Foreword

Spacecraft Formation Flying: Dynamics, Control and Navigation provides a comprehensive treatment of the subject in a widely accessible fashion. The text fills an important void and the authors have utilized the advantage they enjoy, being among the leaders in researching this subject, to write an authoritative exposition. The result is an up-to-date text that will be broadly useful to academics and professionals in governmental and industrial research. The focus is on spacecraft formations in low Earth orbit, with a detailed discussion of modeling, control, and navigation; with consideration of both translation and attitude relative motions. While this is an integrative sub-field in astrodynamics, and guidance, navigation and control, the number of unique challenges and contributions addressed make it clear that a text dealing with formation flying is needed. This book fulfils this need. Chapter 1 provides an introduction and defines the several kinds of formations: orbit tracking, leader/follower, virtual structures, and swarming. Also considered is an introduction to the drivers that dictate fuel consumption such as atmospheric drag and station-keeping. Chapter 2 provides a concise introduction to astrodynamics, considering both the unperturbed (Keplerian) motion as well as the method of variation of parameters. The perturbations of main focus are the zonal harmonics due to Earth oblateness. Chapter 3 presents fundamental ideas from mechanics, optimization, control, and estimation theory. This chapter develops the Lagrangian and Hamiltonian generalized formalisms for establishing equations of motion, and also discusses Lyapunov stability theory and its use in constructing stable control laws. Also presented are recent contributions to Kalman Filter theory with emphasis on the several alternative forms for the Unscented Kalman Filter that addresses the critical issue of maintaining covariance estimates that are reflective of nonlinear dynamics in the error propagation between measurement updates.

Chapters 4 and 5 develop the nonlinear and linearized dynamics of relative spacecraft motion, with emphasis on judicious coordinate choices, accounting for oblateness perturbations, and of central importance in Chapter 5, developing the several forms of the relative motion state transition matrix central to estimation and control. Chapters 6–8 focus on dynamical modeling of relative motion using orbit elements and the mitigation of the effects of perturbations. Chapter 6 considers short time motion with time series approximations whereas Chapter 7 utilizes generalizations of classical perturbation methods to examine

solutions for the J_2-perturbed relative motion. Chapter 8 introduces additional methods for analyzing J_2-perturbed relative motion, including selection of judicious initial conditions and techniques for the minimization of fuel consumption and achieving balanced fuel consumption. Chapter 9 addresses the problems that arise in rotation-translational coupling. Chapter 10 is devoted to several aspects of formation control, including control based on averaging, impulsive control based on variation of parameters, and various special cases that provide useful insights. Chapter 11 provides practical insight into how to implement impulsive maneuver commands. Chapter 12 is devoted to measurement models and Kalman Filter implementations for various navigation algorithms. Several examples are included. Chapter 13 is focused on approaches to achieve high fidelity formation flight simulations, and example results are presented. Finally Chapter 14 provides a summary and perspective looking to future developments in this field.

The overall treatment is at a level such that any individual with a senior undergraduate level background in orbital mechanics and control systems can access the majority of the material, and apply it efficiently in mission analysis or design. The level of abstraction is at an intermediate level with frequent appeal to physical and geometric reasoning to motivate the derivations and interpret the results obtained. For specialized aspects of text such as orbit perturbation theory, Kalman Filter and control theory, and the methods of classical mechanics, of course, additional reading of classical works and recent literature will be needed to supplement the treatments presented. The central contribution of this book is to have an authoritative, integrated presentation of spacecraft formation dynamics, navigation and control by these leaders in the field. I am delighted to recommend this book with conviction.

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