bacteria: The best way to fight them is a better understanding

The fight against pathogenic bacteria is far from over because these organisms are becoming more resistant to antibiotics. New vaccines and antibiotics are thus needed today more than ever.

>>> Mamadou DAFFE, CNRS Senior scientist, director of the Molecular Mechanisms Mycobacterial Infections Department at IPBS and Claude GUTIERREZ, professor at Paul Sabatier University and Director of LMGM.

Eighty years after the discovery of penicillin, infectious diseases remain a major global health problem. For instance, tuberculosis causes two millions deaths a year worldwide and we are also facing a real re-emergence of multi-resistant strains. New antibiotics and vaccines are thus urgently needed. The best way to achieve this goal is to decipher the mechanisms by which pathogenic bacteria cause disease and resist treatment. Some of these are being studied at the IPBS and LMGM.

Tuberculosis and leprosy

The teams in the Molecular Mechanisms of Mycobacterial Infections department at IPBS are studying *Mycobacterium tuberculosis* and *M. leprae,* the bacteria that cause tuberculosis and leprosy. The genomes of these bacteria have recently been sequenced, with the aim of defining virulent factors and how they work and identifying novel enzymes involved in the biosynthesis of components essential for the survival of the bacilli to use them as targets for the development of new drugs and finding new vaccines -- either by modifying the currently used BCG vaccine, or by using non-peptidic antigens. This strategy combines a genetic approach together with the unique composition and immunological properties of the mycobacterial envelope.

The seven teams that make up the department possess complementary skills that include chemistry and biochemistry, structural biophysics, molecular and cellular biology and immunology. Over the last three years, the department has discovered four novel therapeutic targets and new mycobacterial non-peptidic antigens that interact with receptors of T-lymphocytes. The results include five patents, collaboration with pharmaceutical firms and numerous scientific publications.

Resistance to antibiotics

At the LMGM, 12 research teams study the fundamental processes that govern the organisation, dynamics and expression of microbial genomes, including those of several pathogenic bacteria.

Many bacteria can acquire new genetic determinants of both pathogenicity and antibiotic resistance by "horizontal exchange" of DNA via transformation, transduction or conjugation. The mechanisms involved in the mobility and capture of such elements are studied in *Escherichia coli or Vibrio cholerae.* The mechanism of bacterial transformation in *Streptococcus pneumoniae* is also under study. Transformation contributes to the genomic plasticity of *S. pneumoniae* and thereby allows this bacterium to circumvent host defence mechanisms using high antigenic variability or by rapidly evolving genes conferring antibiotic resistance. A particularly important finding from these studies is that the presence of sub-lethal doses of antibiotics induces transformations and helps bacteria evolve drug resistance. Among the current research topics at LMGM is the epidemiologic analysis of emergent pathogenic *E. coli* strains and discovering how they adapt to environmental stress. This study includes looking at the stress encountered by the phytopathogen *Xanthomonas campestris* upon infecting its host cells. A very promising and patented work involves T4-type bacteriophages and their use in antibacterial therapy or as an alternative to antibiotherapy.

To summarise, the IPBS and LMGM teams perform excellent and internationally recognised research in molecular and cell microbiology and strongly contribute to the efforts of Paul Sabatier University, and more largely the Toulouse research conglomeration, a place of reference for research in microbiology.

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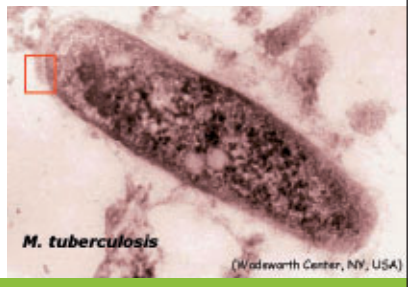


>>> The mycobacterial envelope is very complex and unique. Its biogenesis is specially targeted by anti-tuberculosis drugs.

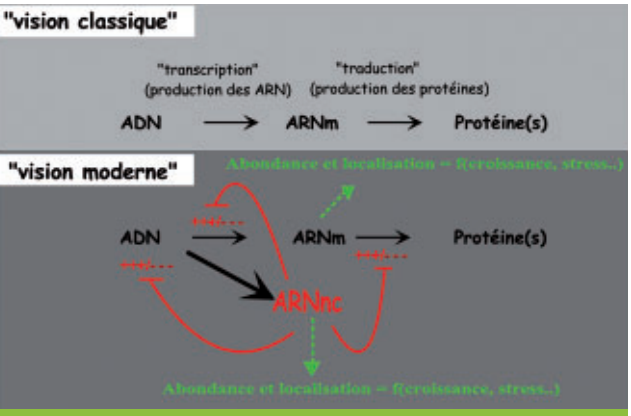
The hidden life of RNA

>>> Jérôme CAVAILLÉ, CNRS senior scientist at the Molecular Eukaryote laboratory (LBME, joint laboratory UPS/CNRS).

Until recently, RNA was thought to be a simple intermediary in the production of proteins from DNA. It is now known to be a crucial regulator in DNA expression itself.

DNA contains genetic information that is passed on from generation to generation (it is a major component of chromosomes and thus of genes). Proteins, encoded by genes, are involved in a large number of essential cellular functions including catalysis of chemical reactions (enzymes), cell shape (cytoskeleton), interactions and communications between cells (antibodies and hormones) and transport of other molecules (such as haemoglobin). For a long time, RNA molecules, which are copies of certain segments of DNA, were seen simply as intermediaries, carrying genetic information from DNA to proteins. Hence, the majority of them are called messenger RNAs or mRNAs. This protein-centric point of view, routinely described in student textbooks, is now being overturned.

Remarkably, only a small fraction of our DNA content (< 2%) is dedicated to protein synthesis. For many years the remaining, extra DNA (also referred to as "junk DNA") was thought to be unimportant. This situation is dramatically changing and the scientific community now accepts that junk DNA might have unexplored functions. Indeed, a huge number of studies have demonstrated that a large fraction of this noncoding DNA generates RNA molecules that play key roles in cell metabolism by regulating DNA replication, protein synthesis or maturation of other RNAs. The repertoire of these noncoding RNAs (ncRNAs) might thus be as complex as that of mRNAs themselves and studies of these molecules are now revolutionising our vision of genome evolution, genome regulation and gene functions. This can be illustrated by the recent identification of a novel class of small non-coding RNAs involved in gene silencing (the so-called microRNA, siRNAs and piRNAs).
The discovery of the RNA-mediated gene silencing phenomena was recently acknowledged by the Nobel Prize in Medicine 2006, awarded to Andrew Fire and Craig Mello.



>>> Although RNAs have long been seen as just intermediaries in gene expression (top), they are now believed to act as key players in the control of gene expression (bottom).

It is not enough to simply synthesise RNA in the cell, its abundance, availability and subcellular location must be controlled as well. To this end, numerous molecular mechanisms are able to fine-tune the production and decay rate of RNA according to cell growth and it is now accepted that mRNA/ncRNA degradation plays an important role in the regulation of cell proliferation and differentiation, and apoptosis (programmed cell death).

Through a vast number of experiments and models in eukaryotes and prokaryotes (bacteria and Archaea), research teams at LBME, LMGM, CBD and IPBS are discovering the molecular and cellular mechanisms that underlie RNA function. For example, the LBME groups are studying how regulatory small RNAs are synthesised and how these molecules work. RNAs are never "naked" in the cell but are associated with specific proteins and form stable RiboNucleoProtein (RNP) complexes. Assembly and intracellular trafficking of these RNPs are also under intense study. At LMGM, researchers are developing molecular and genetic methodologies to understand how RNA is degraded in bacteria and ongoing research is underway in Archaea, in which RNA degradation mechanisms need to be explored. By combining transgenic mice and molecular experiments, a team in the CBD is focusing its attention on proteins called AUBPs that specifically bind mRNAs in their untranslated regions and so control the stability of these molecules. Regulatory small RNAs (for example, siRNAs) can be used by researchers as a tool too to inhibit gene expression. For instance, a team at the IPBS is studying electrically-mediated siRNA delivery in mice tissues and tumours.

Although this is clearly basic science, these ongoing research programmes will shed more light on the pathology of several human disorders in which RNA biosynthesis and/or function is deregulated. This occurs in many cancers and several rare diseases, including Prader-Willi syndrome, Diamond-Blackfan syndrome or congenital dyskeratosis.

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Fluid mechanics is everywhere!

Bursting with mathematical equations and physics theory, fluid mechanics finds itself in domains as diverse as energy production to the circulation of cerebral fluids.

>>> Jacques MAGNAUDET, CNRS Senior Scientist, Head of IMFT (joint laboratory UPS/INP/CNRS) and Henri-Claude BOISSON, CNRS Senior Scientist, Deputy Head of IMFT

Moving fluids exist on microscopic to astrophysical scales, and from fractions of seconds to light years. These huge scale disparities often make it difficult to understand fluid flows and predict how they will behave. However such an understanding is imperative for finding solutions to a great number of problems, related to the environment, transportation, energy, industrial process and health, where fluids are involved as transport agents and/or in chemical reactions.
The most common way to study fluid flows is based on a multi-scale approach. This consists of understanding and modelling the complexity of a process or a phenomenon in successive stages, starting from elementary, detailed local mechanisms and integrating these step-by-step into larger scale models. The approach generally combines mathematical modelling, laboratory experiments and calculations. From a fundamental point of view, the goal is to improve our knowledge of media in which complexity arises from specific properties.

Scientists in the Toulouse region are studying the following topics:

Hydrodynamic instabilities:

Researchers look at how the flow of a fluid changes when one of its characteristic parameters is varied. Starting from a stable state, the flow becomes unstable because its governing equations are nonlinear - problems that are often studied using mathematical methods and numerical simulation. Detailed laboratory experiments are then used to complete these studies to observe specific aspects of flow instabilities in real life. The goal is to understand how instability starts and to predict how the unstable flow evolves. Such studies might eventually allow fluid instabilities to be controlled, an area in which the Fluid Mechanics Institute of Toulouse (IMFT) has direct collaborations with the Toulouse Mathematics Institute (IMT), the Laboratory for Plasma and Energy Conversion (Laplace), the Institute of Aeronautics and Space (ISAE) and the French Aerospace Laboratory ONERA. The ultimate objectives of this research are to improve the performance of airplanes, ships, cars and trains.

Two-phase Flows:

Flows in two-phase media are intrinsically complex owing to the relative motion of the two distinct phases. They exist in a wide variety of topological configurations (drops, bubbles or films, for instance) in which mobile or deformable interfaces deeply affect the flow structure within each phase. Research in this area is concerned with the specific dynamics of this type of flow, which dramatically modifies heat and mass transfer. A good understanding of these flows is the key to controlling and optimising many industrial and environmental processes as well as energy management, especially in space applications.

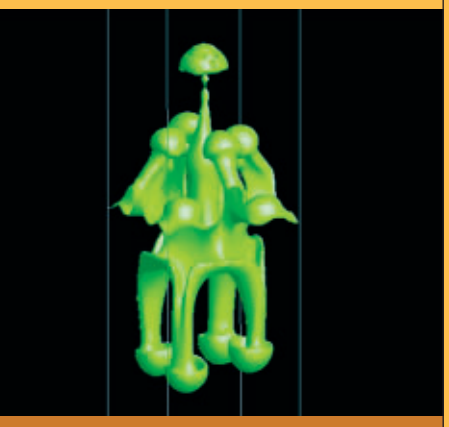
Reactive Flows:

Reactive flows involve heterogeneous fluids under the influence of internal effects produced by chemical reactions. These reactions create energy transfers, modify the structure of the corresponding flows and increase the complexity of the system. The phenomena encountered in such flows may be turbulent or unstable -- for example flame instabilities. While some situations are similar to those encountered in the study of hydrodynamic instabilities, reactive flows have certain fundamental characteristics. Direct applications as a result of this research include improving car engines, combustion chambers, rockets and furnaces.

Flow interactions in the living world

Novel mechanisms, such as natural selection, genetic evolution and metabolism, come into play in fluids that contain or transport living

>>>



>>> A heavy fluid is superimposed on a lighter one in a vertical square duct. Under the effect of gravity both fluids mix together: the heavy fluid flows down (preferentially near the corners), while the lighter one flows up (preferentially in the core of the duct). The image shows the boundary of the mixed zone at a given instant, represented by the surface on which both fluid phases are present in the same concentration.

Headline

A clash of two sciences: When biology meets fluid mechanics...

Both these sciences have grown in parallel. Biologists and biotechnologists are concerned in isolating genes or making them react together without taking evolutionary modifications into account. For their part, fluid mechanists did not believe they could integrate living behaviour into mathematical models. Only over the last few years has dialogue been established between these two domains. Multi - disciplinary approaches still need to progress though in order to face the huge challenges in this field.

>>>

organisms. In environmental flows, researchers also encounter problems related to bio-film formation, which plays an important role in the growth of phytoplankton in rivers. Such interactions also have an important impact on soil pollution. Finally, fluid interactions are crucial for internal exchanges inside the human body. A typical situation is brain microcirculation, where the fluid flows through an incredibly complex network. Research in this field requires close collaboration between fluid mechanists, biologists, neurologists and many other scientists.

The Fluid Mechanics Institute of Toulouse (IMFT) is entirely devoted to fluid mechanics and promotes close links with many other laboratories in the Toulouse area that are also working in the domain of fluid mechanics, applied mathematics and computer sciences. These include labs at Paul Sabatier University, such as Laplace, IMT, the Informatics Research Institute of Toulouse (IRIT), labs from the Midi-Pyrénées Observatory, the National Centre of Meteorological Research (CNRM), the Biosystems and Process Engineering Laboratory (LISBP), the Chemical Engineering Laboratory (LGC), the Mechanical Engineering Laboratory (LMGT) and centres like the European Centre for Research and Advanced Training in Scientific Computation (CERFACS) and the French Aerospace Laboratory (ONERA).

>>> Simulation of a Stokes wave plunging in deep water performed with JADIM (in-house code)

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Teaching and research in fluid mechanics at Paul Sabatier University

The Mécanique Energétique Procédés (Mechanics, Energetics and Process) masters degree offers many specialised courses in fluid mechanics. The second year of this course is split into two: Dynamique des Fluides Energétique et Transferts (Fluid Dynamics, Energetics and Transfers), which is geared more towards research, and Modélisation et Simulation en Mécanique et Energétique (Modelling and simulation in Mechanics and Energetics), which is oriented towards industry.
See: http://www.ups-tlse.fr/82364038/0/fiche___pagelibre/&RH=rub02.

Fluid mechanics is also taught in the Sciences de la Terre et de l'Environnement (Earth Science and the Environment) masters degree, specifically in the Hydrologie Hydrochimie Sol et Environnement (Hydrology, Hydrochemistry, Soil and Environment) course or in the Génie de l'Environnement (Environmental engineering) course.
See : http://www.ups-tlse.fr/3AHHS0_71/0/fiche___formation/&RH=rub02

PhDs are undertaken within the framework of doctoral schools :
Mécanique Energétique Génie Civil et Procédés (MEGeP) (http://www.imft.fr/MEGeP/); Sciences de l'Univers de l'Environnement et de l'Espace (SDU2E) (http://sdu2e.omp.obs-mip.fr/sdu2e/); and Aéronautique et Astronautique (AA) (http://www.isae.fr/ed-aa/)

Headline

Controlling flow to reduce pollution

Fewer harmful gases and lower noise emissions: flow control could significantly reduce the impact of transport on the environment. The economic implications are huge.

>>> Christophe AIRIAU, assistant professor at Paul Sabatier University, moderator of the "Instability and Control" team at IMFT (joint laboratory UPS/INPT/CNRS)

Enhancing the lift force and reducing drag are the main goals in flight transport today. Large lift allows a civil aircraft to fly with a maximal load while a small drag decreases the power and propulsion needed and reduces energy consumption in the engine (be it electrical, solar or fossil fuel).

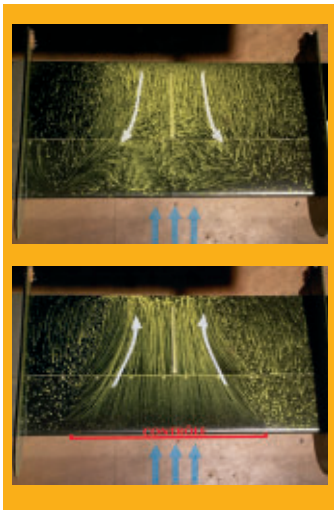
A predictable flow (also known as laminar flow) induces a weaker drag than a turbulent flow, where predictability is hindered by the generation and dissipation of random fluctuations and coherent structures. However, a laminar flow is very sensitive to any perturbations and quickly becomes unstable, which explains why natural flows are mainly turbulent. Moreover, turbulence generates strong pressure fluctuations that propagate in air, inducing unwanted noise. The goals of flow control are to reduce drag and noise emission while increasing lift by acting on turbulence or stabilising any perturbations.

Active control

Passively controlling the shape of an airfoil or of any vehicle has always been important for optimising aerodynamics. Many new experimental, theoretical and numerical approaches to active control have been developed since the 1990s, where actuators transfer energy from the wall into the fluid to improve performance (for example, from the wing section to the entire vehicle itself).

Recently, at IMFT and some other labs around the world, theories usually employed in industry to automatically control flow were used to render flows more stable or even make them stationary. However, this new work mainly concerned laminar or weakly turbulent flows. Moreover, the approach rapidly reached its limits since fluid mechanics deals with from 1000 to several million mathematical variables, figures that cannot be treated automatically in classic fluid control theory.

Today, two new methods are employed. The first one is open loop flow control where the control law, once activated, is no longer modified with respect to how efficient it is. With the technique of adjoining operators and direct numerical simulations using



>>> Micro-jet control on a wing to decrease drag and enhance lift close to the aerodynamic stall. Before (top) and after (bottom) control: lift increased by 20 %. Photo: A. Kourta, IMFT + LEA (Poitiers)

0.1 million variables, the noise emission in a simple compressible flow (shear layer) has been successfully decreased by several decibels. Similar applications have eliminated instabilities in some other laminar flows.

Feedback

At the Toulouse Mathematics Institute (IMT) Jean-Pierre Raymond's research team is developing other new flow-control techniques. These consist of computing control feedback laws of reduced order (the model has just 1000 to 10000 unknowns). Such feedback control is more efficient than an open-loop control since it depends on the real flow state measured by sensors. IMT and IMFT are working together to apply these new methods to more and more complex flows.
Developing and testing more efficient actuators is currently being carried out inside these labs and in collaboration with many academic partners and industry (for example, Dassault and Renault enterprises) by the Control of Flow Separation research group.

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Headline

The science of sprays and bubbles

How does bubbling fuel behave inside a spacecraft's propulsion engine? The answer lies in the study of two-phase flows.

>>> Sébastien TANGUY, assistant professor at Paul Sabatier University and Catherine COLIN, professor at INPT (researchers at l'IMFT, joint laboratory UPS/INP/CNRS)

Two-phase flows are very important in fluid mechanics, both for their wide range of applications and their fundamental scientific interest. There are many two-phase flows applications where a liquid phase and a gas phase interact, for example in spray formation (with applications in internal combustion for propulsion) or bubbly flows commonly encountered in process engineering.

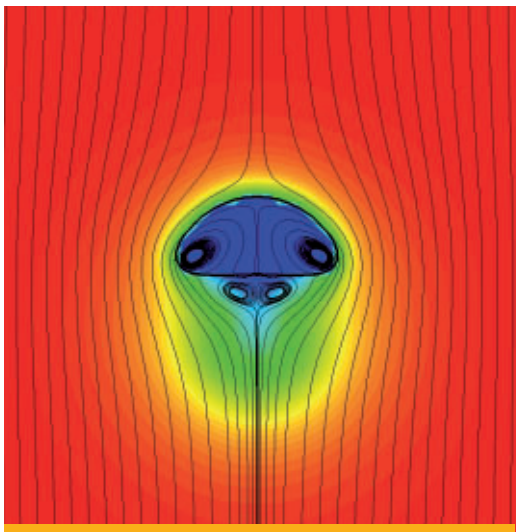
For the last two decades, the INTERFACE team at IMFT has been studying phase changes in gas-liquid flows. Phenomena such as boiling flows, droplet vaporisation or bubble condensation need to take into account thermal effects that affect hydrodynamic flow behaviour, which leads to more complex flows.

Nucleate boiling (hot wall bubble formation) is a very efficient thermal mechanism. Indeed, experiments have shown that wall convective thermal transfer coefficients can be improved if vapour bubbles are formed. However, if the wall temperature is too high, a film boiling transition (where the hot wall is completely covered by a continuous vapour film isolating the wall from the liquid) can occur. This is known as the so-called "boiling crisis".

This change in the two-phase flow configuration leads to a fast transition in the thermal transfer regime, which leads to a large decrease in the convective thermal transfer coefficient. This phenomenon is still poorly understood, and is particularly important in the cooling systems of nuclear plants.

The space industry is also interested in efficient cooling systems -- current thermal stresses for rocket propulsion systems are huge, both for burnt gas nozzles and combustion chambers. It is therefore crucial to use integrated and efficient cooling systems to alleviate the thermal and mechanical stresses that spacecraft materials experience. In this context, boiling flow studies are important for developing optimal systems for heat transfer.

Our work consists in studying different kinds of heat transfer -- latent heat, conduction and convection in simplified configurations. We have carried out nucleate boiling experiments for single bubbles to determine bubble growth rates, detachment diameters and how frequently bubbles are formed.



>>> Simulation that allows the temperature field and the current lines around an ascending, boiling bubble to be visualised

These experiments were performed under both standard gravity and micro-gravity conditions during airplane flights or rocket probes. Flat plate-free boiling was studied under micro-gravity conditions during the CNES "COMPortement des Ergols dans les Reservoirs" programme for the ARIANE V spacecraft.

The effect of forced convection effects on bubble detachment is the goal of the European Space Agency's project "Convective Boiling and Condensation". Thanks to these different experiments, new expressions for the bubble detachment diameter as a function of wall overheating and flow shear rate have been proposed.

Nucleate boiling heat transfer models are essentially based on empirical data. Direct numerical simulation of boiling flows could therefore be performed in parallel, for a more astute understanding of physical processes that occur on small scales during boiling.

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Headline

Particles, droplets and engines

How can particles and droplets with a diameter of just a few microns influence oil refining and combustion in car engines? Numerical tools and supercomputers can give us some answers.

>>> Pascal FEDE, assistant professor Paul Sabatier University, Department of Mechanical Engineering and Benoît BÉDAT, assistant professor at Paul Sabatier University, Department of Mechanics at IMFT (joint laboratory UPS/CNRS/INP).

Flows containing several billion particles or droplets are present in fluidised beds and internal combustion engines. In such systems, several exchanges occur on the micron scale. These are: transfer of momentum, mass and heat between the carrier fluids and inclusions, inter-particle collisions and collisions with walls, and droplet coalescence. These transfers are tiny on the scale of individual particles and droplets but they start to influence the macroscopic flow via collective effects as the numbers of particles become huge.

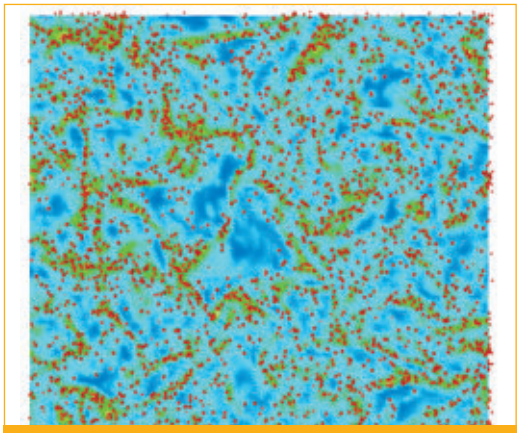
Million droplet trajectories

One of the objectives of the Flow and Combustion group at IMFT is to model such phenomena to improve predictive numerical tools. The researchers in the team are developing a mesoscopic method, called discrete particle simulation, in which numerical simulation of gaseous turbulent flow is coupled with computing the individual trajectories of several million particles and droplets. The transfers around each particle and droplet are not explicitly resolved but are taken into account by integral laws instead -- for example, via the drag force or vaporisation laws. These computations are numerical experiments that allow scientists to understand the local structure of the droplet or particle cloud and to validate existing theories. This strategy has allowed the team at IMFT to propose theoretical models that better take particle collisions and interface transfers into account. Moreover, a new approach to analyse turbulent-laden particle flows has been developed.

Droplet clusters

When particles or droplets begin to move at the same speed as large vortices in a fluid, they can segregate into clusters in a specific area of the flow where the vorticity is low. This phenomenon, called preferential concentration, can be important for the practical applications mentioned earlier because evaporation or chemical reactions are then concentrated in some areas of the turbulent flow.

For example, we can observe fuel droplets forming in clusters, which is characteristic of the preferential concentration phenomenon in the figure below. The



>>> Snapshot extracted from a 3D simulation of a droplet cloud evaporating in hot turbulent air. (The coloured portion corresponds to the fuel vapour field).

droplets evaporate in their own vapour, leading to the formation of rich or lean areas of fuel vapour. These heterogeneities at large scales can remain in the turbulent flow and produce poor combustion with unburned gas and soot formation.

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Fluidised bed

A fluidised bed is an industrial process used, for example, in the production of hydrocarbon fuel. In such a bed, a cloud of particles is transported by air flow injected into the bottom of the reactor. The behaviour of the dispersed phase is assimilated in the fluid. This process improves the exchange surface of the reaction between the two phases and assures good mixing.

When life and fluid mechanics come together...

Modelling river and coastal flows is far from trivial when chemical exchanges need to be taken into account, when there are living species present or when seashells make the bottom of the flow rougher...

>>> Frédéric MOULIN, assistant professor at Paul Sabatier University at IMFT (joint laboratory INPT/UPS/CNRS) and Stéphanie BOULÊTREAU, CNRS scientist at the ECOLAB (joint laboratory UPS/CNRS).

A crude description is often sufficient when modelling the purely dynamical aspects of a river or coastal flow on short time scales. To this end, researchers use the "hydraulic roughness", which measures how the drag exerted by a coastal or river bed slows the flow down.

However, river and coastal beds are complicated places and house living organisms that adapt themselves to the flow above but modify it by changing the conditions below. The organisms also modify biogeochemical fluxes in the flow because they consume, fix and produce various chemical species (like nitrates for instance).

Impact of human activity

Human activities greatly complicate models of hydrosystems on time scales large enough to take into account biological evolution at the bottom of a flow. Predicting the impact of human activity in the long term is based on models that include how living populations evolve as they are exposed to various environmental factors. For example, hydrodynamic forcing is one of the dominant factors in river and coastal ecosystems.

From a purely biological point of view, laboratory studies or in situ measurements produce a correct description of the development of organisms as a function of the physico-chemical conditions present. For instance, nutrient availability, light and the concentration of pollutants, can all be described. In the case of river biofilms, the taxonomic composition will depend on the development conditions but this also evolves with time, making it even more difficult to model this major biological parameter in some river ecosystems.

Another major difficulty arises when results obtained in laboratory (obtained with very slow or even no flow at all) need to be applied to natural conditions. For example, where flows are energetic and strongly turbulent (like in river and coastal flows). Here, local conditions surrounding living species at the bottom of the flow (such as the concentration of nutrients and oxygen) must be known before the biological models can be applied. Yet, these local conditions will depend on the characteristics of the turbulent flow higher up. Moreover, besides this indirect effect of the flow driving matter exchange between the bottom and the free stream above, another effect may be present -- mechanical and direct -- that controls the growth of organisms. In the case of river biofilms, for instance, studies in hydraulic channels at the IMFT show that the formation of filaments is limited by the intensity of flow turbulence, which can produce energetic vortices strong enough to tear off longer filaments. This leads to the development of structurally different biofilms, depending on the hydrodynamic conditions they were exposed to during their growth. This is a typical example of flow-structure interaction which is one of the research specialities at IMFT.

Flow around shells

Using fluid mechanics to describe river and coastal hydro-systems has motivated experimental studies in hydraulic channels of river biofilm growth or of turbulent flows around shells. The hydrodynamic conditions can then be described quite accurately and input to state-of-the-art measurement techniques available at IMFT (for example, particle imaging, velocimetry and laser doppler velocimetry), allowing precise studies of the interplay between living organisms and hydrodynamics. Of course, this work is fundamentally multidisciplinary, and based on close collaboration with other research teams, including the "Hydro-bio-géochimie des bassins versants" team at the Ecolab laboratory (UMR UPS/CNRS) for research activities on river biofilms.

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>>> artificial substrates in a hydraulic channel turbulent flow at the IMFT, covered by a growing river biofilm.

Headline

Micro-vascular networks in the brain

These networks supply healthy and cancerous cells with nutrients but they are still little understood. New cerebral imaging techniques could now solve this problem.

>>> Franck PLOURABOUÉ, CNRS scientist at IMFT (joint laboratory UPS /INP/CNRS) and Caroline FONTA, CNRS scientist at the Center for Brain Research (CERCO, joint laboratory UPS/CNRS).

Cortical micro-vascular organisation plays a central role in a large number of fundamental and clinical contexts, such as functional cerebral imaging, micro-vascular haemodynamic modelling, tumour growth and normal angiogenesis, and anti-tumour therapeutic strategies. Although potential applications are important, the organisation of micro-vascular networks is still poorly understood and little studied. Firstly, this is because these structures are very complex and are distributed over length scales of microns and millimetres and secondly, because of a "community effect". Most studies have concentrated on identifying cellular or molecular mechanisms that could help us better understand the interactions between elementary biological components.

New imaging techniques are revolutionising this domain of research offering the possibility of observing vascular and cellular components in 3D, using either two-photon microscopy, ultra-fast fluorescent lasers and synchrotron tomography. Such state-of-the-art techniques require scientists from many different backgrounds to work closely together.

We have contributed to these new projects using synchrotron tomography for analysing how micro-vascular networks are organised in space. This unique tool has allowed us to analyse large volumes of cerebral cortex -- on the order of several tens of cubic millimetres with micron-scale resolution. We have shown that vascular density and tissue-vessel distance are fractal at small scales and have discovered that the vascular density becomes homogenous at distances of about 50 to 80 microns. Significant differences between normal and tumour-laden vascular networks have also been found since tumours have a higher metabolism than healthy tissue. We now plan to study the cortex in more detail, how micro-vascular networks evolve in time during normal and pathological angiogenesis and model blood flow in these networks.

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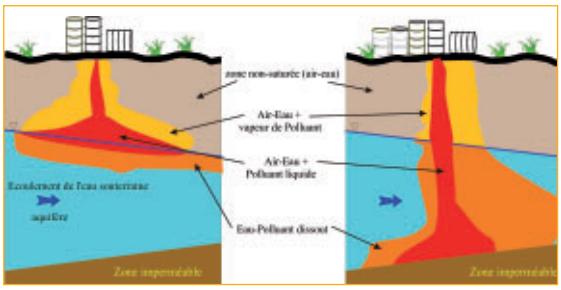
>>> Synchrotron tomography of primate cortex volume injected with a contrast agent, from L. Risser, et al., J. Cereb. Blood flow and Metabolism, 27, 293-303, 2007. Scale bars are 100 microns in each direction.

Soil and groundwater pollution

Depending on its chemical composition and the type of soil on which it is discharged, pollution can be broken down or stopped in its tracks before it reaches the aquifer layer of a river.

>>> Michel QUINTARD, CNRS senior scientist and Gerald DEBENEST, assistant professor at INPT, researchers at IMFT (joint laboratory UPS / CNRS / INP).

The study of pollution in soils is a multidisciplinary field where fluid mechanics in porous media plays an important role. When chemical contamination occurs, the amount of pollutant transferred to the aquifer is mainly determined by gravity, and/or driven by the load of rainwater filtering down to the water table. For example, the mechanical properties of fluids and porous media lead to very different contamination scenarios in cases of pollution caused by a fluid that is partially miscible with water. This is a very common scenario (see the database on contaminated land, http://basol.environnement.gouv.fr), as illustrated in the figure below.



>>> Behaviour of a partially miscible liquid pollutant during infiltration in an aquifer.

Contamination scenarios

The left hand side of the figure represents pollution by a LNAPL (light non-aqueous phase liquid), that is, a hydrocarbon liquid less dense than the water phase. The liquid enters the soil and stops flowing when it meets the water table. The fluid exchanges contaminants in the porous medium with the gas phase and with the liquid phase, where the contaminants may dissolve. The aquifer water may even end up carrying the dissolved pollutant to a domestic or irrigation pumping well.
In the second case (right hand side), the pollutant is a DNAPL (dense non-aqueous phase liquid), that is, a liquid more dense than water (such as a chlorinated solvent, for instance). Therefore, it can cross the water table barrier and eventually reach the impermeable zone at depths often much larger than the water table depth itself.
To perform risk analyses and to protect against contaminants, we need to know how the contaminants travel through the soil and the aquifer, while taking into account a possible natural decrease in the concentration of these pollutants before they arrive at a pumping well. Apart from purely mechanical mechanisms, natural attenuation may involve biochemical degradation, thanks to the presence of biofilms (for example, bacteria clusters) in the soil.

Detoxification

To model these coupled mechanisms, which is a complex task, we have developed a set of mathematical and numerical techniques that work at the various scales encountered in the natural environment.
Our methods are particularly useful in characterising a polluted site and especially when considering remedial procedures to return the site to its original state, if possible.
Understanding these processes requires a multidisciplinary approach, which has led us to develop scientific links with different laboratories, including ECOLAB (Joint laboratory UPS / CNRS) and Gérino Magali's team at Paul Sabatier University. This collaboration has allowed us to begin studying detoxification processes at the interfaces of river hydrosystems. The main objective of our research is to improve our understanding of pollution attenuation thanks to the presence of biofilms in a porous medium representative of a river bottom.

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Research at Paul Sabatier University

Research at Paul Sabatier University is developed in 68 laboratories organised in research units, supported both by the University and by at least one of the following research institutions: CNRS, INSERM, IRD, INRA, CNES...
The research staff includes about 2350 scientists whereas the administrative and technical staff consists of 1130 people.
The number of graduate students is around 1900 in six doctoral schools.

The main research themes developed on Paul Sabatier University are:

> **Mathematics:** 1 laboratory.
> **Physics and nanophysics:** 5 laboratories.
> **Chemistry and Materials Sciences:** 6 laboratories.
> **Engineering Sciences:** 6 laboratories.
> **Computer sciences and information systems:** 2 laboratories.
> **Sciences of Earth, Space and Universe:** 7 laboratories.
> **Life and Health Sciences and Biotechnologies:**
> **Biology and Life Sciences:** 11 laboratories.
> **Health Sciences:** 14 laboratories.
> **The Humanities and Social Sciences,** 4 laboratories.

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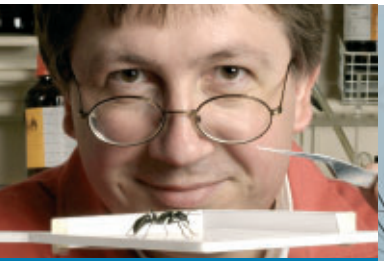

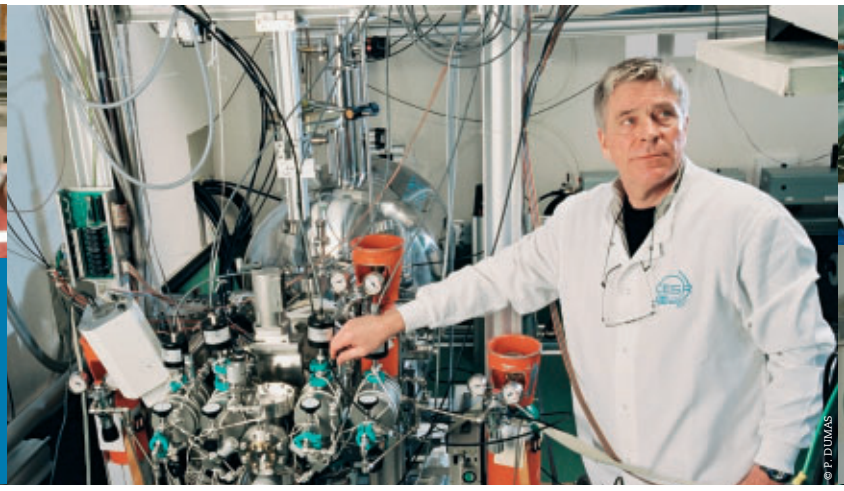

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