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NAVIGATIONAL TECHNIQUES AND DISPLAYS FOR INTERPLANETARY SPACE FLIGHT

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The University of Michigan
WILLOW RUN LABORATORIES
Ann Arbor, Michigan

This is the first quarterly report under Contract Number AF 33(616)-5523 between Wright Air Development Center of the United States Air Force and Willow Run Laboratories of The University of Michigan, covering the period 1 March 1958 through 31 May 1958.

ABSTRACT

This first quarterly report of the subject contract discusses the ascertainment, acquisition, and assimilation by project personnel of material relevant to interplanetary navigation. Terrestrial navigational techniques and the physical phenomena of space are being investigated to determine their applicability to space navigation. Several possible criteria for space navigation are being studied.

Because of man-hour limitations, it has been decided to confine this study to navigational techniques for a journey from an orbit around the Earth to an orbit around a planet rather than considering a complete Earth-to-planet journey.

Specific objectives for the remainder of the contract are being formulated.

PREFACE

The objective of this contract is to evaluate methods for navigating space vehicles in interplanetary flight. Interplanetary navigation must provide a means for guiding a space vehicle from its origin to its destination in the solar system so that it arrives at the proper point in space at the proper time and with the proper vector velocity.

As a result of the evaluation studies, recommendations will be made both for navigational techniques to be used under various conditions of space flight and for research and development to be performed on techniques and equipment which might show promise with further refinement.

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OBJECTIVES FOR THIS QUARTER

1. Determine the various navigational criteria which might be used in interplanetary flight.
2. Investigate the use of known physical phenomena (cosmic rays, etc.) as sources of information for interplanetary navigation.
3. Determine the applicability of terrestrial navigational techniques (celestial, inertial, radar, and radio) to interplanetary navigation.
4. Assemble and catalog a bibliography of literature covering existing work in the field of space navigation.
5. Familiarize project personnel with the areas of science which are particularly related to space navigation.

2
CURRENT PROGRESS

2.1 NAVIGATIONAL CRITERIA

The navigational criteria, or rules which will govern the passage of the space vehicle from its origin to its destination, can be in many forms. Minimal fuel, direct homing, and straight-line intercept are among the simpler paths which may be considered. The many variables of space flight prohibit the consideration of all possible paths; therefore, only those which appear most reasonable in the near future will be selected for thorough study.

The major effort of the project will be directed toward the detailed study of orbit-to-orbit navigation problems between the Earth and its Moon, and the Earth and Mars. The navigational problems of Earth-to-Earth-orbit flights seem to be well taken care of in other programs. The detailed study of planet-orbit-to-planet navigation appears to be beyond the scope of this program because of man-hour limitations.

2.2 PHYSICAL PHENOMENA

The investigation of some of the physical phenomena of interplanetary space (e.g., cosmic rays, ion and electron streams, electric and magnetic fields, radiation pressure, gravitational fields, etc.) has shown that little factual information is known. The trend of that information does not indicate a source of navigational data.

Primary cosmic rays are high energy particles (probably protons) which originate beyond our solar system and strike the earth with uniform intensity from all directions. The origin and directional properties of the particles in outer space are presently subjects for speculation only. Similarly the origin and directional properties of the streams of electrons and ions are not established. These appear in the earth's upper atmosphere and are presumed to exist in space.

Presently compiled data indicate little or no navigational information is available from radiation pressures or from interplanetary gravitational, electrical and magnetic fields.

Doppler shift of detected radiation in space has possibilities for providing direct measurement of velocity. The known methods involve the displacement of spectral lines (including the change of frequency of radio signals) or measurement of the aberrational displacement of the sun or other stars in suitable parts of the sky. Inaccuracies arise from the difficulty of aligning the spectral lines of a star with its reference element (a resolution limitation) and the motion of our solar system with respect to the stars chosen for reference. (This motion is large compared to that of the space vehicle and its exact magnitude and direction are unknown.) Although this latter source of error can be eliminated by confining the measurement to the Doppler shift of sunlight, the resulting velocity measurement does not appear adequate for navigational purposes.

Active Doppler radar systems take advantage of the doubled Doppler effect by reflection and permit a direct measurement by comparison of the transmitted and received signals. Active radar systems are limited by relatively short operating ranges and appear to have their best use while navigating near a planet.

Additional data on all these phenomena are still being compiled. The examination of these data for their navigational properties may yet lead to their application in interplanetary techniques.

2.3 TERRESTRIAL TECHNIQUES

The investigation of terrestrial navigational techniques has revealed that they are generally adaptable to interplanetary navigation. Celestial navigation stands foremost in the group as a passive means of obtaining the angular relationship of the space vehicle to the stars and planets.

Sightings on the stars alone will yield accurate information on the angular orientation of the space vehicle but not its position. Even the nearest stars are at such great distances that motions within the solar system cause only small apparent displacements of the stars. During interplanetary flight, planets exhibit large apparent motions due to the relative motions of the space vehicle and the planets. Sightings must be made on bodies within the solar system so that accurate data for position determination, and hence navigation, will be obtained. Celestial navigation in space has the important advantage of an extremely low optical noise level since atmospheric disturbances are absent.

Inertial navigation is limited to the situation in which accelerations can be sensed by vehicle-borne accelerometers. The accelerations produced by the vehicle's propulsion system are easily sensed and probably represent the most important contribution that inertial systems can make to the navigational problem. Vehicular accelerations during free fall are nonexistent, rendering an inertial navigational technique useless during this time. [1]

Radio and radar navigational techniques can be applied to space through extension of the transmission and base line distances. Electromagnetic transmission over interplanetary distance is practicable with the use of transponders. For those techniques requiring base lines, two major considerations contribute to the complexity of such a navigational system.

In terrestrial navigation, the base line is fixed with respect to the terrestrial coordinate system in which the vehicle navigates. But in space navigation this base line is not fixed in the heliocentric coordinate system in which the space vehicle navigates. This line rotates both about the earth and about the sun in a predictable but complicated manner.

To obtain sufficient accuracy for extended distances of space flight, the base line length must be in excess of terrestrial distances. In order to achieve these extra-terrestrial lengths, earth-orbiting instead of fixed stations on the earth must be used.

In no case, however, will the accuracies of earth-based techniques approach those required for terminal navigation near another planet.

The greatest disadvantages of these electronic techniques are the complexity of the equipment involved and the electric power required. On the other hand, some form of electronic data-link

[1] In principle, the differential accelerations which occur between different positions within the space vehicle can be measured. For example, within the framework of a vehicle in a free-fall orbit about the sun, the acceleration of gravity varies a small amount at those points in the vehicle which are different distances from the sun. The reason for the variation is that all parts of the vehicle are constrained to follow the orbit of the vehicle's center of gravity. Measurement of this infinitesimal difference in acceleration will be a formidable task.

between the earth and the space vehicle will be desirable anyway, and the navigational technique may grow as an extension of this feature.

2.4 BIBLIOGRAPHY

A bibliography of books, periodicals and reports concerned with navigation in space has been assembled and catalogued for the convenience of project personnel. Perusal of the University library files, the military ASTIA document files, and miscellaneous lists of references has provided the bibliography information. The literature which seemed most pertinent as determined from titles or abstracts has been ordered. The reference material is being reviewed as it becomes available.

2.5 FAMILIARIZATION PROGRAM

Specialists among project personnel presented lectures on inertial guidance and celestial mechanics to familiarize others in the group with the fundamentals which will be involved in this project.

Mr. Fred L. Bartman, Research Engineer at the University engaged in upper-atmosphere research, was consulted in regard to the physical phenomena such as cosmic rays and ion streams which might be a source of navigation data.

Mr. Harry C. Carver, Professor of Mathematics at the University, presented his proposal for a technique of interplanetary position determination through the measurement of the angular separation of planet pairs. His proposal, which is particularly suited for graphical solution (with the assumption that the vehicle and reference planets are coplanar), will be evaluated with other celestial techniques to be considered.

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OBJECTIVES FOR THE NEXT QUARTER

1. The various navigational criteria which might be used in interplanetary travel will be evaluated in relation to the navigational sensing and processing accuracies required for the particular criteria. The most appropriate criteria will be selected for further study.
2. The use of various physical phenomena in space as sources of navigational information will be evaluated in a documented form which will consider the known characteristics of each phenomena.
3. Terrestrial navigational techniques will be further evaluated for the type and quality of navigational data each technique can provide and the limitations of the technique for interplanetary navigation.
4. Project personnel will be familiarized with the new areas of interest as this information is assimilated from available sources.

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Specific objectives for the remainder of the contract are being formulated.

1. Aircraft and Flight Equipment
2. Astronomy, Geophysics and Geography
3. Navigation

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