MASSACHUSETTS INSTITUTE OF TECHNOLOGY

APOLLO

GUIDANCE AND NAVIGATION

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SPACE NAVIGATION GUIDANCE AND CONTROL

Volume 2 of 2

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PREFACE

The material in this book was assembled to support a series of lectures to be given by the authors in Europe in June 1965, under the sponsorship of the Advisory Group for Aerospace Research and Development, an agency of NATO.

The general subject of Space Vehicle Control Systems is the subject of discussion with particular application to the present Manned Lunar Landing Program. The man-machine interaction along with requirements of the mission are first described. These mission requirements in terms of specific hardware along with the performance requirements and underlying reasons for choice are next explained. Lastly, the theoretical background, the system analysis and the derivation of the control functions to integrate the hardware into a precision guidance, navigation and control system are discussed. The book is organized into seven sections following the pattern of the lectures.

Section I provides historical background to the fundamental problems of guidance and navigation. The basic physical phenomenon and associated instrument techniques are discussed.

Section II continues with background information going more specifically into the problems and approach of the guidance, navigation and control of the Apollo manned lunar landing mission. This section illustrates some of the basic philosophy and approaches to the Apollo tasks, such as the success enhancing decision to provide equipment that will perform all necessary operations on-board and using all ground based help when available.

Section III concerns in detail the analytic foundation for performing on-board calculations for navigation and guidance. The achievement of a unified and universal set of equations provides an economy in on-board computer program to perform all the various mission tasks.

Section IV covers in detail the mechanization of the inertial sensor equipment of the Apollo guidance and control system.

Section V provides the same visability into the optical navigation sensors and measurement techniques.

Section VI provides background and specific techniques in the mechanization of on-board digital computers. Application to the Apollo mission illustrates several problems of interest such as the method for providing reasonable and straightforward astronaut data input and readout.

Section VII concerns the specific problems and solutions of vehicle attitude control under conditions both of rocket powered flight and the free-fall coast conditions. The Apollo mission provides a diversity of examples of this area of technology in the control schemes of the command and service module, the lunar landing vehicle, and the earth entry return configuration.

The general problems of Space Navigation, Guidance, and Control requires a great variety of discipline from the engineering and scientific fields. The successful completion of any one space mission or phase of a space mission requires a team effort with a unified approach. Of equal importance are the software deliveries and performance with the hardware. This lecture series is an attempt to integrate many of the disciplines involved in creating successful and accurate space vehicle control systems.

These lectures represent, on every ones part, an interplay between equipment and theory. While in each case emphasis may be on one or the other, in the whole equal emphasis is applied.

All sections may be treated as separate entities however in the case of Section III through VII it is helpful to have the background of Section II. There is cross reference between sections to avoid unnecessary duplication.

It is observed that the authors have emphasized the Apollo mission and hardware as examples in their treatment of the subjects. This is partially because of their intimate familiarity with Apollo in the development work at the Instrumentation Laboratory of MIT and partially because Apollo provides, in an existing program, an excellent example in its multiple requirements and diversity of problems. Because Apollo is currently under development, no particular attempt has been made to make reference only to the latest configuration details. Indeed the authors have utilized various stages of the Apollo development cycle without specific identification in every case as they provide the guidance, navigation, or control technique example desired.

The authors wish to express their appreciation to NASA for the opportunity to participate in the lecture series and for permission to use material from the research and development contracts NAS 9-153 and NAS 9-4065. They also recognize that this does not constitute approval by NASA of this material. In addition, they wish to thank the many members of M. I. T. 's Instrumentation Laboratory; who are working on the Apollo system, for their inspiration and generation of material.