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Book Review

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Review of Flight Dynamics

Edited by Robert F. Stengel, Princeton University Press, Princeton, New Jersey, 2004, 752 pp., $95, ISBN 0691114072

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FLIGHT dynamics education has historically been dominated in the classic textbooks by Etkin and Reid [1], McRuer et al. [2], Roskam [3], McCormick [4], and Nelson [5]. All of these texts are largely based upon the seminal textbook from the 1940s by Perkins and Hage [6], and the linear modeling methods contained in the U.S. Air Force Data Compendium (DATCOM) [7]. Because Perkins and Hage [6] and Hoak and Finck [7] use the component buildup approach of dividing the aircraft into wing, wing–body, and wing–body–empennage elements, these methods were satisfactory for most military and civil designs up through the 1960s. With the introduction of aircraft with significant wing–body blending in the 1970s (B-1, F-16, F/A-18), and highly unconventional configurations in the 1980s (YF-23, F-117) and 1990s (X-45), the methods presented by these historical textbooks were clearly becoming less relevant. These newer configurations can possess significantly different features which have a pronounced effect on stability and control, such as chined forebodies, serrated trailing edges, and unusual fuselage cross sections. Although aircraft such as the SR-71 possessed some of these features as far back as 40 years ago, the point is that these features are almost commonplace today.

Numerical methods of all kinds have made tremendous strides in the intervening years too. In addition to the well-publicized advances in computational fluid dynamics (CFD), the area of fluid/structure interaction, and in particular aeroelasticity, has experienced significant advances. An improving capability to analyze highly nonlinear aeroelastic problems, such as the decades-old problem of wing store flutter in high-performance fighter aircraft, is opening a door previously shut to undergraduate- and graduate-level flight dynamics, stability, and control courses [8].

Since 2000, there has been a resurgence in flight dynamics textbooks, as witnessed by the introduction of modern texts such as Pamadi [9], Yechout et al. [10], Schmidt [11], and Phillips [12]. The subject of this review is the latest newcomer to this group, and at 845 pages of text is essentially the tome of career works of distinguished researcher and educator, Robert F. Stengel. Many items from his previous text [13] and his scholarly publications have been masterfully integrated throughout this text. It should be noted up front that this text is unique and represents a significant departure from both the classic texts and its modern text peers.

The first significant difference is in scope and intended audience. The overview is a broad background in both engineering and engineering science, and the intended audience is not only undergraduate students, graduate students, practicing engineers, and researchers, but also interested nonaeronautical engineers and aircraft enthusiasts in general. For this reason, the text covers subjects as elementary as trigonometry, right up through linear algebra. To quote the text, "The book is intended for readers with a broad background and interest in engineering and science…Because it uses common notation and does not assume a strong background in aeronautics, *Flight Dynamics* is accessible to a wide variety of readers."

The presentation in *Flight Dynamics* is also unique. It uses a very novel approach to integrating and developing its topics and methods, instead of using the traditional Perkins and Hage [6] incremental development style. In pedagogical terms, *Flight Dynamics* uses a problem-based learning (PBL) approach vs the traditional topical-based learning. This means that each major section starts with the posing of a problem, and then introduces the mathematics and analysis methods on an as-needed basis, right in the chapter, instead of placing them in stand-alone chapters or appendices. For example, eigenvalues, eigenvectors, and positive definite matrices are introduced on page 173 during the development and discussion on principal axes, as is matrix modal modeling. Classical and modern linear system methods such as Bode, root locus, and Nyquist plots are also interwoven throughout the text, instead of appearing in their own chapters or appendices. Interestingly, both time-domain and frequency-domain techniques appear almost interchangeably in the same sections of the text. This fresh approach will be sure to have its adherents, but possibly also its detractors, who will want to see topics such as numerical integration algorithms, linear algebra, and Fourier and Laplace transforms appear in appendices or dedicated chapters, not tightly woven throughout the text.

Flight Dynamics uses SI units almost exclusively, and contains MATLAB code for several useful functions, in addition to six degree-of-freedom simulation and linear system analysis tools as online supplements to be downloaded. Almost every major topic and subtopic imaginable is covered, including some very specialized ones. However, if a particular topic is mentioned in the text but not covered in detail, the interested reader is directed to the seminal NASA report source material. An entire appendix is devoted to this purpose, organized by topic area. The book is organized around its chapters as follows:

Chapter 1 introduces categories of aircraft types, missions, and basic dynamics of flight.

Chapter 2 covers turbulence in good detail. It derives transformation matrices and introduces aerodynamic forces and moments, plus classical subsonic aerodynamics with some supersonic aerodynamics. Other topics include center of pressure, static margin, stability derivatives, propulsive forces and moments, and propellers and gas turbines.

Chapter 3 derives the equations of motion addressing kinetic and potential energy, power, and specific excess power P_S. Page 169 provides equations of motion transformations in *seven* different axis systems: body, inertial, alternative inertial, alternative body, velocity, wind, and air mass. Nonflat Earth effects and wind shear and wake vortices are also included. Control surfaces are addressed, with surface plots showing force or moment increment plotted vs deflection angle and angle of attack or sideslip angle. The chapter then turns to the solution of nonlinear differential equations, including Euler integration, modified Euler, predictor–corrector, Adams–Bashforth (which is MATLAB's ODE 13 algorithm), and of course Runge–Kutta integration. Interpolation and spline routines for constructing aerodynamic and propulsive functions are also presented. A topic that this reviewer has never seen in a flight dynamics text, computational neural networks, is introduced as an alternate method for modeling multivariate nonlinear functions. The chapter concludes with an example of trimming, and simulated dynamic responses which showcase the standard longitudinal and lateral/directional modes.

Chapter 4 covers methods of analysis and design, with state-space representation of dynamical systems and local linearization methods followed by modeling of stability and control derivatives introduced via classical DATCOM methods. Nonlinear analysis such as using the phase-plane is addressed, and linear system analysis aspects are covered too, including the notions of controllability and observability, linear quadratic regulators (LQR), and Fourier analysis. There is a nice section on uncertainty with respect to model parameters and control inputs, together with a discussion and example of Monte Carlo methods. Linear aeroelasticity, vibrations, and fuel slosh are covered, and the chapter wraps up with a nice discussion of flying qualities and flight control systems, including optimal state estimation and design for stochastic robustness.

Chapter 5 is focused on longitudinal motions, Chapter 6 on lateral/directional motions, and Chapter 7 on coupled longitudinal and lateral/directional motions. These chapters introduce the classical notions of inertial coupling and reduced-order models such as the short period approximation, together with the effects of wind shear, compressibility, and aeroelastic effects. Flight at high angles of attack is addressed in an entire section of its own, including spins, pilot–aircraft interactions, and controller design consisting of gain scheduled stability, command augmentation systems (CAS), adaptive neural network control, and robust nonlinear-inverse dynamic control (dynamic inversion).

There are five appendices, but not of the type usually contained in engineering textbooks. Here, the appendices are mainly succinct descriptions of custom MATLAB functions and routines which can be downloaded from a Web site for this text. The appendices contain constants, units, and conversion factors; descriptions of a mathematical model and 6 °-of-freedom simulation of a business jet; a linear system survey of MATLAB routines; a MATLAB M-file listing for a tutorial and exploratory learning-style paper airplane program; and a comprehensive bibliography of NASA reports related to aircraft configuration analysis.

With this extensive coverage, it is natural to ask what is not included. Perhaps the only significant omission is the lack of homework problems. However, several good worked-out examples are provided in each chapter, as well as extensive references. This lack of homework problems should not pose much of problem for a graduate course, and, for an undergraduate course, it can be addressed by selecting problem sets from other texts. In comparison to other undergraduate texts the reviewer is familiar with and has used, this text does not contain as much of the modeling aspects as, say, Roskam [3] or Nelson [5], nor does it use flight-test data as extensively as Yechout et al. [10]. It does, however, present significantly more analysis methods and simulation results than any of the three, thereby making it a unique member in this set of textbooks.

The extensive collection of techniques and results in a single source make it a valuable reference for the practicing engineer who is already familiar with flight dynamics. For classroom use, it is clearly an outstanding graduate-level text as evidenced by the preceding topical discussion and the statement from the author's Web site: "This book combines a highly accessible style of presentation with contents that will appeal to graduate students and to professionals already familiar with basic flight dynamics." It is also clearly suitable for a first undergraduate course in flight dynamics, depending on the needs and structure of the course and instructor. In several aerospace engineering departments, the first course on flight dynamics is also a combined first course in classical control. For this reason, many of the classic and newer texts contain significant and detailed sections (often dedicated chapters) on transfer functions, root locus plots, Bode plots, etc. These later topics are presented in this text, but do not seem to be intended as rigorous, stand-alone treatments of these topics. Of course, an instructor who uses this text in an undergraduate course can easily pull from and/or assign these rigorous classical control treatments from another text as and if needed. The simulation and linear system analysis tools will clearly be beneficial in an undergraduate setting too.

Professor Stengel is to be congratulated for writing an outstanding book for the practicing engineer and student alike, which fills a significant niche in the flight dynamics literature. Interested readers can learn more about the book from its Web site, in addition to downloading the MATLAB codes for analysis and simulation and lecture viewgraphs: http://www.princeton.edu/~stengel/FlightDynamics.html.

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