Preface

The purpose of this book is to connect classical mechanics to the simulation of engineering mechanisms. It should be accessible to upper-level undergraduates, beginning graduate students, and practicing engineers. It is reasonably self-contained. The reader should have had some basic physics and undergraduate courses in statics and dynamics. A solid grounding in linear algebra and ordinary differential equations is sufficient mathematical training. The book makes extensive use of vectors, so the reader should be comfortable with that. Numerous illustrations should make it easier to keep track of the vectors. I do not explore numerical analysis in any depth. I assume that the reader will have some sort of package available for numerical integration of systems of ordinary differential equations. The examples worked in the text were done using the built-in routines in *Mathematica*.

I wrote this for a course I have taught for a few years. I wanted a book that covered the usual classical mechanics material used by physicists, but in an engineering context. The first three chapters cover mostly classical material: particle dynamics, the Euler-Lagrange equations, rigid body dynamics, the Euler angles (and other options for describing rotation), and constraints, both holonomic and nonholonomic, including a section on modeling one-sided constraints such as those supplied by a wall. I discuss these topics with some of the common illustrations, but also with examples with much more engineering flavor, such as kinematic linkages and simple robots. I even use a model of an overhead crane in Chap. 1 as an example of particle dynamics. Chapter 1 shows how ballistics on a rotating Earth can be handled in an inertial space, and contrasts that with the usual approach through the Coriolis force. Chapter 2 develops the moments and products of inertia, angular momentum, and the kinetic energy associated with rotation about the center of mass by "building" rigid bodies from collections of particles. The heart of the chapter is rotation. I focus on the "standard" z-x-z set of Euler angles, but also touch on the aeronautical yaw-pitch-roll system, as well as introducing extra rotations where necessary, explaining how to do this. Chapter 3 develops the idea of generalized forces using the rate of work, a direct analogy to the method of virtual work used in statics, as well as explores constraints and Lagrange multipliers for dealing with ordinary nonholonomic constraints. I explore the behavior of the general rolling coin as an introduction to wheeled systems in which the wheels are not confined to the vertical, illustrated in Chap. 8 by the unicycle).

Chapters 4 and 5 discuss alternate approaches to these dynamical problems. The major contribution from Chap. 4 is the null space method, which eliminates the need for Lagrange multipliers. Chapter 5 introduces Kane's method, which is a Newtonian rather than a Lagrangian method, but one that does not require free body diagrams. I do not use Kane's method in the rest of the book, but his contribution of what I call the method of *Z*s is crucial to formulating problems that are relatively efficient numerically. This is the end of the theoretical development, and the chapter recommends the use of Hamilton's equations (introduced in Chap. 4) combined with the null space method and the method of *Z*s to handle the examples in the final two chapters. I summarize the recommended method at the end of the chapter.

Chapter 6 is entirely optional. It covers the basics of electric motors in case one wants to use them in applications. It also covers stability and linear control. The idea is to have this material available in the text for those who wish to apply it to mechanisms. There are some examples of the successful application of linear control methods to nonlinear systems.

Chapters 7 and 8 consist of applications chosen to illustrate the various techniques presented in the text. Chapter 7 deals only with holonomic systems. Chapter 8 deals with wheeled vehicles, including vehicles/mechanisms with casters rather than ordinary wheels.

There is more than enough material for a one semester course. The text could serve as the basic reference for a 1-year course supplemented by more complex examples, and perhaps more on numerical methods. I suggest that any course cover most of Chaps. 1, 2, 3, 4 and 5. The section on rotating coordinate systems can be omitted without compromising any of the material later in the book, as can the section on one-sided constraints. One could also skip the material on Kane's method per se, but the rest of Chap. 5 is necessary.

The rest of the book deals with applications. I try to tailor the applications to the interests of the members of the specific class. The student is in some sense ready for anything after getting through Chap. 5. Some students and some applications require Chap. 6, others do not.

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