

Preface

Zeytounian's (2012) book makes a good case that his RAM approach deserves more serious computational attention than it has received. His presentation is generally clear, though Springer should have devoted more effort to cleaning up the English and the typography.

Robert E. O'Malley, Jr—Books Reviews of SIAM Review 54(3) page 613

The most outstanding Chap. 4 of Zeytounian's (2014) book develops the basic Navier-Stokes-Fourier (NSF) equations in a historical context. Overall, readers will realize the unique value of Zeytounian's work and perspective and will come to appreciate his willingness to tackle very difficult problems, aiming to help Fluid Dynamical Numericians. An example is modeling turbo-machinery using the number of blades on a rotor as a large parameter.

Robert E. O'Malley, Jr—Books Reviews of SIAM Review 56(3) page 569

My last two books were published by Springer-Verlag in Heidelberg in 2012 and 2014. As a *research monograph*, the 2012 book is mainly devoted to the Navier-Stokes-Fourier (NSF) system of equations for a Newtonian fluid in the case of compressible, viscous, and heat-conducting flows. The main tool developed there was what I call the *Rational Asymptotic Modelling (RAM)* approach. In this 2012 book, the main objective has three facets. *First*, to “*deconstruct*” the NSF system of equations in order to bring some unity to the various partial, simplified, and approximate models used in classical Newtonian fluid dynamics; this first facet of the main objective is obviously quite a challenge and has very important pedagogical consequences for university education. The *second facet* of the main objective is to outline a consistent rational asymptotic theory for modeling fluid flows on the basis of a typical NSF initial and boundary value problem. The *third facet* is an illustration of our *rational asymptotic modeling (RAM) approach* for various tough technological and geophysical problems from aerodynamics, thermal and thermocapillary convections, and also meteo-fluid dynamics.

Concerning the 2014 book—a “*Scientific Autobiography*”—the reader is guided through my somewhat *unconventional career*: first *discovering* fluid mechanics, and then devoting more than *fifty years* to *intense work in the field*. Using both personal and general historical contexts, this account would be of benefit to anyone

interested in the early and contemporary development of an important branch of theoretical and computational fluid mechanics.

The present book (written during the years 2013–2016), together with the two mentioned above, is a major part of a “trilogy” providing a challenging modern point of view of fluid dynamics that examines the origins of working models and their classification. This lecture course seems to correspond well to a suggestion of Paul Germain (see the conclusion in his last paper [1]) concerning “*fluid mechanics inspired by asymptotics*” as a new way to look at problems, which has proven itself very useful in gas dynamics, hypersonic, supersonic, and hypersonic aerodynamics, magnetofluid dynamics, progressive waves, internal structure of shock waves, hydrodynamic instability, combustion with high activation energy, waves near breaking, atmospheric motions, convection in liquids, nonlinear acoustics, and so on! More precisely then, in the present book *Challenges in Fluid Dynamics*—a close companion to the 2012 book—the reader will find many new facets and applications of our rational asymptotic modelling (RAM) approach.

In particular, my purpose has also been to provide a logically consistent answer to two questions mentioned below concerning the curious “fragmentation” of Newtonian fluid dynamics, which generates a never-ending and varied list of fluid dynamics problems describing certain very particular models of fluid flows! These two very reasonable questions were raised in a book written over 40 years ago by Martin Shinbrot [4]:

Where is he to begin [concerning, the never-ending list of particular fluid flow models], and which of these is fundamental, and which created to aid in the explication of some specific physical problem?

In reality, it seems to me that today *most fluid dynamicists and applied mathematicians only learn the answers to these two questions after they have worked on a specific fluid dynamics problem presented to them on an ad hoc basis.* The first step here is the dimensionless analysis of NSF problems with specific non-dimensional parameters relating to the various physical effects and associated with the corresponding terms in NSF problems. The second step involves the emergence from these dimensionless NSF problems of a large family of approximate rational reduced working models, which leads to a classification according to limiting values (mainly zero or infinity) of a large number of dimensionless reduced parameters (in NSF problems): Reynolds number (viscosity), Mach number (compressibility), Prandtl number (heat conduction), Strouhal number (unsteadiness), Froude/Boussinesq numbers (gravity), Rossby/Kibel numbers (earth rotation), Grashof/Rayleigh numbers (thermal convection in liquids), Marangoni number (thermocapillary effect), and so on.

In this way, we also get a clear view of the origins of the emerging reduced working models, and this gives another understanding of the NSF equations, and undoubtedly a new status to the Stokes “fluidity” concept, discussed in Sect. 1.3, as a basis for classical Newtonian fluid mechanics. I think, on the one hand, that these emerging approximate rational reduced working models, derived using the RAM approach, should also be very welcome for “pure” mathematicians, when they

discover that there are rigorous results concerning the existence, regularity, and uniqueness of solutions of various initial-boundary value problems in fluid dynamics! This seems to me obvious if we take into account the fact that, in so-called “*mathematical fluid dynamics*”, the considered fluid flow problems are very often in no way *rigorously* linked with the fundamental classical NSF equations for Newtonian fluid flows!

At the same time, the approximate rational and consistent reduced working models we derive from very stiff NSF problems should also be valuable for *numericians* dealing with *numerical simulations/computations* using high-memory *high-speed computers*.

In a certain sense, Chap. 4 of our 2014 book, devoted to the *interrelationship between NSF equations and our RAM approach*, can be considered as a short preliminary presentation of the *NSF system of equations via the RAM approach*, in the space of just 54 pages. And in Sect 3.4, the reader will find a short, but nevertheless illuminating account of the RAM approach, through a rather *laborious* application to the derivation and justification of some approximate reduced working meteo-atmospheric models for the weather forecast.

Obviously, a Zeytounian “trilogy” is basically very different from a traditional course of lectures on fluid dynamics, and gives a different, rather challenging view of fluid dynamics, in which the NSF system of equations is given the most important place! Indeed, the *main novelty* in our approach comes chiefly from the fact that *the fundamental system of NSF equations governing the Newtonian motion of a compressible, viscous, and heat conducting fluid flow is given a central role in our discussion. This leads to a new vision of the universality of NSF equations as a fundamental mathematical system for the study of many aspects of Newtonian fluid dynamics, but also to its “deconstruction” via the RAM approach!*

However, a *strong restriction* is assumed (at least at the present time!), namely, that the considered fluid flows are *laminar*! This is unfortunate because some fluid flows appear to be very *tumultuous, changing rapidly from point to point or from time to time* at a given position in 3D time-space! Such *non-laminar* and very *tumultuous fluid flows*, so-called *turbulent fluid flows* (where the usual laminar motion becomes turbulent if for instance the *Reynolds numbers* is *too high* and there is a laminar portion upstream, followed by a *transition to turbulence*) *definitely fall outside the scope of our considerations in the present book*. Discussion of turbulent motion is necessarily a very *long business*, but the reader can find various valuable books dealing with turbulence, despite the fact that turbulence is a huge subject of intensive ongoing research. It seems to me that, in the book by *Sagaut et al.* [3], the reader can find a comprehensive description of modern strategies for turbulent flow simulation, ranging from turbulence modelling to the most advanced numerical methods.

As a final remark we observe that a consequence of our macroscopic-continuum approach, equations of state and transport coefficients (such as viscosity and heat conduction) are given as phenomenological or experimental data and are not related to microscopic equations, i.e., laws governing molecular interactions.

In *Golse* [2], a paper with 142 pages, the curious and motivated reader will find a good account of the *Boltzmann equation and its hydrodynamic limit*. However, *Golse* mentions (on p. 238 of [2]) rather disappointedly that: “The derivation of the NSF system of equations from the Boltzmann equation leads to dissipation terms that are of the order of the Knudsen number ($Kn \ll 1$; ratio of Mach/Reynolds), and therefore vanish in the hydrodynamic limit, $Kn \rightarrow 0$. In other words, the NSF system of equations is an asymptotic expansion of the Boltzmann equation in the Knudsen number, and not a limit thereof!”

I stress again that the deconstruction carried out in the RAM approach is based on a rationally argued, consistent, non-ad-hoc, and non-contradictory approach to the full unsteady NSF system of equations for modelling Newtonian fluid flows, tackled in the spirit of asymptotics. Our main goal is the modelling, and not the search for solutions to the derived reduced working model equations with initial and boundary conditions. The aim is thus to assist numericians in the context of their simulation/computations using super-high-power computers!

It seems to me that the RAM approach opens up new vistas for the derivation of many valuable working model problems. Such models offer a large panel of tools for fluid dynamicists interested in engineering, environmental, meteorological and atmospheric, or geophysical applications. It gives theoretically oriented researchers a way to exchange with numericians expert in high-speed computing, in order to provide them with models that are much less stiff than “brute force”, starting directly from the full dimensionless unsteady NSF system of equations and boundary conditions!

Let us end this preface with a brief description of the *nine chapters* in the present book, following the *introduction*. *Chapter 1* describes some *historical steps* relating to the discovery of the NSF equations, i.e., from *Newton (1686)* to *Stokes (1845)*, via *Euler (1755)*, *Navier (1821)*, *Cauchy (1828)*, *Fourier (1833)*, and *Saint-Venant (1843)*. I hope that this chapter will stimulate the interest of many readers, and why not also motivate some young mathematicians, to carry out theoretical investigations of more realistic applied problems involving Newtonian fluid flows governed by the NSF equations!

In *Chap. 2*, the reader can find first a formulation of a typical initial-boundary value, unsteady NSF problem in the case of a *thermally perfect gas*, and then the NSF equations applicable to an *expansible liquid*, Navier-Stokes (NS, *physically unreal, but often used by mathematicians*) *barotropic* compressible fluid flow, and NSF equations applied in *nonlinear acoustics as a branch of fluid dynamics*.

In *Chap. 3*, we briefly present the foundations of the RAM approach to emphasize our main *postulate* and *some key steps in its realization*, relating principally to the *dimensionless approach*, *asymptotics*, and various *limiting processes* relative to some of the most significant reduced *dimensionless parameters* in the NSF equations and boundary conditions. The case of dimensionless NSF equations for *atmospheric motions* (Sect. 3.4) is carefully considered to illustrate the possibilities of the RAM approach.

In *Chap. 5*, I have tentatively sketched a “*theory of models*” emerging from the full unsteady dimensionless NSF problem in the RAM approach. In Figs. 5.1 and 5.2, the reader will find many valuable approximate working models, which give a *preliminary idea* about the *origins and classification* of a family of models arising as a RAM limit of the dimensionless NSF problem. In particular, Fig. 5.2 shows the approximate reduced working models for high and low Reynolds numbers ($Re \gg 1$ and $Re \ll 1$), and also for low Mach number ($M \ll 1$).

Chapter 6, is devoted to the RAM “deconstruction/modelling” of *four typical*, but very stiff NSF problems, namely, $Re \gg 1$ and $M \ll 1$, meteo-fluid dynamics models, and models for a weakly expansible liquid heated from below. The approximate working models derived for the above-mentioned typical cases are sketched in Figs. 6.1 to 6.4.

Chapter 8 is a *miscellany* of major applications of the RAM approach I have been involved in over the past 50 years (1960–2010) (see *Sect. 6.1*). Chapters 4, 7 and 9 are devoted to some concluding remarks about Chaps. 2, 3, 5, 6, and 8.

I have written the present book as the last, coming at the end of 40 years of writing, from 1974 to 2014, which has resulted in 14 books, mainly devoted to rational modelling of Newtonian fluid flows. I hope that the above-mentioned “trilogy” will be useful to students in the last years of university and young researchers working in the field of fluid dynamics and motivated by modelling, numerical analysis, and simulation/computation of very stiff complex real technological and geophysical flows. Our “trilogy” should also prove useful as a reference for scientists and engineers working in the various fields of fluid dynamics.

I owe thanks first to Dr. Christian Caron, executive publishing editor for physics at Springer, for his continued support during many years in the edition of my various books, and who suggested to Dr. Jan-Philip Schmidt, Springer editor for interdisciplinary and applied sciences, the publication of the present “Challenges” in the applied mathematics and engineering program. As for my previous books, I had several fruitful discussions with *J. P. Guiraud*, whose help was decisive in rendering my own ideas more precise!

My sincere appreciation goes to Dr. Jan-Philip Schmidt, Springer DE, and his copyediting and production team for their professional and kind assistance.

Paris/Yport
October 2015

R.Kh. Zeytounian

References Cited in the Preface

- [1] Germain P (2000) The “New” mechanics of fluids of Ludwig Prandtl. In: Meier G (ed) Ludwig Prandtl ein Führer in der Stromungslehre. Vieweg, Braunschweig, pp 31–40
- [2] Golse F (2005) The Boltzmann equation and its hydrodynamic limits. In: Dafermos CM, Feireisl E (eds) Handbook of differential equations, evolutionary equations, vol. 2, chap. 3. Elsevier B.V, pp 159–301
- [3] Sagaut P, Deck S, Terracol M (2006) Multiscale and multiresolution approaches in turbulence. Imperial College Press

- [4] Shinbrot M (1973) Lectures on fluid mechanics. Gordon & Breach Science Publishers, New York
- [5] Zeytounian RKh (2012) Navier-Stokes–Fourier equations—a rational asymptotic modelling point of view. Springer, Berlin
- [6] Zeytounian RKh (2014) Five decades of tackling models for stiff fluid dynamics problems—a scientific autobiography. Springer, Berlin



<http://www.springer.com/978-3-319-31618-5>

Challenges in Fluid Dynamics

A New Approach

Zeytounian, R.K.

2017, XXVI, 230 p. 38 illus., Hardcover

ISBN: 978-3-319-31618-5