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Book Review

A Modern Course in Aeroelasticity, Third Revised Edition

E. H. Dowell (editor), E. F. Crawley, H. C. Curtiss Jr., D. A. Peters, R. H. Scanlan, and F. Sisto, Kluwer Academic Publishers, Dordrecht, The Netherlands, 1995, 776 pp., $ 260.00

This is the most recent revision of a text on the subject of aeroelasticity, the second edition of which I reviewed for the *AIAA Journal* in November 1991. In my previous review, I noted that the book was clearly "…the most up-to-date text in aeroelasticity," covering a number of new developments in the field since the publication of the venerable BAH book in 1955 (*Aeroelasticity*, Bisplinghoff, Ashley, and Halfman, Addison–Wesley, 1955). I noted at the time the importance of future revisions of the book but was dismissive of the idea as belonging "···to a world of wishful thinking." Now, less than five years later, I have the pleasure of reporting on the most recent round of revisions in this text. To place these new changes into proper perspective, it may be worthwhile for the reader to obtain a copy of the previous review (*AIAA Journal*, Vol. 29, No. 11, 1991, pp. 2017, 2018).

To summarize, the book has been enhanced with the addition of three chapters devoted to nonlinear aeroelasticity, experimental aeroelasticity, and aeroelastic control. These additions, combined with major revisions of existing chapters on rotary wing aeroelasticity and aeroelastic applications in civil engineering, have added almost 150 pages to an already comprehensive treatment of the subject. The list of contributing authors has also grown and is reflective of the new subject matter included in the text. Were it not for the daunting list price, I would unequivocally recommend the book for course adoption.

In my 1991 review, I noted a few deficiencies with the revised second edition. I am happy to report that almost all of those concerns have been addressed to some extent. The book includes both fundamental and advanced concepts and is a valuable resource for both graduate students and advanced researchers in the field. Extensive reference listings included with each chapter should be of immense value to the research student. The remainder of this discussion is focused on the principal changes and enhancements that have been introduced in the revised third edition.

1) The treatment of static aeroelasticity in Chapter 2 has been minimally enhanced with additional comments on the control surface reversal problem. The principal message of this discussion is that allowing a finite spring stiffness at the hinge does not change the control reversal dynamic pressure.

2) In Chapter 3, the section on typical section flutter in steady flow conditions has been revised with a more detailed examination of the effects of changing the static mass moment per unit span on the inception of flutter. Chapter 4 has remained unchanged in this revision.

3) Chapter 5 deals with stall flutter and was the subject of substantial revision in the second edition of the book. In this version, a short discussion on the use of empirical models for relating airfoil vibratory response to corresponding aerodynamic response has been included. The section on computational stalled flow has been enhanced with presentation of computational results attesting to the frequency entrainment phenomenon. Comments on desired developments in computational fluid dynamics, which range from new turbulence models to more efficient real-fluid flow solvers in a parallel computing environment, make the chapter more complete. The reference list has also been expanded.

4) The chapter on aeroelastic problems in civil engineering structures (Chapter 6) has undergone another round of expansion and revision. In the section on wake oscillator models, a new two-degree-of-freedom cylinder-wake model has been included in the discussions. Characteristics of this model suggest the adoption of a revised single-degree-of-freedom model in which the forcing function contains coefficients to be determined from experimental correlation. Although a number of model parameter variations with reduced velocity are presented in this section, the actual scheme for determining these parameters is not discussed. A good correlation between experimental and model-predicted results attests to the overall validity of the approach. Inherent model flexibility obtained through correlation with experiment is described as the principal strength of this approach for engineering applications.

The section on flutter and buffeting has been revised with the inclusion of the translational degree of freedom h into the equations of lift and moment. However, the figures showing representative flutter coefficients are retained from the previous edition and have not been updated to include the new terms. Similarly, the treatment of three-dimensional flutter and buffeting problems has been revised by the inclusion of the degree of freedom h into the aeroelastic lift, moment, and drag equations. There has also been some reorganization in the presentation of material in this section. A discussion of the explicit forms of buffeting forces and moments is postponed until after a treatment of single-mode flutter and a presentation of the indicial function formulations. The latter provides a more natural lead into the discussion of buffeting force and moment equations. The Fourier transformation of these force and moment equations is introduced (with little detail) as the starting point for a structural response analysis in the frequency domain. The influence of turbulence on bridge section flutter derivatives is also identified in this section but is left as an unresolved research issue. Eleven references have been added to an already exhaustive survey of the field.

5) The second edition did not include revisions to the chapter on aeroelastic problems in rotorcraft. In the revised third edition, this chapter has been augmented with a discussion of unsteady aerodynamics as it relates to the rotorcraft aeroelasticity problem. The focus resides primarily in modeling the vortex wake dynamics and in the exploration of approximate methods for computing aeroelastic eigenvalues in this complex coupled problem. The discussion leads the reader through early developments in dynamic inflow theory, underscoring the importance of including transient downwash effects. An approximate theory of dynamic inflow in hover is presented, along with results indicating differences in measured and computed modal frequencies, both with and without dynamic inflow. The extension of this model to forward flight is also presented in brief. Whereas these models are considered relevant for low-frequency inflow effects, a brief treatment of frequency domain aerodynamics is included as a more reliable approach to account for high-frequency effects. A modification of the Theodorsen flat wake theory to include effects of layered returning wakes is presented in this context. Limitations of frequency domain analysis for rotor applications are also included. The discussion then turns to more recent developments in finite state wake modeling, where a rather brief description of a three-dimensional wake model (perturbation equations), which includes dynamic inflow and lift deficiency effects, is presented. A set of results showing good correlation between experimentally measured and theoretically predicted induced inflow distributions is also included. The reference list has been extended by the inclusion of 20 references that deal specifically with unsteady aerodynamics of rotors. The material presented in the chapter, however, is for the initiated researcher or an advanced graduate student. A considerable follow-up of the cited literature is required for someone new to the field.

6) Chapter 8 on aeroelasticity in turbines has seen minor changes. Five additional references have been included. Most of these references deal with computational fluid dynamics and emergent developments in this field relating to aeroelastic problems in turbomachinery. The importance of finite element based structural calculations, intimately coupled with fluid flow solvers, is emphasized in the context of both predicting aeroelastic instabilities and tailoring turbine blades to exclude the onset of the instabilities in the region of interest. The importance of progressive degradation of the structure and the resulting shifts in instability frequencies is identified as an area for further studies.

7) As with the previous chapter, the discussion on unsteady aerodynamics and aeroelasticity has seen only minor modifications. I liked this chapter in my reading of the second edition and was pleased to note that a short summary of an article by D. Mabey on the physical phenomena associated with unsteady transonic flow has been included.

8) Chapter 10 deals with experimental aeroelasticity. Although short (only eight pages), the chapter alerts the reader to important issues in structural dynamics experimentation and wind tunnel testing procedures; the latter are extended to flight test procedures. Issues such as typical required tests, safety, and cost are also explored.

Chapter 11 represents a substantial addition to the book and explores the subject of nonlinear aeroelasticity. Although the subject of nonlinear phenomena is explored in other chapters of the book as well, the focus of this chapter is on presenting specific problems of aeroelasticity in which nonlinear effects are important, on exploring issues of modeling nonlinear effects, on presenting results indicative of the state-of-the-art, and on developing a "wish list" for further research in this area. After a qualitative description of five different nonlinear aeroelastic problems, the chapter touches very briefly on the mathematical consequences of nonlinearity. Central to this discussion is the distinction between linear and nonlinear models (linear, dynamically linear but statically nonlinear, and fully nonlinear models). More importantly, the criteria for selecting such models (with various degrees of complexity) in different physical applications are also included in summary form.

In the section on representative results, the flutter of airfoils in transonic flow is examined from the standpoint of two models—a typical-section-like phenomenological model and models derived from the numerical solution of the fluid-flow equations. The second approach very naturally leads into a discussion of recently proposed reduced-order aerodynamic models that are similar in concept to the modal methods widely used in structural analysis. Although computing eigenvalues for the fluid-flow problem is nontrivial, these eigenvalues shed additional insight into how artificial viscosity (typically included in some finite difference solvers) affects the identification of physical instabilities in fluid–structure interaction problems. Another interesting physical phenomenon described in this section is the flutter of an airfoil in the presence of free-play structural nonlinearities. Nonlinear effects in the flutter of plates and shells and bluff-body aeroelasticity round off the discussions in this section. A "crystal ball" look into the future is the conclusion to this chapter.

9) The final chapter fills in a rather important gap that existed in the previous version. This compact account of a very busy field has added 79 pages to the book. The chapter systematically decomposes the modeling for aeroelastic control into its constituent components—structural modeling, representation of airloads, the modeling of actuator/sensor dynamics, and computing delays such as those introduced by signal processing. A significant section is then devoted to the development of approximate, reduced-order models. As a precursor to showing representative results, the typical section is selected as the test bed, and a control model for this aeroelastic system is developed to various degrees of complexity. As an educator, I associate great value to this detailed model of a relatively simple system; it is a tremendous teaching tool for introducing first- and second-year graduate students to the subject. A variety of

numerical results for the controlled system (which an initiated student could well duplicate!) augment the presentation of the subject matter. Although an understanding of the basic elements of optimal control theory is expected of the reader, this is not an unreasonable assumption for a book of this type.

With all of these additions, the book is rapidly assuming the shape of a "Handbook of Aeroelasticity." Although the first four chapters and portions of Chapters 7 and 12 could be usefully incorporated into a basic graduate course(s) in the field, the bulk of the material is really targeted toward researchers and practicing engineers. This notwithstanding, this enhanced version is a solid contribution to the technical literature, and the team of authors must be saluted for their efforts.

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