CHAPTER 1

INTRODUCTION

The myriad of geometrical, mathematical, and system design issues embodied in modern spacecraft dynamics and control constitutes a field of fascinating scope, complexity, and beauty. In spite of considerable variety and texture of the fine structure, this field remains macroscopically unified by the fundamental principles of mechanics and basic mathematical methods which have evolved over the past two centuries. It is indeed a pleasure (for us fundamentalists) to observe that an arena of such intense current research forms a comfortable continuum with the classical mechanics and mathematics of the nineteenth century.

The present trend toward much larger and more flexible spacecraft, with the simultaneous quest to achieve orders of magnitude improvements in pointing and shape control, represents a most significant driver for advancing the art/science of modeling and control of complicated dynamical systems. An equally significant challenge is the requirement to develop the sensors, actuators and on board computer systems to implement these control systems.

The class of problems receiving central attention herein arise from missions having requirements for large angle, typically nonlinear maneuvers ("SLEWS"), followed by rapid fine pointing and vibration arrest. We treat these problems in considerable detail, including nonrigid effects and actuator dynamics. We emphasize not only the analytical details of formulating the differential equations governing optimal maneuvers, but also devote careful attention to formulating and applying methods for obtaining practical numerical solutions. Since nonlinear maneuvers of flexible vehicles suffer to varying degrees from high dimensionality, nonlinearity and model errors, algorithms which reliably and universally solve all of these problems are impossible to develop. However, practical methods have been developed for solving a significant fraction of these problems.

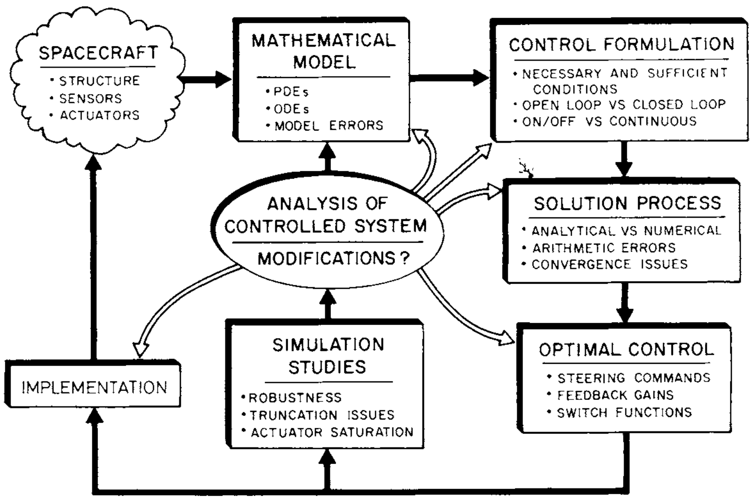

Figure 1.1 **An Overview of Spacecraft Dynamical Modeling, Optimal Control Determination, and Simulation/Implementation**

Referring to Figure 1.1, we overview the class of problems discussed in this monograph. Actual spacecraft are collections of rigid and elastic bodies, sensors, and actuators. An actual structure of distributed material properties, input/output relationships of the several sensors and actuators, and various complicating issues such as material ageing effects, reconfiguration, nonlinearities, unmodeled external disturbances, and random affects are impossible to treat in a completely rigorous, determinstic fashion. Of course, feedback controls are motivated by our inability to perfectly model a system. However, a significant degree of modeling is invariably required to develop precision automatic controllers. The starting point for designing a control system is usually a model of the on-orbit system's input/output behavior. Thus the design, analysis, and performance evaluation of the controlled system is based upon our artistic engineering ability to construct adequate mathematical models. The process of modeling the structure, formulating and computing optimal controls, and analyzing the system's controlled dynamics is usually an iterative process, as outlined in Figure 1.1. While a control law can be made "optimal" with respect to our mathematical model, we can only approach optimality for the actual spacecraft.

The text is divided into four main parts: Chapters two through five are devoted to formulating basic geometrical, kinematical, and dynamical results which facilitate efficient construction of the differential equation models for spacecraft dynamics. Chapters six and seven present the major aspects of deterministic optimal control theory and discuss methods for solving the resulting two-point boundary-value problems. Chapters eight through ten present applications of the methods of the earlier chapters to determine maneuvers for a variety of vehicle models, performance indices, and terminal constraints. The final chapter deals with several novel methods useful in computation of feedback controls and in efficient computation of closed loop response. The appendices collect useful results which we elected not to include in the main text, for reasons of continuity. Appendix A, in particular, presents a concise treatment of systems of autonomous linear (and quadratically nonlinear) differential equations.

In view of the current explosive rate of research and publication in this field, the literature citations, while extensive, are no doubt incomplete. Our main objective in writing this monograph is to provide a unified source for those seeking demonstrated methods which can be used to compute optimal controls for large angle nonlinear maneuvers. This objective is not set to eliminate the necessity for studying the literature, rather, it is felt that the subject is sufficiently well developed, yet the literature is sufficiently diffuse, that achieving this objective will greatly expedite future work in this field.