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BOOK REVIEW

An Introduction to Gravity Currents and Intrusions. By M. Ungarish. CRC Press, 2009, 489 pp. ISBN-10: 1584889039, ISBN-13: 9781584889038 $89.95 (USD).

Few sub-disciplines of fluid mechanics share the conceptual simplicity yet lengthy record of investigation of gravity currents, primarily horizontal flows driven by (typically small) density differences. The challenge facing a prospective review author on the subject is therefore twofold: how to describe physical phenomena and related mathematical concepts without undue repetition and in a way that gives due credit to seminal earlier studies. Noteworthy previous reviews have been written by Simpson (1987) and Huppert (2006). The former emphasized their importance in geophysical phenomena, e.g. in the context of thunderstorm outflows and sea-breeze fronts. The latter, more expansive in scope but shorter in length, added discussions of porous media flows and also drew attention to the connection between gravity current and granular flow. In spite of the profound analytical contributions made by these authors, neither review is especially heavy on equations. Stepping into this void is M. Ungarish whose recent monograph devotes most of its 489 pages to the development of a unified theoretical description of gravity current flow in a wide variety of incarnations.

The book is divided into two sections with Parts I and II considering, respectively, the gravity current motion in uniform and stratified environs. Part I begins with a derivation of the one-layer shallow-water equations as they pertain to a rectilinear, non-rotating gravity current flow. Helpfully, Ungarish includes a discussion of the canonical lock–release problem and its analysis via the method of characteristics, finite-difference solution of the shallow-water equations and finite-difference solution of the full Navier–Stokes equations. Chapter 2 concludes with a detailed summary of self-similar solutions and the transition between a buoyancy–inertia regime and a buoyancy–viscosity regime. Chapter 3 revisits the classical analysis of Benjamin (1968), whose front condition expresses the front speed as a function of the relative depth of the gravity current. Also included is a clarification of energy dissipation, in particular for the limiting case of a thin gravity current propagating through a deep ambient. Self-similar solutions are then re-examined and compared against the predictions of ‘box models’, simplified descriptions that ignore variations of the flow parameters along the direction of flow. Here and elsewhere, Ungarish demonstrates the surprising utility of the box model approach, but concludes with an appropriate caution: ‘. . . box model results should be used with great care’.

In Chapter 5, Ungarish introduces a two-layer shallow-water model and thereby highlights the influence of the initial conditions on the qualitative features of the flow. The discussion underscores the need for research in resolving the following questions: (i) How can one-layer models reproduce important predictions from their two-layer counterparts even when the gravity current fluid initially spans a significant fraction of the channel depth so that motions in the ambient should not be regarded as ‘negligible’? (ii) How can one interpret the front speed measurements of Härtel, Meiburg & Necker (2000) and others in light of the shallow-water restriction that the flow must remain subcritical?

After the discussion of axisymmetric and rotational flows, Chapter 9 examines circumstances where the density contrast between the gravity current and the ambient diminishes over time and is largely devoted to the study of sedimenting flows. Two contrasting settling models are described; the shallow-water equations are suitably modified so as to reflect their influence.

Non-Boussinesq systems are introduced in Chapter 10. Now there is a pronounced asymmetry between dense and buoyant flows as exemplified quantitatively by the different choked flow conditions for heavy and light gravity currents. Thereafter, in Chapter 11, the question of viscous gravity current flow is examined. The governing equations are parabolic rather than hyperbolic so that a Benjamin-type front condition is not required. Self-similar solutions to this 'intrinsically simpler' problem are discerned.

Part II of the book is largely a generalization of the results of Part I to the case of a stratified environment. Special attention is paid to the circumstance in which the density varies linearly with height and then again to the case where the gravity current density matches that of the heaviest ambient isopycnal, a description naturally amenable to the study of intrusions. A one-layer shallow-water model is again adopted; an acknowledged drawback of this approach is that internal waves, assumed to be of second-order importance insofar as they influence gravity current flow, are neglected. For a linearly stratified ambient, the generalization of Benjamin's front condition is non-trivial. Accordingly, Ungarish advocates for the application of a less rigorous but 'convenient and physically acceptable' surrogate. Self-similar solutions being generally unavailable, a larger emphasis is now placed on numerical solutions to the shallow-water equations.

Throughout, the level of discussion is advanced. Ungarish provides a useful summary of the requisite mathematical tools in the appendices and does not shy away from putting these to purposeful employ. On the other hand, each chapter is largely self-contained; for experienced readers, the monograph can be used as a helpful reference in guiding future research. Ungarish's consideration of different geometries, flow regimes, etc. is broad, making his book of potential interest to researchers from disparate fields including oceanography, atmospheric science, hydraulic engineering and others. Of course, with its analytical focus, one assumes that Ungarish's target audience is fellow theoreticians. Experimentalists and numerical analysts may recognize avenues for novel research, e.g. related to high-concentration, polydisperse flows, which are necessarily given modest attention in Chapter 9. Here, however, Ungarish's monograph ought to be read in conjunction with other recent reviews and refereed contributions. A similar recommendation applies to members from the applied geophysics community.

A drawback of the exposition is that, much like a paper-based thesis, the discussion occasionally reads too much like an amalgamation of previous work with whole paragraphs reproduced essentially verbatim from Ungarish's published papers. Notwithstanding Ungarish's numerous provocative contributions, one sometimes misses, as with most biographies of freshly retired politicians, the 'long view' that an intervening time interval may afford. For example, Ungarish's claim that 'energy-conserving (non-dissipative) shallow-water flows are theoretically possible... [but] of little practical importance (in the context of Boussinesq lock–release flows)...' could benefit from reference to the contemporaneous numerical simulations of Ooi, Constantinescu & Weber (2007).

A final comment, neither positive nor negative, is that Ungarish often derives his solutions using the empirical front condition of Huppert & Simpson (1980) rather than Benjamin's theoretical estimate. This choice is made for pragmatic reasons but is not without consequence: '... the propagation of the inertial [gravity] current is governed by the jump conditions at the nose.' It should be recalled, however, that Huppert & Simpson's correlation derives from 38 experiments of a rectilinear gravity current propagating into a uniform ambient. Further to my opening remarks, Huppert is and Simpson was a talented experimentalist; they undoubtedly used leading visualization hardware for the day. Even so, and given the substantial advances in digital photography and, for that matter, direct numerical simulation and large eddy simulation algorithms over the past three decades, now seems an opportune time to revisit these earlier experiments for the purposes of validation and, more importantly, extension to other pertinent configurations, e.g. an axisymmetric flow in a stratified ambient. If the theoretician is to reach to the shelf for a front condition, there is no harm in having experimentalists and numerical analysts supplying multiple volumes from which to choose.

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