PREFACE

This monograph is the outgrowth of our recent work directed toward solving a family of problems which arise in maneuvering modern spacecraft. The work ranges from fundamental developments in analytical dynamics and optimal control to a significant collection of example applications. The primary emphasis herein is upon the most central analytical and numerical methods for determining optimal rotational maneuvers of spacecraft. We focus especially upon the large angle nonlinear maneuvers. We also consider large rotational maneuvers of flexible vehicles with simultaneous vibration suppression/arrest.

The rotational maneuver problem is inherently nonlinear since the general motion of a rigid body is nonlinear (owing to nonlinear kinematics and gyroscopic coupling effects). When one accounts for flexibility, multi-body effects, and actuator dynamics, it becomes immediately obvious that this family of problems embodies the dual curse of nonlinearity and high dimensionality. These two features, together with various aspects of coordinate selection, model truncation, boundary condition effects, and the physical nature of various approximations, make this a unique member of the parent family of nonlinear optimal control problems. Depending upon the details of the particular vehicle's mathematical model, the admissible controls, the performance index, and boundary condition specification, we find that the degree of difficulty of optimal rotational maneuver problems ranges from near-trivial to impossible.

The present developments make clear distinctions between (i) formulating the differential equations governing an optimal maneuver, (ii) calculating the maneuver and (iii) actually performing the maneuver. We also point out that significant interplay can occur between (i), (ii) and (iii), through, for example, coordinate choices. An infinity of necessary condition formulations govern a typical optimal maneuver; the coordinates selected sometimes prove of crucial importance, computational misery is not conserved! Of course, a small but important subset of the optimal maneuvers can be solved in a closed analytical form. These cases are considered and continuation methods are introduced which use these analytical solutions as generators for more powerful and broadly applicable numerical solution methods.

For the more difficult maneuver problems, having both high dimensionality and nonlinearity, we find that a naive first assault with off-the-shelf methods has a low probability of success, primarily due to the likely absence of the "good starting guess" required to initiate the various iteration processes. Thus we devote a considerable portion of this monograph to development and demonstration of successive approximation methods (based upon *continuation* and *homotopy chain* imbedding concepts) which are designed to minimize the extent to which prior empirical knowledge is required.

Optimal open loop maneuver controls must usually be augmented by closed loop, feedback controls to compensate for model errors and disturbances, especially during the terminal (fine-pointing) phase of a high precision maneuver. While we do not dwell upon feedback control per se, we do present some particular new results which will be useful in designing feedback controls. In particular, the new material presented in Chapter 11 will be found widely useful for terminal control and tracking maneuvers.

We are indebted to numerous colleagues and our outstanding graduate students for collectively investing several man-years into the developments incorporated herein. We acknowledge these contributions in context, but we

would like to thank the following individuals (in alphabetical order!) for their especially significant direct and indirect contributions:
K. T. Alfriend, S. P. Altman, A. K. Amos, H. D. Black, J. N. Blanton, D. S. Bodden, R. A. Broucke, R. W. Carmen, C. K. Carrington, H. M. Chun, J. E. Cochran, Jr., N. G. Creamer, J. P. Dunyak, T. A. W. Dwyer, III, D. Frederick, L. A. Gambino, S. L. Hendricks, S. Herrick, D. L. Hitzl, A. F. Herzberg, P. G. Ifju, I. D. Jacobson, J. N. Juang, M. G. Kaplan, T. R. Kane, C. L. Keller, L. G. Kraige, P. W. Likins, K. B. Lim, R. W. Longman, L. Meirovitch, D. L. Mingori, H. S. Morton, Jr., T. Papis, M. Rajan, S. Rajaram, D. W. Rew, M. H. Rheinfurth, R. S. Ryan, M. Salkind, K. Soosaar, T. E. Strikwerda, B. Strunce, C. E. Thomas, R. C. Thompson, D. H. Townsend, S. R. Vadali, W. Vander Velde, V. Venkayya, C. J. Weeks, and C. E. Williams.

We are also most grateful for the support of the following organizations: The Air Force Office of Scientific Research, The Air Force Wright Aeronautical Laboratories, The Charles Stark Draper Laboratories, Inc., The U.S. Naval Surface Weapons Center, The Defense Advanced Research Projects Agency, and Virginia Polytechnic Institute and State University. We are in debt to Ms. Marge Foland and Ms. Nancy Menda for their expert and invaluable support in editing and preparation of an early draft of this manuscript. We are pleased to acknowledge the extraordinary expertise and dedication of Mrs. Vanessa McCoy for her painstaking typing of several final drafts and preparation of the final manuscript. Finally, we thank our families, most especially Elouise and Hari, for their consistent encouragement and patience while we struggled to complete this monograph.