AIRCRAFT CONTROL AND SIMULATION

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Third Edition

Dynamics, Controls Design, and Autonomous Systems

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To Deane, Bill, and Richard
B.L.S.
To my sons, Chris and Roma
F.L.
To Amy, Elliot, and Theresa
E.N.J.

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PREFACE

This book is primarily aimed at students in aerospace engineering, at the senior and graduate level. We hope that it will also prove useful to practicing engineers, both as a reference book and as an update to their engineering education. In keeping with the rising importance of autonomous aircraft systems in the world today, the third edition includes two new chapters that cover principles of unmanned aerial vehicle design and control.

As the subtitle suggests, the book can be viewed as having three Parts. Part I comprises Chapters 1–4 and presents aircraft Kinematics and Dynamics, Modeling, and Simulation, with numerous design examples using classical control methods. Part II, consisting of Chapter 5–7, covers Modern design techniques including Linear Quadratic design, which is based on optimality principles. Also included are LQG/Loop-Transfer Recovery and digital control implementation. Part III contains two newly added Chapters 8 and 9 that that detail the modeling, simulation, and control of small unmanned aerial vehicles.

In addressing simulation of aerospace vehicles we have reviewed the relevant parts of classical mechanics and attempted to provide a clear, consistent notation. This has been coupled with a thorough treatment of six-degrees-of-freedom (6-DOF) motion, including a detailed discussion of attitude representation using both Euler angles and quaternions. Simulation of motion over and around the Earth requires some understanding of geodesy and the Earth's gravitation, and these topics have also been discussed in some detail within the framework of the WGS-84 datum. Familiarity with these topics is indispensable to many of the engineers working in the aerospace industry. Given this background the student can independently construct 6-DOF simulations and learn from them.

High-speed motion within the Earth's atmosphere entails aerodynamic forces and moments. We have reviewed aerodynamic modeling, and provided many graphical examples of such forces and moments for real aircraft. The small-perturbation theory of aerodynamic forces and moments is also described in detail. This study of 6-DOF motion and aerodynamic effects culminates in two realistic nonlinear aircraft models, which are then used for design and simulation examples in the rest of the book.

We have provided computer code in both MATLAB and Fortran to perform simulation and design with these models. Involvement with the models and designs will demonstrate many ideas in simulation, control theory, computer-aided design techniques, and numerical algorithms. The design examples are easily reproducible, and offer a great deal of scope to a class of students.

Before starting feedback control design we have reviewed linear systems theory, including the Laplace transform, transfer functions, and the state-space formulation. Transform theory views dynamic systems through their poles and zeros and leads to many convenient graphical and back-of-the-envelope design techniques, while state-space techniques are ideally suited to computer-aided design. We have attempted to pass "seamlessly" between the two formulations.

Classical control design is illustrated through many examples performed on the aircraft models using transform domain techniques supported by an underlying state-space model. Modern design in the later chapters simply uses the state-space models.

Finally, we note that the choice of topics herein is influenced by our experience in the broader area of guidance, navigation, and control (GNC). Very few engineers entering the aerospace industry will find themselves designing flight control systems, and those few will take part in the design of only two or three such systems in their careers. Instead, they will find themselves involved in a broad spectrum of projects, where a good grasp of classical mechanics, dynamics, coordinate transformations, geodesy, and navigation will be invaluable. The importance of modeling and simulation cannot be overstated. Large sums of money are spent on mathematical modeling and digital simulation before any hardware is built.

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