PREFACE

The fields of space guidance and attitude control, as well as advanced systems and components for terrestrial guidance and control, are growing at a phenomenal rate. The literature in some of these areas is doubling itself every one to three years. To help cope with this kind of explosive growth in limited technical areas, the profession needs both personal meeting grounds and a publication forum in which to present current work. Normal publication channels in technical journals serve the latter purpose, but, except for occasional survey or tutorial treatment, it is not the purpose of the ordinary technical paper to give an integrated picture of an entire field. Thus the usual literature in the field, in this case guidance and control, does not adequately mirror the growth of the field or sharply delineate the areas of keenest current interest. In effect, isolated technical papers give one the same viewpoint as looking at single frames of a strip of motion picture film--important pictures, perhaps, but not a complete substitute for running the entire film occasionally.

By combining into one volume a number of papers carefully chosen to illuminate important areas of technical development, it is possible to get this broader view of the whole field, its state of the art, and its pattern of development. This is the purpose of the present volume. The papers it contains have been selected from the Guidance, Control, and Navigation Conference sponsored by the American Rocket Society at Stanford University, Stanford, California, August 7-9, 1961. However, the book is in no sense a proceedings of the meeting, since the editors chose only certain papers that would best illustrate current problem areas and trends.

In arranging the papers, the editors have grouped them broadly into space guidance and path control, terrestrial guidance concepts and components, and other control topics. The first of these comprises three major mission phases: ascent from Earth to an orbit or space trajectory operations in space requiring navigation or guidance, and descent to the surface of Earth or the moon. The second group includes the system aspects of inertial navigation, gyroscopes as basic components of inertial navigation, and topics in optical navigation. The third group is less homogeneous. Its major divisions are adaptive control, a subject currently in the forefront of modern control theory developments, and attitude control, the major control phase in a space environment.

The boost or ascent phase represents the beginning of any space or missile operation. The ingredient problem areas are the launch itself, control of the boost trajectory, and control of the velocity increment at injection so that the resulting free flight trajectory is close to the one desired. The first paper, by C. E. Kohlhase, in Section A, Ascent, is an analysis of the geometric effects resulting from variations in launch time, particularly the resulting variations in asymptotic direction and path velocity. These error effects can be compensated by suitable changes in the ascent guidance constants, provided that the guidance rationale is sufficiently flexible to accommodate these changes. The editors remark that the launch time problem involved in near-simultaneous launch of more than one vehicle has arisen as an especially important topic in relation to the technique of in-transit rendezvous proposed by C. E. Kaempen (at the 11th International Astronautical Congress, held in Stockholm, August 1960). The second paper, by D. Lukes, illustrates the way in which the Pontryagin Maximum Principle, of so much current interest in control theory, can be applied to the optimum boost control problem. The formulation is carried to the explicit display of the differential equations for a two-point boundary value problem, and Lukes remarks on the solutions of these by digital computation. The fact that solutions are not displayed is merely a manifestation of the fact well recognized in control circles that it is very difficult, in general, to find numerical solutions to the optimum control problem using Pontryagin's method. Nevertheless, the Principle is considered to be of basic importance in control theory, which makes this early application of it to boost control of considerable interest. The third paper also is based on the Pontryagin Maximum Principle. W. Schmaedeke and G. Swanlund here apply it to the derivation of optimum injection guidance. Again the entire boost history is followed, a key assumption in the development being that the deviations from the nominal (presumably "optimum") trajectory during ascent are sufficiently small so that the error behavior can be represented by a linear description. Because of the relative unfamiliarity of the method, the authors include a brief survey of the Maximum Principle, also helping to provide background for the preceding paper.

In relation to Space Operations, Section B, there are three major categories of guidance and control problems. One type of control which may be exercised over an extended time period is attitude control, a topic sufficiently extensive so that it is treated separately in Section H. The remaining guidance and control problems are related to relatively short powered maneuvers, the two major instances of which are embraced by "rendezvous" and "orbit and trajectory correction." The first paper in this section, by R. S. Swanson, P. W. Soule, and N. V. Petersen, motivated by a rendezvous situation but actually treating station keeping, can be considered an example of the orbit correction problem whose goal is to maintain a vehicle in a "rendezvous-compatible" situation (a term originated by Petersen and his colleagues). Whether corrective maneuvers must be initiated at all, of course, is a function of the growth of initial errors. The paper by H. J. Gordon considers the expected initial errors for a lunar or interplanetary trajectory and develops their interpretation in terms of errors at the target. An interesting inverse situation is presented by A. Peske and M. Ward. They show how deviations in flight can be related to terminal rather than initial errors, thus providing a very direct basis for determining the size of needed en route corrections at any instant. W. C. Marshall, in the fourth paper, also uses a linear perturbation technique to examine the propagation of initial errors along an arbitrary trajectory, as well as the growth of error from disturbing forces of several types. Although the formalism is quite general, the lunar mission is especially in mind. An important question in space guidance or control operations is the accuracy with which vehicle position can be determined. This determination can be done aboard, when it is known as the space navigation problem, or on Earth, when it is known as the tracking problem. Since the former seems to have received the lion's share of past treatments, the final paper in this section, by C. R. Woods and E. B. Mullen, is an attempt to restore balance to the subject.

As manned space missions come more to the fore, the re-entry phase becomes increasingly important. Even for unmanned systems, soft landing on a surface can be of great interest when it is desired to deliver an instrument package intact. These cases can be subsumed by the term "descent," the title of Section C. The papers in this section by no means cover all of the problems of descent, but they do hit several important high spots. R. K. Cheng and I. Pfeffer's article concerns the guidance for a soft lunar landing, about which little has heretofore been published. Controlled re-entry, specifically longitudinal range control, is treated by R. Rosenbaum, whose way of achieving such control uses a lifting vehicle, with the result that the importance of accurate lift to drag prediction is clearly seen. The remaining paper, by P. C. Dow, D. P. Fields, and F. H. Scammell, considers the guidance and control problems that arise during two methods of re-entry at escape velocity. The first of these uses an apparent target and proportional steering, the second a method of explicit guidance in which the impact point is predicted.

Section D contains four papers on the subject of inertial navigation. The Transit satellite navigation system, which is now in operation, represents a major breakthrough in navigation technology. J. W. Crooks, R. C. Weaver, and M. M. Cox in their paper describe how maximum accuracy can be obtained from such a system through the use of sideband folding techniques. In any inertial navigation system, damping must be introduced in an optimum manner if maximum performance is to be obtained. The way in which servo techniques may be used to describe system performance and permit the design of specific damping equalizers is discussed in the paper by C. Broxmeyer. Redundancy has often been proposed as a technique for improving reliability. R. R. Palmer and D. F. McAllister's article considers how, for long term navigation, redundancy in the form of multiple system operation also can be used to improve navigational accuracy. In the final paper of this section, M. Kayton treats the fundamental limitations on inertial measurements.

Section E, Inertial Components, is directed toward the design of gyroscopes, which are the basis of any inertial guidance or navigation system. Design features are described which permit the designer to obtain the maximum possible performance from these precision instruments. Papers by C. O. Swanson, S. Osband, and R. P. Durkee discuss the more conventional designs, and a paper by A. Nordsieck provides a timely look at the electric vacuum gyroscope.

Optical techniques and devices for navigation are considered in Section F. The subject is introduced in a paper by E. M. Wormser and M. H. Arck which treats the application of infrared navigation sensors to a variety of space projects. R. G. Franklin and D. L. Birx discuss how velocity indications may be derived from the measurement of optical Doppler shift and describe how lasers might be employed for optical heterodyning to shift the optical Doppler frequencies to the radio-frequency range where they may be measured by existing methods. Optical heterodyning is further discussed by W. C. Reisener, who describes an interesting technique involving a traveling wave tube mixer. Microwave currents are generated due to the interference of the two optical signals at the photosensitive cathode of the mixer tube.

One of the most frequently discussed topics in modern control theory is adaptive control. Adaptive systems have been applied in practice to terrestrial flight control, but only recently have astronautical applications been developed. Section G contains two papers on adaptive control. The first, by H. P. Whitaker and A. Kezer, actually is rather general, that is, not specifically astronautical in character, but concerns a subject of special importance in both terrestrial and astronautical applications: the way in which reliability can be improved by means of adaptive systems. On the other hand, the paper by W. E. Miner, D. H. Schmieder, and N. J. Braud is directed toward the booster guidance and control problem with special application to Saturn.

The satellite attitude control problem has a number of interesting facets, of which four are represented by the papers in Section H. One of the important questions in this field is the nature of the torque on the vehicle. Gravitational, magnetic, and other torques have been treated in the literature; in this section, R. J. McElvain adds an analysis of solar radiation pressure. One of the methods of closed loop active control employs combined reaction wheel and jet actuators, about which relatively little detailed analysis has been published. The paper by D. B. DeBra and R. H. Cannon is a good discussion of many aspects of this problem. The other method of closed loop control which is of special current interest is pure jet actuation, in relation to which the major problem is the choice of a control logic and the resulting limit cycle response that is typical of such on-off devices. The paper by P. R. Dahl, G. T. Aldrich, and L. K. Herman concerns limit cycles in the presence of external torques, often neglected in other analyses, while that of R. S. Gaylord and W. N. Keller presents a control logic that is effective in reducing the limit cycle without the use of direct or derived rate information. Another major class of attitude control systems is spin stabilization. Even there, however, spin vector control often is necessary. C. Grubin, in the final paper, presents a generalized two-impulse scheme for reorienting the spin vector.

The editors feel that, because the forementioned papers have been selected from those given at the first Guidance, Control, and Navigation Conference sponsored by the ARS Guidance and Control Committee, special acknowledgment and recognition are due those whose efforts made that conference possible. Appreciation is expressed particularly to Stanford University for its unstinting support of the conference. Donald P. LeGalley, Program Chairman, and Robert H. Cannon, Jr., Vice Chairman, deserve special mention. Together with the session chairmen, they were largely responsible for the high technical quality of the papers at the meeting and thus, indirectly, of the papers in this volume. An equally important role was played by Daniel B. DeBra, who, as Arrangements Chairman, did much to insure the success of the meeting.

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