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Bernard Zappoli's contribution to the French scientific life

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ABSTRACT

In November 2014, at the annual meeting of the research group "Fundamental and Applied Microgravity" held in Carqueiranne, France, I was asked to speak on Bernard Zappoli and his accomplishments. The following is an edited transcription of the speech delivered in his honor following his recent retirement as the Head of The Physical Science Programme at the French Space Agency (CNES). After an introduction outlining his human qualities and retirement as engineer emeritus, his career is summarized. It then details the scientific activities he has undertaken during different periods of his career at several universities, the European Society of Propulsion ("Société européenne de propulsion", SEP), and the CNES. Special attention is devoted to the research groups at the CNES/CNRS that we initiated and the management of which I had been sharing with him for several years. Allusion is made to his recent and new retiree activities.

1. Introduction

It may sound easy to praise someone we have known for a long time. In the one hand, that is true, but in another hand, we can forget this or that detail that seemed insignificant at the time. However, this detail may be important to be aware of for anyone who is less familiar with that person and who has no other information to characterize him/her in a particular light. This is what I would like to say about Bernard Zappoli, who was a friend and not just a colleague: he is deeply human and respectful to other people. It follows that he feels injustice more than anyone else, but is also sensitive to the misfortune of others. This trait goes hand in hand with great kindness and, at the same time, with a gaiety that he loves to share.

In the following, his career is characterized from what we know and its merits highlighted.

As codirector for three terms a GDR ("groupement de recherche", or research group) for fluids in microgravity, I am able to note *firstly* that Bernard, who helped to create this research group, has worked hard to maintain it and to ensure that it be financed. *Secondly*, Bernard became emeritus at the "Centre national d'études spatiales" (CNES) (more exactly, "emeritus expert engineer"). Certainly, he will always keep one eye on the GDR, while entrusting it to his successor at the CNES.

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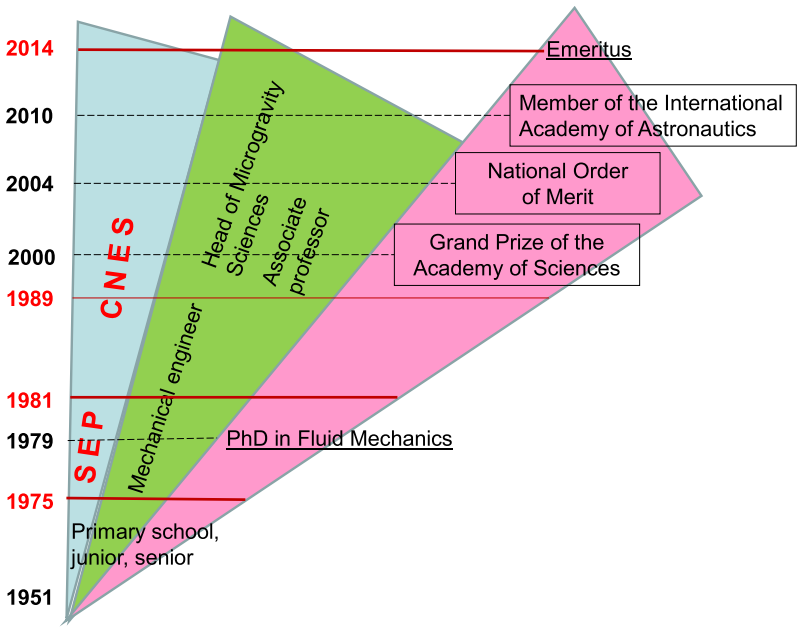

Fig. 1. Diagram summarizing the academic and professional life of Bernard Zappoli.

2. Some remarks on Bernard's career

Fig. 1 summarizes the different periods of activity of Bernard's life, including his professional responsibilities and titles.

Bernard was born in 1951 in Batna, Algeria, and both his parents were teachers. Batna is currently one of the largest city in southern Algeria.

His early education took place in Carpentras, Vaucluse, France.

His graduate studies took place at the University of Marseilles, where he undertook a PhD thesis under the direction of Professor Raymond Brun, during which he continued to be an employee of the "Société européenne de propulsion" (SEP) (see below).

What deserves to be highlighted in Bernard's career is the fact that he performed his professional functions simultaneously with other intense activities:

- science (over 70 publications in international journals, including six in the Journal of Fluid Mechanics, 14 in Physics of Fluids, and 8 in Physical Review; a book entitled "Heat Transfers and Related Effects in Supercritical Fluids" with D. Beysens and Y. Garrabos, 2015, published by Springer [1]);
- education (including at the University of Toulouse as an Associate Professor from 1992 to 2004 and at the ESPCI ParisTech in Paris as an Associate Research Director at the CNRS[1] from 2005 to 2008).

I shall elaborate the first activity "Science", as the second is generally a consequence of the first.

3. Scientific activities

Several scientific themes interested Bernard after his thesis, commencing during the 1980s, to which we will return later. For instance, he led a research team working on the numerical modeling of the interaction between crystal growth and convection. But his other choices can be explained in relation to certain problems at the CNES regarding heat exchange with walls. We shall insist on the following factors.

- Contacts with different people and organizations, such as CEA, Air Liquide, CNRS, and universities have ensured that Bernard paid special attention to critical phenomena. This was also the case of Yves Garrabos and Daniel Beysens.
- Interest in this subject has not escaped other scientists. The need to experiment in microgravity was decisive. We can realize this by summarizing Bernard's scientific collaborations in microgravity research groups on the general theme of

[1] The CNRS (Centre national de la recherche scientifique) is an "établissement public à caractère scientifique et technologique" (EPST). Its activities cover all areas of research.

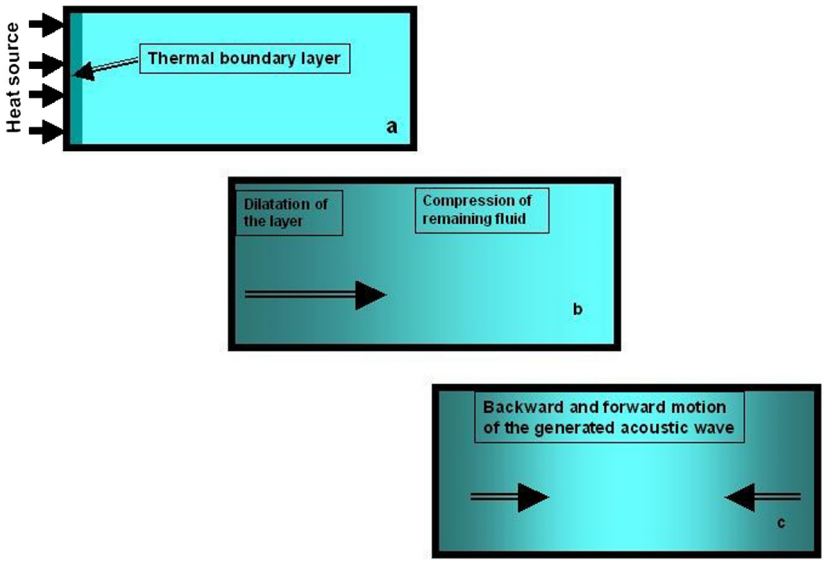

Fig. 2. The piston effect: only the left wall is diathermanous for a short time; the other walls are adiabatic. (a) A thin fluid layer is heated by conduction; (b) the fluid flow is isentropic, but strongly expanding; (c) an homogeneous temperature is quasi-instantaneously reached in the bulk fluid as a result of the outward and return motions of the acoustic waves.

fluids near the liquid–vapor critical point (source: "Assessment for years 2000–2003" GDR P2TPM [2]) with Y. Garrabos, D. Beysens, P. Bontoux, A. Mojtabi, S. Amiroudine, R. Prud'homme, and others.

- An important and decisive point was the discovery of the "piston effect", which characterizes the heat exchange between a wall and a fluid near the critical point in a one-dimensional, confined configuration [3]. He soon became a leader in this field when he showed, by numerical simulations, that heat could be transferred much faster than by diffusion, even in the absence of convection. His idea of using asymptotic expansions to analyze this problem provided the fundamental basis [1]. His willingness to push for an end the analysis generated several PhD theses under his leadership and experimental studies in microgravity in cooperation with NASA. His nomination as Associate Professor of Mechanical Engineering at the University of Toulouse in 1992 offered him an opportunity to keep working on the hydrodynamics of supercritical fluids. In parallel, he used his position at the CNES as head of the Microgravity Sciences program to implement a number of space missions dedicated to this field: the Critical Point Facility (CPF) that flew onboard several Spacelab missions in the framework of the European Space Agency, the "Analyse des liquides critiques dans l'espace" (ALICE) program, which was flown on the Russian MIR space station in the framework of the French–Russian cooperation in space research. This period of his career was extremely intense, yielding pioneering scientific works on supercompressible fluid hydrodynamics. He published a number of seminal papers and the subject is now studied in France, Germany, Russia, USA, and Japan.
- We can qualitatively describe the mechanism of the piston effect—which is, in fact, the fourth mode of heat transfer, by acoustic waves—as follows (see Fig. 2):
  a) a thin fluid layer is heated slowly (very low thermal diffusivity $\kappa = \lambda/\rho c_p$ near the critical conditions) by conduction from a source providing a small amount of heat (Fig. 2a);
  b) this fluid layer strongly expands when heated (very high thermal expansion coefficient $\alpha_L = -\partial\left(\rho/\rho_r\right)/\partial T$ near the critical conditions) and compresses the remaining fluid in an isentropic manner (Fig. 2b);
  c) a homogeneous temperature is quasi-instantaneously reached in the bulk fluid as a result of the outward and return motions of the acoustic waves (Fig. 2c).
- Among the recent studies on critical fluids, significant investigations include the following:
  "Thermoacoustic and buoyancy-driven transport in a square side-heated cavity filled with a near-critical fluid", by Zappoli, Amiroudine, Carlès, and Ouazzani, 1996 [4];
  "Instabilité gravitationnelle dans un fluide supercritique pur", by Zappoli, Amiroudine, and Gauthier, 1997 [5];
  "Boiling crisis and non-equilibrium drying transition", by Nikolayev and Beysens, 1999 [6];
  "Phase transition in hydrogen under vibrations", by Beysens, 2001 [7];
  "Piston-effect-induced thermal oscillations at the Rayleigh–Bénard threshold in supercritical ^{3}He", by Amiroudine and Zappoli, 2003 [8];
  "Supercritical density relaxation as a new approach of droplet vaporization", by Préau, Prud'homme, Ouazzani, and Zappoli, 2004 [9];
  "Stability of a supercritical fluid diffusing layer with mixed boundary conditions", by Accary, Raspo, Bontoux, Zappoli, 2005 [10];

"Numerical simulation of the Poiseuille–Rayleigh–Bénard problem for a supercritical fluid in a mini-channel", by Ameur and Raspo, 2013 [11].

This list contains papers that are not related to the piston effect, but that concern, for example, phase change. Indeed, it is interesting to study the dynamics of phase change near the critical point because of the relative slowness of this phenomenon in this situation. Some of these papers include experimental studies in relation to space experiments. Bernard was directly implicated in the management of experimental studies in microgravity in cooperation with other space agencies.

For the discovery of the Piston Effect, Bernard Zappoli was awarded, together with Daniel Beysens and Yves Garrabos, the Grand Prize of the French Academy of Sciences in 2000.

4. The SEP–CESM period: thesis

The SEP[2]: From 1975 to 1981, Bernard was assigned to the Vernon site ("Grosse propulsion liquide"), where he worked on the design of high-power infrared chemical lasers and, in the same time, prepared his thesis on the kinetic theory of vibrationally relaxing flows.

The "Centre d'études supérieures de mécanique" (CESM)[3]: It was during the period 1974–1979 that Bernard followed my course on relaxing flows and I got to know him.

I was impressed by his courage and motivation, and became interested in the subject of his thesis relating to relaxation phenomena in diatomic gases, similar to the topic of my own thesis about a decade earlier.

The thesis: the orientation of this thesis—under the direction of Raymond Brun—was significantly microscopic. (Although my own work instead covered a macroscopic view of reactive fluid flows, I knew that the appearance and molecular kinetic theory of gases were vital. On the other hand, the team of the "Laboratoire d'aérothermique" that I was managing by then conducted experimental work on plasmas in a rarefied atmosphere and led a theoretical reflection on the molecular scale that comes together.)

The PhD (called at that time "Thèse d'État") thesis titled "Critical approach relaxation phenomena in diatomic gases" was supported by Bernard Zappoli on 4 May 1979 in Marseilles. I could appreciate the quality of this work as a member of the jury.

5. Career at the CNES

From 1981, Bernard was hired by the CNES[4] in Toulouse, and—I think no one can contradict me—he filled a pretty full position, regularly reminding about:

- the programming context,
- the budget,
- ensuring appropriate research themes.

There are several episodes in Bernard's scientific and professional activities at the CNES. Among them are:

– the "Groupe d'étude des phénomènes aérospatiaux non identifiés" (GEPAN);
– the group eventually called "Material Sciences", which Bernard was involved in and to which many of us participated;
– CNES prospective seminars.

5.1. The GEPAN

During the 1980s, the CNES hired Bernard Zappoli, young researcher, PhD in fluid mechanics, and student of Jean-Pierre Petit, to work in Toulouse, researching magnetohydrodynamics (MHD). There, Bernard developed, based on the ideas of Jean-Pierre Petit, a research activity on a propulsion system that could have explained why the close encounters with these objects all reported flying at supersonic speed without shockwaves. When Hubert Curien, the then president of the CNES, created the GEPAN, this group was under the control of a scientific council comprising seven members. The GEPAN functioned as "un département du CNES", a department of the CNES.

[2] The Société Européenne de Propulsion (SEP) was created in 1969 as a merger of the Société d'Études de la Propulsion par Réaction (SEPR) and the Snecma division Engins Espace, to which, in 1971, was enlisted the Laboratoire de Recherches Balistiques et Aérodynamiques (LRBA) of the Ministry of Defense Vernon, who developed the propulsion method for the Veronique rocket. The SEP was incorporated into Snecma in 1997.

[3] The Centre d'Études Supérieures de Mécanique (CESM) was created by Professor Paul Germain to overcome the lack of teaching of mechanics in Paris after the Second World War. He welcomed engineers based on the context of lifelong learning.

[4] The "Centre national d'études spatiales" (CNES) is responsible for conducting the space policy of France. This is an "établissement public à caractère industriel et commercial" (EPIC).

Fig. 3. On the left, Bernard, Denise, and their children at the Great Wall of China [14]. On the right, Bernard at Positano in Italy [15].

5.2. The "Material Sciences" group

This is a group of experts at the CNES on "Fluids and Microgravity", later becoming "Material Sciences". It is primarily responsible for ensuring the expertise of scientific proposals from laboratories. Its findings are reported to the program committee, which makes decisions regarding funding. Bernard was responsible for the CNES and several presidents have succeeded each: Jean-Claude Toledano, Roland Borghi, René Moreau, and Patrick Guenoun [12]. This group is also responsible for the preparation of prospective seminars.

5.3. The prospective seminars

These large seminars are held more or less regularly throughout the body, in which the group (i.e. the GDR) participates simultaneously with other more or less numerous groups (e.g., physicists, astronomers, biologists).

The last one was held in La Rochelle [13]. The recommendations for microgravity research were:

- access to the International Space Station (ISS) remains the main carriageway (though its funding is assumed to continue until 2020);
- parabolic flights must be maintained, as they also play an important role;
- the importance of the DECLIC[5] instrument was emphasized. Indeed, it has shown remarkable results, particularly in water and other supercritical fluids and solidification research;
- support for other projects (granular media, foams) must be maintained;
- in the DECLIC study (in phase 0), new insights for further experiments are recommended, as well as an enhanced version, DECLIC-NG;
- further study of magnetic levitation is recommended, as it can replace microgravity, but only in the case of particular systems.

There have been many missions and conferences, and Bernard made many contacts around the world to develop European as well as global cooperation in the framework of microgravity sciences, involving many of us. These contacts have allowed us to travel the world and see the sights (Fig. 3). I myself have traveled to Beijing, China (1993) [14], Sorrento, Italy (2000) [15], Cleveland, USA (1999) [16], and Moscow, Russia [17].

6. The research groups

The GDR on microgravity was created from a CNES and CNRS initiative in 1992 (stimulated, in particular, by Jean Mahenc, who was the President of its First Scientific Committee, and by Richard Bonneville and Michel Champion, who were members of its steering Committee). Several universities are currently participating: Aix-Marseille-2, Bordeaux 1, Toulouse, Paris-6, and Poitiers.

[5] DECLIC is the acronym for "dispositif d'étude de la croissance et des liquides critiques".

Table 1
List of the successive research groups on microgravity.

Name, number of teams	Period	Direction	Colloquia	References
Mécanique des fluides et phénomènes de transport en microgravité (*Fluid mechanics and transport phenomena in microgravity*) GDR 1028 (Fμg). Number of teams: 9.	01/01/92 to 31/12/95	Roger Prud'homme	Aussois, April 1994 (40 participants)	[18]
Phénomènes critiques, réactions chimiques et milieux hétérogènes en micropesanteur (*Critical phenomena, chemical reactions and heterogeneous environments in microgravity*) GDR 1185 (PR2M). Number of teams: 13.	01/01/96 to 31/12/99	Bernard Zappoli, Roger Prud'homme	Aussois, April 1997 (50 pts), Oléron, May 1998 (37 pts)	[19]
Phénomènes de transport et transitions de phase en micropesanteur (*Transport phenomena and phase transitions in microgravity*) GDR 2258 (P2TPM). Number of teams: 33.	01/01/00 to 31/12/03	Roger Prud'homme	Grenoble, CEA, June 2000 (50 pts), Paris, ESPCI, May 2001 (120 pts), Paris, ESPCI, May 2002, Aussois, May 2003 (50 pts)	[2,20]
Microgravité fondamentale et appliquée (*Fundamental and applied microgravity*) GDR 2799 (MFA).	01/01/04 to 31/12/04	Bernard Zappoli		
Microgravité fondamentale et appliquée (*Fundamental and applied microgravity*) GDR 2799 (MFA). Number of teams: 38.	01/01/05 to 31/12/08	Renée Gatignol	Carry-le-Rouet, October 2005 (59 pts), Fréjus, December 2006 (60 pts), Fréjus, November 2007 (41 pts), Aussois, December 2008	[21]
Microgravité fondamentale et appliquée (Fundamental and applied microgravity) GDR 2799 (MFA). Number of teams: 40.	01/01/09 to 31/12/12	Pierre Haldenwang	Balaruc, November 2009, La Colle sur Loup, October 2010, Porticcio, October 2012	[22]
Microgravité fondamentale et appliquée (Fundamental and applied microgravity) GDR 2799 (MFA).	01/01/13 to 31/12/16	Pierre Haldenwang	Carqueiranne, November 2014 (54 pts), Balaruc, November 2015	[23]

Bernard contributed to the CNES until July 2014, with the GDR undergoing successive and regular renewals since 1992. It is worth to note that the introductions of the successive reports of the GDR, as well as the renewal requests, were mostly written with input from Bernard.

Microgravity is a kind of large scientific instrument with which we can overcome the force of gravity to study the mechanics and physics when a fluid phase occurs.

However, applications in launchers and spacecraft have not been forgotten. This view on microgravity was the guarantee of longevity of the CNES/CNRS research group.

Several themes have emerged over the course of time, such as [21]:

- solidification and crystal growth;
- transport in fluids, instability, and convection;
- combustion;
- fluid interfaces, boiling, condensation, bubbles, droplets;
- foams, emulsions, suspensions, colloidal gels;
- granular media, biomimetic objects;
- critical and supercritical fluids.

We must note, in this regard, the work of Bernard at the CNES to balance the thematics and encourage the entry of new teams. The successive GDRs are indicated chronologically in Table 1. They were led by Bernard Zappoli for the CNES (the names of the CNRS and University directors and codirectors are given). The staffs of the successive groups have held regular working meetings and seminars from the beginning. Since 2001, these meetings were called "annual conferences" (see Table 1).

The objectives of the research groups were as follows.

- GDR Fμg: To gather a scientific community to use the great instrument that represents microgravity to investigate media sensitive to the gravitational field, with at least one fluid phase.
- GDR PR2M: To enhance and develop work leading to estimated relevant results, which was the case for critical phenomena, while keeping a sufficiently distinct scientific community to allow the emergence of new ideas.
- GDR P2TPM: Promote basic systems thinking with at least one fluid phase on critical phenomena, chemistry (combustion, corrosion, etc.), and the dynamics of supercritical fluids. Bernard also had to form new cooperation among the different areas of fluid mechanics, which are thoroughly intertwined with the chemistry and physics of condensed mat-

Table 2
Some of the topical meetings.

Date	Title of the meeting	Location	Participants
March 1994	Common Meeting "Critical fluids and combustion" with GDR 1075 "Combustion in rocket engines"	Paris, CNES	15
November 1994	Modeling hydrodynamics in reduced gravity	Meudon, "Laboratoire d'aérothermique"	20
November 1996	Critical fluids	Paris, LMM	40
June 1999	Interfaces and high gradients	Paris, ESPCI	35
Mach 2002	Fluids under vibration	Paris, ESPCI	
May 2002	Phase fields and diffuse interfaces	Paris, ESPCI	
September 2002	Combustion under reduced gravity	Futuroscope/ENSMA	
March 2003	Influence of external fields on segregation and on structuring in solidification: experiments and simulations	Grenoble, EPM	
July 2005	Vibrations in heterogeneous media	Paris, UPMC	

ter. He also had to support and structure the current trend, characterized by the French participation in the ISS and the development of the DECLIC instrument.

- GDR MFA: Ensure cohesion among the community of teams of individuals in the microgravity environment, conduct promotion and dissemination of scientific information, and initiate or pursue international collaborations.

Topical meetings with the teams also took place (see Table 2).

The work of the teams resulted in numerous publications, some of which have been grouped in GDR conference proceedings [20,24] or the "Congrès français de mécanique" [25,26].

7. Conclusion

Today, Bernard Zappoli continues to work on critical phase transition dynamics in microchannels, in collaboration with Jalil Ouazzani and Yves Garrabos.

I wish emeritus Bernard a good retirement, bringing with it new activities that he desires, some in line with previous interests, with the benevolence of Denise. I also wish him good health, some relaxation, and a well-deserved rest.

Good luck to his successor.

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