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Planetary Spacecraft Navigation

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Preface

This book is based on my 50 years of experience in navigation of Earth entry vehicles, Minuteman ballistic missiles, and planetary spacecraft. At the Jet Propulsion Laboratory, I worked on the Mariner 6, Viking, Pioneer, Galileo, and Near Earth Asteroid Rendezvous missions. At KinetX Inc. I worked on the MESSENGER and New Horizons missions. In writing this book I have drawn on engineering memoranda, conference papers, and publications I have written as well as many notes that I have accumulated over many years. My purpose is to present a book that will describe how navigation is done. The emphasis is on mathematics that have been coded in computer programs used for mission operations. Therefore, the derivations are given in detail since relatively little mathematics actually makes it into operational software. The mathematics that do are generally straightforward, but the programs are large and complex and must be virtually error free. In writing this book, I have frequently checked the mathematics by looking at computer code that I am confident is correct.

Chapter 1 contains the equations of motion exclusive of the force models. Since navigation is concerned with everything that moves, the equations of motion include the kinetic theory of gasses and propagation of electromagnetic waves. The force models are given in Chap. 2. Since motion is in a straight line without force being applied, the force models enable spacecraft to go somewhere. Chapter 3 describes the procedure for designing the trajectory a spacecraft will follow. A detailed derivation of Kepler's equation and Lambert's theorem is given. Just about all trajectory design is based on these two individuals' work aside from Newton of course. Trajectory optimization is described in Chap. 4. Most trajectory optimization is performed by developing an intuitive feel for the problem being solved. Sometimes it is necessary to perform a detailed constrained parameter optimization when there are many more control parameters than constraints. The first constrained parameter optimization using a computer program was the Viking orbit insertion maneuver. Previously, the trajectory designs were mostly Hohmann transfers. Chapter 5 describes the probability and statistics needed for navigation analysis. This is probably the most important navigation design function since it relates directly to the probability of achieving mission success. Orbit determination is described in Chap. 6. At the beginning of planetary spacecraft navigation, orbit determination was a major problem. The Mariner class spacecraft had to contend with orbit determination errors of several thousand kilometers. Missions were flown so we could do orbit determination, not science. Today, the orbit determination error at Mars is on the order of tens of kilometers. This progress may be attributed to the introduction of VLBI. There is still the problem of orbit convergence and this problem is addressed in some detail. The measurements and calibrations are described in Chap. 7. Navigation is primarily concerned with the physical quantity being measured and not the hardware required to perform the measurement. However, some detailed knowledge of the measurement implementation is necessary to write navigation software. The navigation system is described in Chap. 8. The navigation system and navigation operations procedures are constantly evolving. An overview is given that applies to all navigation systems. It is conservatively estimated that there is at least one navigation system for each person doing navigation operations. The final chapter is anecdotal and describes some navigation analyses I performed over the years. My purpose is to describe the type of analyses the reader would be expected to perform if he or she pursued a career in navigation. I hope I have succeeded in convincing the reader that navigation is a lot of fun.

Planetary spacecraft navigation is the result of the work of many individuals including the author of this book. The person who had the original idea is often not known. I have mentioned some individuals in the text who I am aware of and made some significant contribution. Some are contemporary and known personally, but often these individuals are mathematicians and have lived over a 100 years ago. I have made little effort to search the literature and track down the original source. Most of my acknowledgments are anecdotal and the source is discussions in the coffee room that have not been verified. There are a few who have contributed directly to the writing of this book. My wife, Dr. Connie Weeks, Professor Emeritus of Mathematics, Loyola Marymount University, is the source of a large amount of my limited knowledge of mathematics. I cannot recall a question about mathematics where she did not have an immediate answer. The person most responsible for this book being written is Dr. Gerald Hintz who teaches at the University of Southern California. I have known him for about 50 years and since I started writing this book 20 years ago, he has kept encouraging me to finish. Writing this book has not been as difficult as I thought it would be, but rather an enjoyable experience. I must also acknowledge my mother, Eunice Miller, who thought it would be a good idea for me to be the first one on either side of my family to go to college. My sisters, Peggy Joyce, Nan Elizabeth, and Linda Lee, also got behind this major effort and I will be forever indebted to them.

I am particularly indebted to the editors at Springer International Publishing. Hannah Kaufman and Maury Solomon showed great patience in leading me through the process. The production people headed by Batmanadan Karthikeyan transformed my manuscript into what I regard as a work of art.

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