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Book review

Sloshing, by Odd M. Faltinsen, Alexander N. Timokha. Cambridge University Press, Cambridge, UK (2009). 606 pp., £ 80.00, Hardback, ISBN-13: 9780521881111

The breadth and depth of the authors' approach to the topic of their title make this quite a remarkable book. The list of topics discussed is rather comprehensive and includes the following: free and forced oscillations in the linearised problem, coupling with ship motions, viscous loads and damping, nonlinear modal and asymptotic theories, and slamming. Although the book is developed from the perspective of sloshing in ship tanks, much of the material has much wider application in fluid dynamics and mathematical modelling. Where possible, theory is used to describe each phenomenon—and as a consequence the book contains much mathematics—but good physical interpretations are given, and experimental results are used extensively to validate theory or illustrate phenomena that are currently beyond theoretical description. Many topics are discussed in considerable detail and one can only admire the effort that must have been involved in seeking out and compiling the information. Some research monographs focus quite sharply on the authors' own contributions to the topic, but this is not the case here. Although the authors naturally talk about their own work in some detail, they certainly do not neglect the contributions of others—far from it (there are almost fifteen closely spaced pages of references). In addition to the treatment of sloshing, the book doubles as a text book in fluid dynamics and mathematical and numerical methods and, from both points of view, a reader may well find there is little need to seek further information from other sources.

The authors begin with an introductory chapter that explains, with the aid of photographs, the physical phenomena associated with sloshing and then goes on to describe a variety of circumstances under which sloshing can occur. Much of the chapter is devoted to discussion of the various tanks used for the transportation of liquid cargoes by ship, but other areas of application also get a brief mention.

Chapter 2 is a comprehensive introduction to the governing equations for liquid sloshing and almost everything is derived from first principles; for example, derivations of the Navier–Stokes equations and the continuity equation for a compressible fluid are given. Sections in this chapter that are specific to sloshing describe the boundary conditions appropriate to sloshing in a moving tank, and variational formulations of the nonlinear sloshing problem. The important Bateman–Luke variational principle is described for which, crucially, all boundary conditions are natural.

The third chapter is concerned principally with the linearised theory of ship motions induced by waves and how those motions couple with sloshing. The chapter begins with summaries of the important properties of free, long-crested, waves and the statistical description of waves, and then moves on to give (but not derive) the frequency-domain equations of motions for a ship in waves.

Chapter 4 deals with the substantial body of work on the determination of the 'natural' frequencies and modes of the free motion of an inviscid fluid in a tank. Solutions obtained by separation of variables are discussed in some detail and, in particular, the solutions for tanks that are rectangular or a vertical cylinder are used to introduce more general ideas. This is followed by a good and detailed discussion of the Rayleigh quotient, including comparison theorems, and it is shown how simple trial functions can yield good approximations to the frequency of the lowest mode in a very simple way. Asymptotic approximations to the natural frequencies for tanks with small internal structures, for example baffles, are discussed in some detail. These approximations are mostly based on a simple technique (a sort of 'slender body' theory) for which no reference is provided, and hence I assume that it appears here for the first time. Other topics appearing in this chapter include sloshing in a horizontal cylindrical trough, in a spherical tank, and in a two-layer fluid.

Chapter 5 describes the solution of linearised time-domain sloshing problems that arise from forced motion of the tank, and includes the coupling with ship motions. The free-surface elevation and the velocity potential are represented by Fourier series with time-dependent coefficients, and the natural modes obtained in Chapter 4 for particular tank shapes are used in the expansion procedure. The free-surface boundary conditions yield a coupled system of ordinary

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differential equations for the Fourier coefficients. Examples treated include sloshing excited during collision of two ships, and a hydroelastic analysis of a water-filled monotower in waves.

Although damping is mentioned occasionally in the preceding chapters, viscous effects are not fully addressed until Chapter 6. It begins with an account of the elements of boundary-layer theory, with special attention paid to oscillatory flows, and the established theory for the damping of waves in a rectangular tank is described. Morison's equation is used to estimate the decay due to damping for tanks with internal structures, including vertical poles and baffles, and a number of specific scenarios are discussed in detail.

Much of the preceding content might be viewed as preparation for Chapters 7–9, which rely heavily on the authors' own research These chapters form the heart of the book and are concerned with the description of nonlinear sloshing by multimodal methods, which extend the linear theory of Chapter 5. The short Chapter 7 is concerned with the basic formalism needed to describe by a multimodal method the nonlinear sloshing resulting from forced motion of the tank. As for the linear theory, the free-surface elevation and the velocity potential are represented by Fourier series with time-dependent coefficients, but now the coupled ordinary differential equations for these coefficients are obtained from the Bateman–Luke variational principle. The limitations of this approach are discussed (e.g. it cannot be applied to overturning waves). Chapter 8 deals with the application of multimodal methods to two-dimensional sloshing in a rectangular tank. The chapter begins with a useful review of some asymptotic methods for the solution of nonlinear differential equations, before moving on to apply these methods to sloshing problems in which one mode dominates the motion. The so-called 'critical depth' is highlighted, for which one dominant mode is no longer sufficient to describe the fluid motion, and the authors indicate the changes needed to resolve this by including more than one mode at leading order. The theory of nonlinear shallow-water sloshing is also included in this chapter. Chapter 9 begins with a rather interesting discussion of three-dimensional nonlinear phenomena, including excitation of diagonal waves in rectangular tanks and swirling, which occurs more generally in three-dimensional tanks. The nonlinear theories of Chapter 8 are applied to three-dimensional rectangular and cylindrical tanks and experimental results are used in a discussion of sloshing in spherical tanks.

Linear problems involving complicated geometries, and nonlinear phenomena such as overturning, are beyond the scope of analytical or semi-analytical methods and numerical methods are needed. Chapter 10 is a fairly detailed review of methods for computational fluid dynamics as applied to free-surface problems.

Finally, Chapter 11 is concerned with slamming, that is the impact of the liquid with the tank walls, and a variety of physical effects are discussed, including compressibility of the fluids and elasticity of the walls. The chapter includes the results of model tests and describes a series of simplified mathematical models that focus on specific aspects of the impact process.

In general the book is clearly written and it is mostly a pleasure to read; only occasionally do a succession of short sentences make some parts hard going. The book is in double-column format and, for me at least, this does not help the readability of the text. It is inevitable that there will be typographical errors in a book of this size that contains much mathematics but, although I have not been able to make serious checks, it is my feeling that the number is impressively small.

This comprehensive and well-written book should certainly be in the library of any institution where fluid mechanics is an active topic of research. It will be of interest to both engineers and applied mathematicians and, although not cheap, its extensive contents make it good value as a reference text in, and beyond, the topic of its title.

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