Book Review

Turbulence and Chaotic Phenomena in Fluids, edited by T. Tatsumi, North-Holland Publishing Company, Amsterdam, 1984, 556 pp., $65.00.

For some time now there has been a growing consensus that the non-integrable behavior, generic to systems of even a few coupled nonlinear ordinary differential equations, has something to do with the phenomenon of turbulence in fluid flow. It is not a bad idea, at once cutting through a major portion of the Gordian knot known as "the turbulence problem." How does stochastic behavior arise in an entirely deterministic system, even when only a few modes are excited? The phenomenon known as non-integrability, or more seductively as *chaos*, provides several mechanisms to explain this age-old problem.

The "chaos theory" (to use a term that tends to make practitioners of the art cringe) has been gaining momentum for about two decades now. It started in the early 1960s, 1963 to be precise, with the publication of Lorenz' seminal paper on the *strange attractor* that appears in a severely truncated version of the convection equations. "Strange attractors are strange only to strangers" they said. Initially, I suppose, those attracted were "strangers" to the fluid mechanics community. Many physicists and mathematicians saw fluid systems as prime analog devices for chaotic behavior. A number of exaggerated claims were made on behalf of the new insights back then.

The IUTAM International Symposium on Turbulence and Chaotic Phenomena in Fluids, held in Kyoto, Japan, September 5-10, 1983, was intended to provide a survey of how far the noble goals of the chaotic dynamics approach had led toward a solution of "the turbulence problem." According to the Preface, "about one hundred invited participants from fifteen countries took an active part in the Symposium." Another ninety "observers" were admitted. The number of papers presented totalled eighty-six, including ten general lectures. Of these only thirteen or so (under the heading "Generation and Dynamics of Chaos") dealt with chaotic behavior per se. The majority of papers discussed more conventional aspects of turbulence and transition, often in entirely conventional terms, on the assumption that one day all will be explained as manifestations of phenomena and mechanisms seen in the sometimes esoteric models currently being promoted by the "chaos community." Certainly, there still are issues in transition and turbulence that we do not know how to connect with the notions of chaotic behavior in dynamical systems.

So is chaos the same as turbulence? Not quite it would appear. The regime of real relevance for these ideas may be limited to transition, where simple models displaying chaos have indisputably had real impact. Is turbulence chaotic? Undoubtedly, but is that a useful statement? If a coherent structure in a turbulent shear flow is associated with a strange attractor of large (fractal) dimension, do we learn all that much? We have at least widened the appeal of the subject, enriched our language of inquiry, and augmented the toolkit of diagnostics applied to such flows. We have "acquired" a number of powerful and inquisitive minds with backgrounds different from those of the conventional mechanical or aeronautical engineer. That has to be a healthy development of the subject.

Some of the most successful ideas in the theory of turbulence have come about from an almost total disregard of the Navier-Stokes equations. Komogorov's 1941 theory is a case in point. So is Mandelbrot's geometrico-fractal approach to turbulence (and to almost everything else). Why does the Lord, who allegedly does not throw dice, employ fractals so readily and frequently? Why is it so difficult for us to figure out a priori (i.e., from the equations of motion) what dimensionality He choses for those fractals? There is a suggestion behind the work reported in volumes such as this one, that chaos, fractals, intermittency, finite-time singularities, coherent structures, the renormalization group (and maybe other items yet unknown), are part of an explanation of turbulent flow yet to be disclosed.

There are several very nice papers in the volume. I am biased toward the view that turbulence organizes itself into structures, that these obey relatively simple equations of the type found in particle mechanics, and that it is the chaotic dynamics of these structures that gives the turbulence statistics of the large scales in a turbulent flow (and maybe more). So I read with particular interest the papers by Kida and Yamada (Singularity and Energy Spectrum in a Two-Dimensional Incompressible Inviscid Flow), Moffatt (Simple Topological Aspects of Turbulent Vorticity Dynamics), Hasimoto et al. (Chaotic and Coherent Behavior of Vortex Filaments in Bounded Domains), Novikov (Generalized Dynamics of Three-Dimensional Vortex Singularities; the Preface mentions that "Dr. E. A. Novikov... took an unexpected refuge in the United States after the Symposium"), Hussain (Coherent Structures and Incoherent Turbulence), Lesieur (Intermittency of Coherent Structures: An Approach using Statistical Theories of Isotropic Turbulence), Chevray (Entrainment in Turbulent Flows: Mechanics and Implications), and Gollub and Heutmaker (Convective Pattern Evolution and the Onset of Weak Turbulence). There are many others.

The volume, as the body of science it reflects, contains little in the way of grand synthesis, which raises the question: Are we failing to see the "forest" because of the "trees"? Or have we legitimately become so fascinated with individual "trees" that we are willing to forfeit a full view of the "forest"? There are, however, themes that pervade several papers. The numerical simulation study by Brachet, Meiron, Orszag, Nickel, Morf, and Frisch (*Journal of Fluid Mechanics*, Vol. 130, 1983, pp. 411-451) is mentioned frequently. Thermal convection is still a favorite flow in which to study transition to chaos, but the concepts are spreading. Readers of this journal will want to consult the papers dealing with chaos in free shear flows and boundary layers. Saric and Thomas discuss "the subharmonic route to turbulence in boundary layers," Gaster and Sreenivasan and Strykowski pursue the difference between "traditional" applications of chaotic dynamics to "closed systems," such as Taylor-Couette flow, and potential, new applications to "open systems" such as boundary layers, jets and wakes.

The volume includes a list (and group photograph) of the participants, and a memorial tribute by Hans Liepmann to Janos Laufer, member of the Scientific Committee of the Symposium, who passed away suddenly, unexpectedly and prematurely in the summer of 1983.

Apart from the grouping of related papers, the introductory survey by the editor (Irregularity, Regularity and Singularity of Turbulence), and the list of participants indicating contributors, the volume is simply a collection of papers produced from camera-ready copy. In a field with few textbooks or monographs, the individual may have little choice but to acquire several conference volumes of this kind. Libraries will certainly want to consider the book as a useful reference for researchers and students interested in this rapidly developing area of fluid mechanics.

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Structure of Turbulence in Heat and Mass Transfer, by Zoran P. Zaric, Hemisphere Publishing Corporation, New York, 1982, 585 pp., list price $75.00.

The book consists of the proceedings of an IUTAM Symposium on Heat and Mass Transfer and the Structure of Turbulence held October 6-10, 1980, in Dubrovnik, Yugoslavia. This symposium was one in a recent series of meetings on the structure of turbulence (i.e., Washington, DC, 1976 (IUTAM), Berlin 1977 (DFVLR), Lehigh 1978 (AFOSR), Michigan State University 1979 (AFOSR), Madrid 1980 (IBM), and Marseilles 1982 (IUTAM). The volume therefore constitutes a progress report on a very rapidly evolving portion of turbulence studies, the identification, characterization and control of discrete (but random in space-time) structures in turbulent shear flows. The specific aim of the Dubrovnik meeting was the clarification of heat and mass transfer processes by the results achieved in the turbulence structure research. The volume is organized into five chapters: a) coherent structure research for isothermal laboratory flows (both free and bounded), b) flows with heat and mass transfer, c) environmental flows, d) turbulence modeling, and e) flow visualization. Most of the groups recognized to be deeply involved in coherent structure research were represented in the meeting. Of particular interest are two papers on the Reynolds number dependence of turbulent boundary-layer structures. Typically the IUTAM meetings provide unique forums for *international* contributions and this volume is an outstanding example with 46 participants from 12 countries. This book (along with the proceedings of previous and subsequent conferences on the same subject) is a "must read" for engineers and research scientists interested in the understanding, modeling and control of turbulent shear flows. The near term contribution of the research into coherent structures of turbulence appears to be occurring in the control area, including progress on such technologically significant goals as drag and noise reduction, increased cooling effectiveness, and more efficient combustion. Progress is also beginning to occur in the incorporation of coherent structure concepts and measurements into the modeling of turbulent flows. Indeed, the need for zonal models recognized at the recent Stanford-AFOSR meetings on "Complex Turbulent Flows" may be a result of the experimentally observed diversity of the "coherent structures."

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