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Book Reviews

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Aircraft Flight Dynamics and Control

Wayne Durham, Wiley, New York, 2013, 306 pp., $120.00

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AIRCRAFT flight dynamics and control are very broad and deep subjects. They are also subjects in which the principles and methods of mathematics, aerodynamics, mechanics, and control theory are combined to provide results in the form of equations that can be used to design, analyze, and operate things that fly. Thus, the equations are practical. To many, the equations of flight dynamics and control are also truly "works of art."

The author of this textbook is focused on "dynamic" stability and control at the first-year graduate student level holds both opinions. As a former U.S. Navy fighter test pilot and test engineer turned professor, he relies heavily on the previous works of Bernard Etkin [1,2] and notes provided to him by Fred Lutze, a mentor and colleague at Virginia Tech. The book is carefully written, especially in view of the complexity of conventional stability and control notation. A good glossary is provided, and additional notation is defined well in the text.

The book is divided into 13 chapters and five appendices. In chapter 1, the author first explains the evolution of the book from Etkin's *Dynamics of Atmospheric Flight* [2] and Lutze's notes to its present form, and he gives an "overview" of aircraft flight dynamics. Next, he considers that aircraft flight dynamics is principally used to derive and solve equations of motion needed to determine the position and velocity of an aircraft at an arbitrary time. His focus is on the determination of an aircraft's state (which of course includes its attitude and angular velocity) for the purposes of studying the performance and control of aircraft. Performance, control, and flight simulation are discussed briefly. A good roadmap of the book is provided to guide the reader. Since the main objective of the book is to develop and then apply the equations of flight dynamics, multiple chapters are devoted to the development phase. Chapters 2 through 5 deal with kinematics. Reference frames, also referred to as the coordinate systems fixed within them, similar to those in Etkin's *Dynamics of Atmospheric Flight* [2], are presented in chapter 2. They include an "inertial" Earth-centered reference frame, an Earth-fixed (on the surface) frame, a local horizontal reference frame, three body-fixed frames, and a wind-axis system. Notation for vectors and their matrix counterparts is also included, along with the definitions of angle of attack and sideslip angle. This chapter includes problems.

Transformations from one coordinate system to another are the subject of chapter 3. The use of direction cosines, Euler angles, and Euler parameters (see also appendix C) as alternative ways to define general rotations is discussed, and transformations between sets of parameters are described. Customary symbols and principal values used for Euler angles in flight dynamics are summarized. The problems at the end of the chapter are well posed. Kinematic equations for the attitude parameters are derived in chapter 4. Angular velocity is not defined per se. Homework-type problems at the end of the chapter require the application of the concepts and equations. Most of the problems include excellent graphics. The study of flight dynamics requires equations for the translation/rotation of a system of particles, and sometimes the relative motion of some of the particles. So, the author begins chapter 5 with a derivation of the inertial acceleration of a point in an arbitrary rotating reference frame moving with respect to a hypothetical inertial reference frame. He then considers the magnitudes of accelerations of an Earth-centered frame and an Earth-fixed frame due to the motion of the center of the Earth and its rotation to justify the use of a reference frame fixed on a flat nonrotating Earth as "inertial." The translational and rotational equations for a rigid body are then derived, and the conventions for variables used to define the state (position of the center of mass, attitude of a body-fixed frame, velocity of the center of mass, and angular velocity of the body-fixed frame) of an aircraft's motion are defined. Notation is introduced for forces and moments. A brief discussion of grouping variables into longitudinal and lateral-directional sets is provided.

Chapter 6 is focused on characterizing the forces and moments needed in the equations derived in chapter 5. The author does not attempt to describe in detail "the sources of the dependencies of the forces and moments on other variables." Instead, he acknowledges the use of "sweeping generalizations and hand-waving ... to provide a high-level rationale..." for the methods adopted to characterize the forces and moments. He then presents enough information on assumptions and nondimensional quantities to forewarn the reader. Explanations of how aerodynamic coefficients depend on altitude, flight speed, angle of attack, sideslip angle, angular velocity components, and control variables are, as promised, brief. Included is a brief presentation of linear approximations to coefficients needed in stability and control analyses. Also, the author mentions the availability of experimental data for coefficients in tabular form. The problems at the end of the chapter illustrate the dependencies of aerodynamic coefficients. The six-degree-of-freedom equations of motion for a rigid-body model of an aircraft flying over a flat nonrotating Earth are presented in chapter 7 in terms of body-fixed variables and in terms of mixed wind-axes and body-fixed variables. Steady-state flight conditions are defined, and special cases are identified. The problem of determining state and control variables required for "trimming" an aircraft in a steady state is illustrated by using the linearized (in sideslip angle and control deflections) lateral-directional equations. Chapter-end problems address longitudinal trim and engine-out trim. Chapter 8 deals with the linearization of the chapter 7 equations of motion. This book's focus is more on obtaining linear equations for use in control design than on control-fixed stability, as in Etkin's *Dynamics of Atmospheric Flight* [2]. Both dimensional and nondimensional linear equations based on a steady, straight, symmetric flight state are derived and presented in convenient matrix forms. For the reader's convenience, material on the solution of linear, ordinary, differential equations with constant coefficients is provided in chapter 9. Regarding the problems at the end of this chapter and others, it is assumed that the student using the book is reasonably proficient in using MATLAB® or similar software.

In chapter 10, the author provides two good examples of solutions to the linear longitudinal-and lateral-directional equations. The author has used Fedeeva's algorithm (appendix D) and MATLAB to calculate explicit state transition matrices and transfer functions, and to compute eigenvalues and eigenvectors. The fundamental control-fixed modes are discussed, and some typical time responses are presented. The author's background makes him very familiar with flying qualities, which are the subject of chapter 11. This very good chapter presents useful material from the authoritative civil and military references. Consideration of flying qualities and the fact that many aircraft require automatic flight control to meet specifications provides motivation for the study of automatic flight control in chapter 12. This chapter contains a good introduction to automatic flight control, and the reader is referred to the references for more in-depth treatment of classical control theory and its application to aircraft. The basics of feedback control are followed by roll control, placement of short-period mode eigenvalue placement using pitch rate and angle-of-attack feedback, and control of the phugoid mode using thrust. A very interesting analysis of the coupled roll-spiral oscillation exhibited by the Northrop M2-F2 lifting body is provided. Two current trends in automatic flight control, dynamic inversion and control allocation, are considered in chapter 13. It is noted that nonlinear dynamic inversion was used to design the control system for the Lockheed Martin F-35. Since nonlinear control methods are beyond the scope of the text, to illustrate the concept, the author provides an example of linear dynamic inversion as applied to the M2-F2. Regarding control allocation, some of the author's seminal work on control allocation is presented.

The appendices contain 1) a MATLAB code to calculate state matrices (appendix A); 2) linearization details (appendix B); 3) a derivation of Euler parameters from rotation matrices and the rotation formula (appendix C); 4) Fedeeva's algorithm (appendix D); and 5) MATLAB commands used to calculate results for examples (appendix E).

The literature pertaining to aircraft flight dynamics is extensive. In this clear and concise first-year graduate textbook, based on his notes and problems used in teaching a course many times, the author has provided a useful addition to that literature.

References

[1] B. Etkin, *Dynamics of Flight–Stability and Control*, 2nd ed., John Wiley & Sons, New York, 1982.
[2] B. Etkin, *Dynamics of Atmospheric Flight*, John Wiley & Sons, New York, 1972.

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