

Radyadour Kh. Zeytounian

Five Decades of Tackling Models for Stiff Fluid Dynamics Problems

A Scientific Autobiography

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Foreword

Radyadour Kh. Zeytounian first entered my life in March 1967. He was giving an oral presentation on the role of mathematics in meteorological science. As an external co-worker at ONERA (National Office for Aerospace Studies and Research), I accompanied R. Legendre who had been invited to a meeting organized by the French “Météorologie Nationale” in Paris (Quai Branly). Legendre was the chief responsible research scientist at ONERA and my supervisor Paul Germain (in 1967) the General Director of ONERA.

We were impressed by Zeytounian’s presentation, and by September 1967 he joined the Department of Aerodynamics at ONERA as a research engineer. Meantime, I had the opportunity to speak with Zeytounian and was fascinated by his odyssey through the Soviet Union.

By 1955, I had the exceptional chance, thanks to Germain, to join ONERA as a research engineer and took on a career which seemed forbidden to me due to my somewhat different background.

Knowing from Zeytounian that he had emigrated to Soviet Armenia from Paris, with his parents, in 1947, at the age of 19 without any formal education, I was impressed to hear the narration of his 10 years up to 1957 that led him—under particularly unusual conditions—to attain a diploma in mathematics from the Faculty of Physics–Mathematics of Yerevan State University, with nothing less than distinguished mention, the best possible, in 1954. This impressed me a whole lot, and his scientific excellence continued: In March 1961 he obtained his Ph.D. from the Physics Department of Lomonosov Moscow State University (MGU) under the supervision of the famous I. A. Kibel. Then, in 1964, he became Chief Research Scientist (in Dynamical Meteorology) at the USSR Academy of Sciences in Moscow—mainly based on his theoretical research and numerical simulations of lee waves downstream of a mountain in a stratified and baroclinic atmosphere.

So, I was certainly convinced that it would be most rewarding for me to work with Zeytounian, so I eventually joined ONERA as an external co-worker, and we began a long-lasting, fruitful collaboration where we extensively exchanged our views over the years. This cooperation proved to be most beneficial for both of us, as proven by some 26 publications during the 1970s up to 1986.

In 1967, Zeytounian's first concern was to obtain the *Doctorat d'État ès Sciences*. The material was provided from his Moscow theoretical and numerical results on the "Lee waves downstream of a mountain" obtained during the years 1961–1965. Paul Germain, who accepted to join the Jury with Paul Queney (University of Paris) as Chairman, raised an objection about the basis of Zeytounian's work: "... he argued that it was based on Boussinesq approximation, the one discussed (in ad hoc manner) in the well known Course of Theoretical Physics by Landau and Lifshitz Vol. 6 (§56, 2nd edn. 1954)."

Germain asked for matched asymptotic expansions (MAE)—for a rational justification of Boussinesq approximation—which with Germain we had used to justify asymptotic expansions of shock internal structures in power of the inverse of the Reynolds number for a vanishing viscosity case.

That was a discovery for Zeytounian and he was enthusiastic with MAE, and most of our common work then employed this. Concerning our work, I must say that the ideas often arose from Zeytounian and I spent time to formalize much of his ideas. He was imaginative and pressed to complete each piece of work. As an example, he had the idea to write a book on flows at low Mach numbers, but I always found some complicated matter to unravel so that the project seemed to fail; but Zeytounian eventually completed it with his "Topics in Hypersonic Flow Theory" (LNP 672) which was published by Springer in 2006.

If I may be proud of something, it is to have revealed MAE to him, but I do not intend attempting to explain how he discovered his main contribution to fluid dynamics, what he calls rational asymptotic modeling or RAM—this is all to himself!

Paris, France
May 2012

Jean-Pierre Guiraud

Preface

My entire scientific life, from 1958 on (when I was 30 years old), has been devoted to modeling the fluid flow problem governed by Navier–Stokes–Fourier (NSF) equations (see Chap. 4). Every beginner in fluid dynamics will become aware of such models such as the inviscid flow over an airflow or a laminar boundary layer. The advanced researcher will be familiar with a large number of such models, derived heuristically from NSF equations.

A very large number of works have been published on constructing and using various models, and I have devoted all my scientific activity from 1970 to 2012 in a search towards unifying all of these contributions in a scientific discipline of itself. This rational asymptotic modeling (RAM) underlines “rational” (as opposed to ad hoc) and “asymptotics” for emphasizing the two main concepts in this approach. Let me specify that turbulence—a large class of motions with complex, irregular, and rather unpredictable features—is beyond the scope of this RAM approach. However, in the 1980s, with Guiraud, two short *notes* on asymptotic rational modeling of turbulent flow were published (Zeytounian and Guiraud [1] and Guiraud and Zeytounian [2]); see also the paper by Deriat and Guiraud [3] in a different context.

The RAM approach actually resulted from a quite long struggle both with specific fluid dynamics problems as well as with my personal life, especially from age 19 to 38, first in Soviet Armenia and then in Moscow. My Armenian period of almost 10 years led me to acquire in Yerevan the basic university education as a pure “mathematician.” The second period, again almost 10 years, spent in Moscow up to 2 September 1966, as a “Soviet research worker,” made me familiar with the mathematical physics of partial differential equations and gave me a good background on fluid dynamics meteorology while I was working for a Russian Ph.D. under the supervision of Ilia Afanasevich Kibel, one of the leading Soviet scientists in the field of theoretical hydrodynamics of his time, who is mainly famous as the founder of a hydrodynamic method of weather forecasting and for implementing mathematical methods in meteorology (see, also, our paper of 2004 [4], at the occasion of the 100th birthday of I. A. Kibel).

Before engaging in the subject of the present scientific autobiography, let me provide you with a short biosketch: Paris from birth to age 19—suddenly, in early September of 1947, under very special circumstances, I find myself in Soviet Armenia, to spend the next 19 years there and in Moscow. Before that time my education was very basic, only having obtained the first elementary certificate in 1941, followed by 2 years as a student at a lycée. Having returned to Paris in September of 1966, I eventually managed to be granted a French *Doctorat d'État ès Sciences Physiques* from the University of Paris, at the age 41, in 1969.

With this scientific autobiography, I intend to guide the reader through a rather untraditional career, pointing out along the way how I first encountered fluid mechanics to then devote further 55 years to intensely working to reach a deeper understanding of that scientific matter.

I intend to convince the reader that there is an amazing way to get an overall view of the very large variety of fluid flow models. More than that, I want to show that gathering these models in a particular way for specific flow situations is a first step in organizing a numerical simulation, then applying the RAM approach as a necessary implement before moving on to a numerical simulation by means of high-speed computers.

My quite deep and particular interest for theoretical fluid dynamics has guided all of my scientific activities. In Chaps. 1–3, I elaborate on my long journey to reach a better understanding of the way particularly to solve stiff fluid flow problems and my discovery of the RAM approach.

Chapter 1, “Ten Years in Armenia,” is a narration of how I learned the basic mathematical physics tools for my later research. A special argument that I am making is in my disagreement with the commonly held notion that early teaching is decisive for future life as a researcher. In this chapter I also tell about the special influence of my supervisor at Yerevan State University, Serguei Mergelyan, who directed my university mini-thesis.

Chapter 2, “The Moscow Period with I. A. Kibel,” is a narration of my own growing involvement with fluid mechanics research in the context of dynamical meteorology and my Kandidat thesis (1961, Russian Ph.D.) on local unsteady atmospheric circulations and also my approach to lee waves above and downstream of a mountain from 1960 to 1966. It is strongly inspired by my deep gratitude and respect for my mentor and research supervisor, Ilia Afanasevich Kibel, who I consider to have been the undeniable leader in dynamical meteorology in the Soviet Union from the beginning of the 1940s to the end of the 1960s. This chapter also sketches a highly risky rupture: my fruitful first steps as a (Soviet!) researcher and my return to France on 2 September 1966, with my family, Natalia and Christine!

Chapter 3 is devoted to the essential part of my French scientific career: the time at the Météorologie Nationale in Paris (1966–1967), then at ONERA (1967–1972), and at the University of Lille-I (1972–1996), my collaboration with Jean-Pierre Guiraud from 1970 to 1986 playing a decisive role in the steady development of the RAM approach—associated with this, my seven books published by Springer, Heidelberg, from 1974 to 1994, which all arose out of my teaching at the University of Lille-I.

Chapter 4 is an elaboration of the Navier–Stokes–Fourier equations and the RAM approach. Here, I sketch the historic developments of the relevant aspects in Newtonian fluid mechanics inspired by asymptotics during the period considered and refer to our research within that context discussing various aspects of the RAM approach.

In the *Retrospective Summary*, I first show the advantage of the RAM approach in finding new solutions for certain classical fluid flow phenomena and give comments on how RAM can assist numericians engaged in computational simulations of complex problems of engineering interest with the help of high-speed computers. RAM is the ultimate approach for solving fluid dynamics problems with the help of high-speed computers.

Particularly, I wish to thank Jean-Pierre Guiraud, who has provided stimulation and encouragement, who read most of Chaps. 1–3 and made many useful suggestions and who also kindly proposed to draw up the above Foreword.

With a special note of appreciation, I would like to thank Dr. Christian Caron, Physics Editor at Springer, Heidelberg, for his devoted support and who proposed the main title of the present monograph. My sincere appreciation also goes out to the Springer copyediting and production team for their professional and kind assistance.

Yport/Paris
February 2013

Radyadour Kh. Zeytounian

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Bio-Express

- 1928 French-born in Paris of Armenian heritage
- 1947 Emigration to Yerevan, Soviet Armenia
- 1949–1954 Student at Yerevan State University
- 1954 Master of Sciences in Mathematics at Yerevan State University—mini-thesis with Sergei Nikitovich Mergelyan
- 1954–1955 High school teacher at Aravnadoune near Edjmiatzin (Armenia)
- 1955–1956 Laboratory assistant at the Institute of “Water and Energy,” Armenian Academy of Sciences, Yerevan
- 1957–1966 Ph.D. student of Prof. I. A. Kibel in the Meteorological Center in Moscow
- 1961 Kandidat of Sciences in Physics (Russian Ph.D.) from Moscow State University (MGU)
- 1964 Chief Research Scientist (Dynamical Meteorology), USSR Academy of Sciences, Moscow
- 1966–1967 Research scientist at the French Météorologie Nationale, Paris, with Guy Dady
- 1968 Publication of a course for the École de la Météorologie: “Mésométéorologie” for engineers, Météorologie Nationale, Paris
- 1967–1972 Chief Engineer in the Aerodynamics Department at ONERA (French National Office of Aerospace Research), Chatillon, France
- 1969 Doctor d’État ès Sciences (Physics) from the University of Paris
- 1972–1996 Full Professor of Fluid Mechanics at the University of Lille-I, France
- 1972–1986 External Scientific Co-worker in the Aerodynamics Department at ONERA; jointly with J. P. Guiraud published 26 papers in various scientific journals
- 1974 Publication of his first book (in French) in Lecture Notes in Physics (LNP 27), Springer, Heidelberg
- 1976 Visiting Professor at the University of California, Berkeley (invited by Maurice Holt)

- 1982 Recipient Laureate, Academy of Sciences, Paris
- 1982 Visiting Professor at Akademgorodok, Novosibirsk (USSR), Institute of Mechanics (invited by N. N. Yanenko)
- 1983 Coordinator of CISM course “Models for Atmospheric Flows”—Von Karman Session, Udine, Italy, October 3–5
- 1986–1987 Publication of two volumes “Course on Asymptotic Models for Fluid Dynamics” (in French), LNP 245/276, Springer, Heidelberg
- 1990 Publication of the monograph “Asymptotic Modelling of Atmospheric Flows,” Springer, Heidelberg
- 1991 Publication of the textbook “Mécanique des Fluides Fondamentale” (LNP m4), Springer, Heidelberg
- 1991 Publication of the course “Meteorological Fluid Dynamics” (LNP m5), Springer, Heidelberg
- 1994 Publication of “Modelisation asymptotique en mécanique des fluides newtoniens,” Vol 15, in “Mathématiques & Applications,” SMAI (in French), Springer, Heidelberg
- 1990 Visiting Professor at the Instituto Pluridisciplinar, UCM, Madrid (invited by M. G. Velarde)
- 2000 Codirector, with M. G. Velarde (Madrid), of a CISM Summer Advanced School: “Interfacial Phenomena and the Marangoni Effect”—Oswatitsh Session, July 10–14, 2000, Udine, Italy
- 2002 Editor, with M. G. Velarde (Madrid), of “Interfacial Phenomena and the Marangoni Effect,” CISM “Courses and Lectures,” Udine, Italy; Springer, Wien New York
- 2002 Publication of the monograph “Asymptotic Modelling of Fluid Flow Phenomena” (in English), Kluwer Academic, Dordrecht
- 2002 Publication of the Course (first part) “Theory and Applications of Nonviscous Fluid Flows” by Springer, Heidelberg
- 2004 Publication of the Course (second part) “Theory and Applications of Viscous Fluid Flows,” Springer, Heidelberg
- 2006 Publication of the monograph “Topic in Hypersonic Flow Theory” (LNP 672), Springer, Heidelberg
- 2009 Publication of the monograph “Convection in Fluids—A Rational Analysis and Asymptotic Modelling” by Springer, Heidelberg
- 2012 Publication of his thirteenth book: “Navier-Stokes-Fourier Equations—A Rational Asymptotic Modelling Point of View,” Springer, Heidelberg
- 2013 “Scientific Autobiography,” Springer, Heidelberg

Zeytounian authored and coauthored more than 150 publications (surveys and review papers, notes in CRAS, scientific journals, conferences, and courses), which are partly quoted in the Bibliography [Z1–Z88] at the end of the book. The other cited references are listed at the end of each chapter.

For more than 50 years (1960–2012), Zeytounian’s main scientific activity has been in the area of theoretical fluid dynamics—mainly in asymptotic modeling of fluid phenomena—and also in a “fluid dynamician” approach to fundamental mathematical problems of the dynamics of fluids.



Introduction

Until September of 1947 my life had been quite remote from forestalling a scientific career. Born in Paris into an Armenian family immigrated from Turkey at the beginning of the twenties—France has been and is my country! I passed my childhood in Courbevoie, a Parisian suburb, and attended primary school there on Ficatier street near the Seine. With final examinations in June 1941, during the Occupation, I got my *Certif*. After the high school entrance exam at *Lycée Paul Lapie* in Courbevoie, my classical secondary education lasted a brief 2 years, only. So, for 4 years, until the summer of 1947, looking for some sort of “business,” and taking my father’s advice, I helped my two elder brothers, Antoine and Tigrane, who produced tailor-made suits at home, as an apprentice. I was doing several small jobs of sewing, but mainly delivering within the city center of Paris around the Place de la Bourse and near the Metro station Saint Philippe du Roule. Especially during summer holidays I was a very active member of a scouting organization, and I also practiced all kinds of sports, most particularly table tennis. Curious by nature, passionate in discussions, and rather a “brawler,” I had many friends. Reading was my favorite pastime, especially novels, books on ancient history, and popular science (nuclear physics, outer space, rockets, the atomic bomb, . . .). I also collected stamps, which allowed me to acquire some knowledge of geography and history, the *Passage des Panoramas* in Paris being a favorite hangout for this hobby of mine—spending my Sunday mornings at the open-air stamps market at the Rond-Point of the Champs-Élysées.

Advancing in age, I did not want to continue as a tailor apprentice . . . but I did not have a real future perspective . . . and I could not imagine what else to do! During this time, my parents were often discussing to possibly emigrate to Soviet Armenia! Two arguments stood out: In 1946, Stalin apparently accepted a request by the Armenian Catholicos Patriarch George VI concerning the return of Armenians dispersed throughout the world to return to Soviet Armenia. Armenia, this mythical country dominated and protected by the shadow of Mount Ararat. But, by irony of fate, my parents had no idea of what this enigmatic Soviet Armenia could possibly be in reality—this oriental Armenia—in the depths of the Caucasus, wedged between Iran and Turkey. For my part, I did not take this idea as a serious