J. Fluid Mech. (2000), *vol.* 419, *pp.* 345–347. Printed in the United Kingdom

BOOK REVIEW

Sands, Powders, and Grains: An Introduction to the Physics of Granular Materials. By J. Duran. Springer, 2000. 214 pp. ISBN 0 387 986561 1. DM 129.

Pattern Formation in Granular Materials. By G. H. Ristow. Springer, 2000. 161 pp. ISBN 3 540 667016. DM 159.

Over the last few years there has been an explosion of research in the physics of granular matter, ranging from the statics to the dynamics of granular flows. There are several reasons behind this seemingly sudden interest. The first is that there is new physics and that open questions abound: '... almost everything is yet to be discovered' declares Pierre–Gilles de Gennes in the Foreword of Duran's book. This extends from problems that non-experts may regard as having been solved long ago – e.g. stacking and packing of spheres, studied first by Johannes Kepler and still of interest today – to new puzzling segregation (un-mixing) issues and the entire issue of granular media as a distinctive form of matter. The second reason, and this applies to people trained in fluid dynamics, is that in granular flow problems, intuition built on fluids often does not work; this poses an irresistible challenge. Related to the intuition issue is the absence of a clear, unequivocal, starting point. Exceptions notwithstanding, in most areas of fluid mechanics, the Navier–Stokes equations are the conventional point of departure; the edifice builds solidly on this. True, knowing the equations is clearly not enough and the various branches of fluid mechanics are a clear proof of this fact. The starting point in granular flows is, however, much less clear, and it may be argued that in fact there is none. According to the issue at hand several alternative viewpoints are possible: continuum and discrete descriptions (particle dynamics, Monte Carlo simulations, cellular automata and variations thereof). Moreover, the continuum and discrete descriptions of granular flows are regime-dependent and this may require adopting different sub-viewpoints. An added attraction for researchers is that experimentation, even though it often requires far more sophistication than may appear at first glance, is still accessible and creativity still plays a more important role than the sheer scale of instrumentation. Finally, a third reason for the appeal of granular matter is the clear interplay between science (understanding and explaining) and technology (making and building); it is apparent that inroads into sophisticated scientific questions can have an immediate impact on technology and practice (most branches of engineering as well as geophysical sciences). It is thus hardly surprising that research papers appear at an ever increasing pace and that there are now many reviews covering various aspects of the subject. Part of this literature has been published by the fluid mechanics community (much of the material, before the area became fashionable, appeared in the engineering literature and is now being rediscovered). However, by far, the bulk of the most recent material is geared towards physics. The amount of literature is quickly becoming overwhelming.

The two slim books reviewed here attempt to remedy the situation of information glut. The book by Jacques Duran is from France; the monograph by Gerald H. Ristow, from Germany. One quotes Poincaré in the Preface, the other Heisenberg in the Introduction; surprisingly, both quotations are about experiments. By and large both focus on concentrated granular media (as opposed to dilute particulate systems in rapid motion) consisting of non-cohesive particles (i.e. the interactions between the particles are purely mechanical). If a number is needed, we can think of dry particles, 100 μm and above, though with suitable modifications, the ideas apply to materials several orders of magnitude larger than this.

The book by Duran was developed for students at the University of Paris and is a translation of the 1997 French edition. The objective is to 'highlight the fundamental principles governing the physics [of granular materials]'. The chapters are balanced and insightful. Chapter 1 (17 pages), the introduction, covers orders of magnitude, examples from industry and geophysics, and gives a brief historical review. Chapter 2 (33 pages) deals with 'Interaction in granular media' and covers interactions between two particles – the classical Hertz model and a new soft crust model – before ending with a discussion of interactions among several particles and the classical work by Ralph Alger Bagnold. Chapter 3, at 65 pages, is the longest. It covers fluidization, decompaction and fragmentation. It starts with questions of stacking of balls and gets into indeterminacy (and how randomness appears in seemingly clearly posed problems), Reynolds dilatancy and the classical silo model of Janssen (used several times throughout), arches, dynamical properties of granular piles, including the influence of walls, surface instabilities in extended granular media, and vibrations. Chapter 4 (34 pages) addresses granular media in a state of flow and covers sand piles, including differences between convex and concave piles, presents a discussion of the angle of repose and the dynamical angle of repose, the relaxation angle in small and big piles, and avalanche models, including a cellular automaton description, and a stick-slip model. Chapter 5 (29 pages) focuses on mixing and segregation and covers axial segregation in a rotating drum, segregation by vibration (including the ubiquitous Brazil nut effect), segregation by vibration and shearing, and segregation in long cylinders. All the discussion is restricted to circular containers. The last chapter, Chapter 6, is a thoughtful introduction to the challenges of numerical simulations.

The outcome is an excellent blend of experiments and computation. There are many footnotes but, unusually, they do not get in the way. The translation is very good. Occasional minor errors pop up here and there – changes in notation, variables undefined. I could not detect (a common occurrence) needless repetition; one has to look carefully to see that figures 124 and 47 are the same. Minor imperfections are easily correctable in future editions. The territory covered is vast and the author takes pains to explain that there are difficult choices in deciding what to include and what to leave. The author also correctly points out the lack of standardization, even in matters of terminology. Thus in, Chapter 3, fluidization is not what is normally understood in chemical engineering or what normally has appeared in the pages of the *Journal of Fluid Mechanics*, and fragmentation is not as understood in fragmentation theory – crushing and grinding of rocks, a 'low-tech topic' with a nice mathematical structure that can be used to describe size populations resulting from abrasion and erosion.

Ristow's book focuses more on research, and, as the title indicates, titled towards pattern formation. Chapter 1, the Introduction, is just a couple of pages long. Chapter 2 introduces experimental phenomena, covers shear flow and dilatancy and commonly used materials. Chapter 3 (22 pages long) addresses vertical shaking. It covers heap formation, convective motion, surface patterns, and ends by discussing segregation. Chapter 4 (13 pages long), on the other hand, is devoted to horizontal shaking. Chapter 5, devoted to pouring and formation of heaps, is titled 'Stratification', and in 14 pages covers effects of size and shape on stratification patterns, including continuum models of sandpiles. Chapter 6 (13 pages long), titled 'Conical Hopper', discusses flow dependence on size of orifice, segregation during outflow, and density waves. The forte of the book is in Chapter 7, titled 'Rotating Drum', which at 43 pages long, covers more than a quarter of the book. It discusses different flow regimes, avalanches, continuous flow, radial size segregation as well as density segregation and the interplay between the two, before concluding with axial segregation and competition between mixing and segregation. The concluding remarks chapter is just 2 pages and an Appendix on Numerical methods at 15 pages long concludes the book. Thus, the ending – mixing and segregation followed by numerical methods – is the same in both books.

Duran's book has been used in course work and it shows. Chapters flow easily and they are fairly even. The author is clearly enthusiastic about the subject, but the tone is measured and careful. Caveats, when necessary, are given. On the other hand, at the pace the field is moving, there are omissions. The book has just over 100 references but only a handful from 1995–1996 and nothing beyond that. Also, two central references in the numerical simulation chapter are to PhD theses. Ristow's book, on the other hand, has over 300 references (with titles, though it is a pity they do not include the page range) and several are from 1999. The index of Duran's book is only twice the length of the table of contents; something more detailed would be more helpful.

I would hope that there are plans for a second edition of Duran's book. As for immediate needs, my advice for a course would be to use that by Duran supplemented with Ristow's. The combination should help both researchers and students.

J. M. Ottino