# TRIBOLOGY: INTERACTIONS BEYOND THE SURFACE

*A tribute to Prof. Jean-Marie Georges*

Interfaces
Friction
Teaching
Research
Engineering
Archaeology
Cognitive sciences
Art
Industry
TRIBOLOGY
Contact
Surfaces

LTDS
Laboratoire de Tribologie et Dynamique des Systèmes

**Ecole Centrale de Lyon**
**Ecully, France**
**March 30th -31st, 2016**

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# Program & Abstracts

# Biography of Pr. Jean-Marie GEORGES (1939 – 2015)

Jean-Marie was born in Chaumont (Haute-Marne) in 1939 and studied at the Ecole Centrale de Lyon, where he obtained his doctorate in 1964. His scientific career started in the French engineering industry at the Center for Hydromécanique et Frottement in Saint-Etienne, where he studied electro-chemical surface treatments to reduce surface wear, which was also the subject of his Ph.D. thesis. In 1968, Professor Georges left France to continue his research work at the Massachusetts Institute of Technology.

On his return to France Professor Georges took up an Academic appointment at the Ecole Centrale de Lyon and in 1970 established the Département de Technologie des Surfaces. In 1992, the laboratory was enlarged and renamed the Laboratoire de Tribologie et Dynamique des Systèmes (LTDS). The laboratory is now recognized as one of the leading tribology research groups worldwide. Throughout his career, he also maintained close international relations, especially with Japan and the University of Tohoku in Sendai.

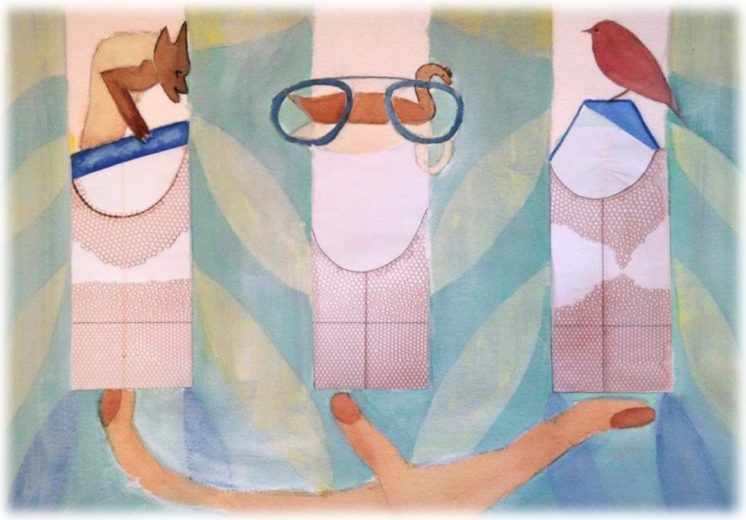
*Painting by Jean-Marie Georges*

Professor Georges' research focused on understanding tribology mechanisms at the nanometer scale. To do this, he and his group designed and developed highly sensitive equipment capable of measuring and understanding lubricating film properties at the molecular level. These new capabilities initiated the study of boundary films, molecular friction, surface rheology, and lubricant additive mechanisms. Professor Georges is particularly known for his work on zinc dialkyl dithiophosphates which are an important class of lubricant antiwear additives. The research was reported in many significant papers published in international journals. One outstanding aspect of his work was the ability to communicate his research to a wider audience and to place the findings in an engineering context. The work did not exist in an academic vacuum but contributed to the benefit of industry and society. For this reason, Professor Georges participated in the program "la main à la pâte," teaching at a secondary school, generating giant soap bubbles to the delight of the schoolchildren and their teachers. His studies are summarized in his book published in 2000: Frottement, usure et lubrification: La tribologie ou science des surfaces.

*Painting by Jean-Marie Georges*

During his career, Professor Georges received many national and international awards recognizing the importance of his work. In 1993, he was elected senior member of the Institut Universitaire de France (IUF). Professor Georges also received the 1994 Tribology Trust Gold Medal from the Institution of Mechanical Engineers UK which is awarded each year to outstanding Tribologists on the world stage. The citation states the award is “In recognition of his outstanding contribution to tribology and in particular, to the development of techniques for the measurement and analysis of surface forces on the molecular or nanometric scale.”

Professor Georges was a great scientist, respected and admired by all, at ease amidst tribologists and physicists in France and worldwide. We are indebted to him and remember him as a great man, a great teacher, with an unlimited curiosity, a communicative enthusiasm, grand gestures, and an unforgettable laugh.



*Painting by Jean-Marie Georges*

# Program of Wednesday, March 30th, 2016

| | |
|---|---|
| 8:30 | *Welcome coffee* |
| 9:00 | Introduction - **Frank DEBOUCK & Etienne GEORGES** |
| 9:15 | Scientific talk - **Irwin SINGER**<br>***Remembering Jean-Marie Georges through photos and videos*** |
| 10:15 | *Coffee break* |
| 10:30 | Scientific talk - **Koshi ADACHI**<br>***Running-in: playing with friction history to promote super-low friction*** |
| 11:30 | Scientific talk - **Alain PROCHIANTZ**<br>***Transcription factors, traveling across the surface… and beyond*** |
| 12:30 | *Lunch* |
| 14:00 | Panel discussion: ***What is the future for surface engineering in research that involves global industrial partnerships?***<br>*Discussion leader:* ***Bertrand NICOLET***<br>**Gérald BRUSSOZ** **Philippe-Franck GIRARD** **Philippe MAURIN-PERRIER**<br>**Samuel STREMSDOERFER** **Christoph WALLNER** |
| 15:30 | *Coffee break & Posters* |
| 16:00 | Scientific talk - **Hugh SPIKES**<br>***Boundary film-forming polymer additives*** |
| 17:00 | Scientific talk - **Philippe-Franck GIRARD**<br>***The world demand for energy increases with population growth*** |
| 18:00 | *Wine tasting & Posters* |
| 19:30 | *Transfer to banquet* |
| 20:00 | *Banquet* |

***To Thursday, March 31st*** ***To list of posters***

# Remembering Jean-Marie Georges through photos and videos

*Dr. Irwin Singer, retired from Naval Research Laboratory (USA)*

I first met Jean-Marie Georges about 35 years ago, when he and two colleagues (J.M. Martin and P. Kapsa) visited W. Zisman's lab at the Naval Research Laboratory (NRL) in Washington, D.C. He talked about tribology of interfaces and materials at the Laboratoire de Tribologie et Dynamique des Systemes (LTDS), which he had recently founded at l'Ecole Centrale de Lyon (ECL). I was impressed. We next met in Lyon, twice, during my sabbatical at Cambridge University in 1985-86. First in September 1985 during EuroTrib-85, held in Lyon; secondly, seven months later, when I visited LTDS to write about tribology research for ONR's European Scientific Notes. Over the next seven years, Georges and I saw each other often, at Gordon Conferences and Leeds-Lyon meetings, then in Braunlage, Germany (summer 1991) and during my NRL sabbatical year at LTDS in 1992-93. Braunlage was the site of the NATO ASI meeting on friction at the microscopic and macroscopic level, in which Georges was an invited lecturer. I will show several video clips of Jean-Marie (and Françoise) at the meeting. I met with Georges many times during my subsequent visits to LTDS and saw him last at Lyon Perrache in 2006. He and Françoise were racing to a train, carrying their art supplies, on their way to some part of France to paint. "What a life," I thought.

# Running-in: playing with friction history to promote super-low friction

*Pr. Koshi Adachi, University of Tohoku (Japan)*

Low friction technology is recognized as one of key issues for high efficient usage of energy in mechanical systems. To achieve the low-friction, new materials, coatings, surface treatment methods, lubricants and new surface design have been strongly required.

In dry contact, boundary lubrication regime and mixed-lubrication regime except perfect hydrodynamic lubrication regime, friction surfaces at a stable friction condition always change significantly from the initial designed surface. That is to say, design concept for initial surface to control formation of friction interface is needed for further low friction technology.

On the other hand, it is well-known that beginning of sliding so-called running-in period is an important for stable friction by formation of well-conformed interface. Recently, self-formed nanointerfaces during running-in period, which satisfy super-low friction, have been reported.

In this presentation comprehensive overviews of the super-low friction by nanointerface formed automatically during running-in are introduced. And from the viewpoint of nanointerface formed during running-in, future of ultra-low friction technology is discussed.

# Transcription factors, traveling across the surface… and beyond

*Pr. Alain Prochiantz, Collège de France*

Homeoproteins represent a family of a few hundred transcription factors first identified through their developmental functions. However, they are also expressed in the adult where they serve several physiological processes.

Most homeoproteins contain two conserved regions allowing intercellular transfer, a rather unexpected finding that led to the proposal that homeoproteins are not only cell autonomous transcription factors but also non-cell autonomous signaling entities.

Several examples of this novel signaling mechanism will be presented from the formation of compartments in the developing nervous system to the regulation of physiological plasticity in the post-natal and adult cerebral cortex.

The fact that homeoproteins are internalized by live cells suggests that blocking or, alternatively, enhancing their capture through pharmacological or genetic manipulations could be of therapeutic interest. This will be illustrated with animal models of neurological and psychiatric diseases.

Finally, it will be shown that these novel signaling proteins, at least for the few that have been studied, display several non-cell autonomous modes of action that include the regulation of protein translation and gene transcription, plus the control of the chromatin epigenetic status.

**One recent review**

Alain Prochiantz & Ariel A. Di Nardo. Homeoprotein Signaling in the Developing and Adult Nervous System. *Neuron* **85**: 911-925, 2015

## *Notes*

Wednesday, March 30th, 2016, 14:00–15:30

# Panel discussion:

# What is the future for surface engineering in research that involves global industrial partnerships?

*Discussion leader:*
*M. Bertrand NICOLET (Business Development VP, MANUTECH-USD, France)*

**M. Gérald BRUSSOZ** (Project Team Leader, FERRARI, Italy)

**M. Philippe-Franck GIRARD** (Délégué Direction Scientifique, TOTAL, France)

**Dr. Philippe MAURIN-PERRIER** (President, IREIS, France)

**Dr. Samuel STREMSDOERFER** (Chairman Executive Officer, JETMETAL, France)

**M. Christoph WALLNER** (Head of Materials Engineering, Production Innovation Center, DENSO INTERNATIONAL EUROPE, Germany/Japan)

# Boundary film-forming polymer additives

*Pr. Hugh Spikes, Imperial College London (UK)*

Polymers have been widely used for many years as additives in engine and transmission oils in order to increase the viscosity index of their blends. However, in the 1990s it was shown at both ECL and Imperial College that some polymers can also adsorb on polar solid surfaces to form “immobile” layers, having much higher viscosity than the bulk lubricant. These films are able to reduce friction by promoting surface separation in slow speed conditions. These functionalised polymers are now recognised to be part of the tool box used by lubricant designers to develop fuel efficient lubricants. This presentation will review past research on polymer-based lubricant additives and describe how they have become an important component of the tool box used by lubricant designers to develop fuel efficient lubricants.

# The world demand for energy increases with population growth

*Mr. Philippe-Franck Girard, TOTAL (France)*

Due to greenhouse effect and new targets in $CO_2$ emission control to avoid to reach more than 2° of Global T° increase at the end of the century will influence more and more the energy mix. Although non-hydrocarbon and renewable sources of energy are increasing the cost of energy will be the key factor for influencing the increase of gas production instead of classical crude oil for hydrocarbons. Integrated companies are already proposing $CO_2$ reduction along all the value chain from the well to the end of life of products. In this chain the physic of interfacial phenomenon and rheology are playing a key role at different steps. Petroleum industry engineers in exploration and Production fields are studying how to recover more oil in existing reservoirs with EOR (Enhanced Oil Recovery) techniques , including emulsions, in refining and chemistry they develop processes for producing a lot of semi-finished bases for which viscosity control is determinant, and at the end of the chain finished products industries like plastics, elastomers, lubricants industries are developing new molecules which are considered as “fuel economy” or “$CO_2$ saving molecules” and lowering the greenhouse impact of man activities. In many aspects the work done by Jean Marie GEORGES was a pioneer work, introducing the fuel economy concept long before it has been adopted by developed countries. This paper summarized major problems encountered in the oil industry and enhance the role of tribology and fundamental work done to understand all interfacial phenomenon and attached physics.

# Program of Thursday, March 31st, 2016

| | |
|---|---|
| 8:30 | Scientific talk - **Jean-François JOANNY**<br>***Collective properties of molecular motors: a model of active friction*** |
| 9:30 | *Coffee break & Posters* |
| 10:00 | Scientific talk - **Mark ROBBINS**<br>***Pressure dependence of lubricant viscosity and load dependence of Superlubricity*** |
| 11:00 | Scientific talk - **Hervé THIS**<br>***New kinds of gels, new physical and chemical behavior*** |
| 12:00 | *Lunch* |
| 13:30 | Panel discussion: ***How to attract to and teach science? How to consider cognition in the education of engineering sciences?***<br>*Discussion leader:* ***Jean-Pierre CLOAREC***<br>**Nancy BURNHAM** **Robert CARPICK** **Suzi JARVIS**<br>**Alain MIDOL** **François SIDOROFF** |
| 15:00 | *Coffee break & Posters* |
| 15:30 | Scientific talk - **Ton LUBRECHT**<br>***On boundary layers and pressure spikes*** |
| 16:30 | Scientific talk - **Haris PROCOPIOU**<br>***Techniques, senses and emotions during prehistory*** |
| 17:30 | Closing remarks - **Denis MAZUYER** |

***To Wednesday, March 30th*** ***To list of posters***

# Collective properties of molecular motors: a model of active friction

*Pr. Jean-François Joanny, ESPCI, Institut Curie*

In this talk, we discuss the collective behaviour of assemblies of molecular motors and in particular the dynamic instabilities and the oscillations that they can generate. We propose a two-state “soft-motor” model for the collective behaviour of molecular motors, which takes into account both the internal motor stiffness and the periodic interaction with the filament. Dynamic instabilities associated with negative friction occur in the two different limits of very rigid and very soft motors. These limits correspond to the two existing theories of motor assemblies, the rigid two-state model and the cross-bridge model. As in the Prandtl-Tomlinson model of tribology, the important parameter monitoring the dynamic instability is the pinning parameter, which compares the stiffness of the motors to the stiffness of the potential.

# Pressure dependence of lubricant viscosity and load dependence of superlubricity

*Vikram Jadhao[1], Tristan Sharp[1], Lars Pastewka[2] and Mark O. Robbins[1]*

*[1] Johns Hopkins University, Physics and Astronomy, USA*
*[2] Karlsruhe Institute of Technology, Germany*

The talk will first describe non-equilibrium molecular dynamics (MD) simulations of the viscosity of the model lubricant squalane. Theoretical results from $10^5$ s-1 to $10^{11}$ s-1 extrapolate smoothly to experimental results for $10^4$ $s^{-1}$ and below. At room temperature, the entire range is fit by an Eyring model with a constant Eyring stress over pressures from 0 to 1 GPa as the Newtonian viscosity | rises from $10^{-2}$ to $10^4$ P. Simulations show that $\log_{10}$ | rises sublinearly with pressure past 3 GPa, implying that there is no divergence of viscosity at finite pressure. Simulations are also consistent with experimental results for | at temperatures down to 160 K. Comparing high and low pressure results suggests there is also no divergence of | at a finite temperature. The implications for models of elastohydrodynamic lubrication will be discussed. The second part of the talk will describe the effect of elasticity beyond the surface on superlubricity in single asperity contacts. As the contact radius increases there is a transition from coherent superlubric motion to dislocation mediated sliding. Three regimes are identified depending on the ratio of contact radius to the core size of interfacial dislocations. At large loads (contact radii), elasticity prevents true superlubricity with vanishing friction. Instead the friction saturates at a value that is surprisingly similar for commensurate and incommensurate surfaces.

# New kinds of gels, new physical and chemical behavior

*Dr. Hervé This, AgroParisTech, Inra, Université Paris-Saclay*

Food can be described at various scales (from the molecular level to the macroscopic scale) using a formalism taking into consideration the nature of phases as well as their relative topological arrangement (This, 2009). It can change during processing such as in the culinary practice (Aguilera, 2012). The Disperse System Formalism (DSF) scheme (This, 2007) can apply to any scale, according to their "degree of complexity". For example, custard which is made of oil droplets O (from milk), air bubbles G (introduced during the initial whipping of sugar and egg yolks) and small solid particles S (due to egg coagulation during thermal processing) all dispersed in an aqueous phase (W), may be described as $[D_0(O) + D_0(G) + D_0(S)]/D_3(W)$. When applied to French classical sauces compiled from culinary books, 23 categories of products were found.

For the "solid content" of food, it was recognized that it is primarily made of gels (This, 2012), i.e. colloidal systems made of a liquid phase in a solid phase. However, the same word "gel" applies traditionally to very different systems, either non connected such as plant tissues (assuming the cytosol is a liquid), or connected, such as jams. Using the DSF, all kinds of gels could be recognized, and in particular new dynamic gels, called dynagels. Their original bioactivities can now be explored, making the basis of a new way of preparing food structured at any scale: "note by note cooking".

## References

J.M. Aguilera, 2012. Edible Food Structures. CRC Press/Taylor and Francis, NY.

H. This, Formal descriptions for formulation. *International Journal of Pharmaceutics,* 344 (2007) pp. 4-8.

H. This, Molecular Gastronomy, a chemical look to cooking. *Accounts of Chemical Research*, 42(5) (2009) pp. 575-583.

H. This, Solutions are solutions, and gels are almost solutions, *Pure Appl. Chem.*, (2012) pp. 1-20.

## *Notes*

Thursday, March 31st, 2016, 13:30–15:00

# Panel discussion:

# How to attract to and teach science?
# How to consider cognition in the education of engineering sciences?

*Discussion leader:*
*Pr. Jean-Pierre CLOAREC (Ecole Centrale de Lyon, France)*

**Dr. Nancy A. BURNHAM** (Worcester Polytechnic Institute, USA)

**Pr. Robert W. CARPICK** (University of Pennsylvania, USA)

**Pr. Suzanne JARVIS** (University College Dublin, Ireland)

**Dr. Alain MIDOL** (Retired, Université Claude Bernard Lyon 1, France)

**Pr. François SIDOROFF** (Retired, Ecole Centrale de Lyon, France)

# On boundary layers and pressure spikes

*Pr. Ton Lubrecht, LaMCoS, INSA-Lyon*

One of the most enigmatic features in EHL has been the outlet pressure spike as first shown by Petrusevitch. In the outlet zone the pressure distribution exhibits a logarithmic singularity. This pressure singularity is accompanied by a local film thickness reduction. Numerical calculations by Dowson and Higginson show the spike shape evolution as a function of the operating conditions. Safa and Gohar were the first to successfully measure the spike using a sensor deposited on the discs.

Even though its existence has been recorded for many decades, the precise behaviour has remained elusive because of numerical and experimental difficulties. The current paper studies the spike shape and location as a function of the operating conditions, using fine grid calculations and a boundary layer analysis. As both its changing position and its singular character make a head-on study complicated, the inlet boundary layer was studied as a first step. A quick comparison shows that the pressure difference behaviour in inlet and outlet zone are very similar. Using this difference with the dry contact Hertzian pressure distribution, the inlet boundary layer is examined. It is shown that the pressure difference is first positive, then it reaches a sharp peak, before a smooth negative zone occurs. For increasing loads (M) the width of the inlet pressure difference sweep reduces as well as its peak height. True to a boundary layer, its width tends to zero. Scaling the height and the width on the dimensionless load parameter (M) makes all the pressure difference curves collapse onto one another.

It is tempting to try the same scaling parameters in the outlet region. However, the inlet pressure difference peak is located at X=-1, whereas the outlet spike moves from X=0 to X=1, for increasing load. Therefore, the pressure spike location has to be fitted first. This done, it can indeed be shown that the same scaling parameters used in the inlet make the pressure spike difference to collapse onto a single curve.

Finally, the issue of obtaining experimental proof of the spike characteristics is addressed. Once again, a direct approach was considered too complicated, and it was decided to try to infer the pressure spike shape from precise film thickness measurements of the film restriction. These measured film thicknesses were compared with detailed numerical calculations. The film thickness difference was computed using the same operating conditions for measurement and calculation. This film thickness difference was deconvoluted into a pressure difference. This deconvolution increases the measurement noise to the same level as the pressure spike. Taking advantage of the angular symmetry of the pressure spike, an arc averaging filter was applied to reduce the noise to 10% of the spike height. For the lubricant and operating conditions studied, the "measured" spike and the computed spike have a very similar height.

At a 10% slide to roll ratio, the spike height shows a significant reduction.

# Techniques, senses and emotions during prehistory

*Pr. Haris Procopiou, University of Paris 1 (Panthéon-Sorbonne)*

The study of use wear traces on archaeological tools and objects permitted to reconstruct several activities within prehistoric settlements, such as food processing and craft productions (metal, leather, stone…). Sounds, melodies, smells and flavours related to these activities have also been considered.

More specifically the study of food processing tools permitted to identify a variety of cereal meals, their texture and flavour. The study of toolkits permitted to reconstruct workshops organisation, as also skills of prehistoric craftsmen. We have shown that prehistoric craftsmen moved out with their own toolkits. During the Bronze Age (3000 -1000 BC), this mobility permitted technological transfers within the eastern Mediterranean, such as stone drilling processes. These skilled and mobile craftsmen, created polished surfaces, equal or superior in quality to actual ones, produced by mechanised processes. By combining ethnographic and archaeological data our study has shown that polishing conveys senses and emotions and requires developed sensory abilities. Traditional craftsmen measure and think with their hands. The texture of the surface, neglected in archaeological studies but also in museums, appears as an essential component of the object. These results stimulated the introduction of new experiences in Museum exhibitions where visitors are invited to discover sensory properties of archaeological surfaces.

# List of posters

| | | |
|---|---|---|
| *Aging effect on tactile perception: Experimental and numerical approaches* | **Emna AMAIED** | *Ecole Centrale de Lyon France* |
| *High temperature nanoindentation : Study of time-dependent mechanical properties of materials* | **Paul BARAL** | *Ecole Centrale de Lyon France* |
| *The influence of realistic stochastic roughness on lubricated friction* | **Julien BONAVENTURE** | *Ecole Centrale de Lyon France* |
| *Etude de lubrifiant confiné sous conditions tribologiques transitoires par SFA* | **Alexia CRESPO** | *Ecole Centrale de Lyon France* |
| *Shearing experiments of confined phospholipid layers characterized by Fluorescence Recovery After Patterned Photobleaching (FRAPP)* | **Li FU** | *Institut Charles Sadron France* |
| *Rubber-ice friction mechanisms: multi-physical and multi-scale approach* | **Sylvain HÉMETTE** | *Ecole Centrale de Lyon France* |
| *Effects of mechanical stress on electronic properties of single III-Nitride nanowires* | **Lucas JALOUSTRE** | *Institut Néel France* |
| *Humidity-related reversible friction behaviour of hard carbon-based thin films* | **Médard KOSHIGAN** | *Ecole Centrale de Lyon France* |
| *Understanding the role of the counterface nature on the wear behavior of DLC coatings lubricated by base oil* | **Stéphanie LAFON-PLACETTE** | *Ecole Centrale de Lyon France* |
| *Structural and nanomechanical characterizations of antiwear films fabricated from a novel nano-additive at nanoscale sliding contact.* | **Imène LAHOUIJ** | *University of Pennsylvania United States of America* |
| *Characterising the use of acoustic emissions as a sensing technique in a tribochemical context* | **James MAKIN** | *University of Leeds United Kingdom* |
| *Effect of Hydrogen and Oxygen Partial Pressure on the Tribochemistry of Silicon Oxide- Containing Hydrogenated Amorphous Carbon* | **Filippo MANGOLINI** | *University of Leeds United Kingdom* |
| *Tribological behavior of self-assembled films of fatty amines and derivatives compounds* | **Toni MASSOUD** | *Ecole Centrale de Lyon France* |
| *Crosslinked-Polymer-Brushes under Shear: Simulation and Experimental Studies* | **Manjesh SINGH** | *ETH Zurich Switzerland* |
| *Relationship between impact dynamics and wear* | **Thibaut SOUILLARD** | *Ecole Centrale de Lyon France* |
| *Experimental and numerical analysis of an ultrasonic wave propagation in tribological contacts* | **Vipul VIJIGIRI** | *Ecole Centrale de Lyon France* |
| *Friction behavior of a lubricated interface under forced reciprocal sliding* | **Malik YAHIAOUI** | *Ecole Centrale de Lyon France* |

***To Wednesday, March 30th*** ***To Thursday, March 31st***

***The organizers would like to thank the following partners for their financial support, which have made this event possible.***