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APOLLO EXPERIENCE REPORT - EVOLUTION OF THE ATTITUDE TIME LINE

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16. Abstract

The evolution of the attitude time line is discussed. Emphasis is placed on the operational need for and constraints on the time line and on how these factors were involved in the time line generation procedure. Examples of constraints on and applications of the complete time line are given.

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APOLLO EXPERIENCE REPORT

EVOLUTION OF THE ATTITUDE TIME LINE

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SUMMARY

The attitude time line is a complete time history of the spacecraft orientation with respect to a reference coordinate system. The need for a complete attitude time line that satisfies mission requirements within operational and equipment constraints is explained. The procedure that was used to generate the detailed attitude time line is discussed, and particular attention is given to mission-oriented problems and to problem-solving methods. The different needs for the time lines of earth-orbital and lunar-orbital missions are cited. A system of pointing-constraint envelopment analysis that is superior to the X-, Y-, Z-body coordinate system is presented. The time line generation effort is explained with reference to mission planning in general and to interface requirements with various working groups in particular.

INTRODUCTION

A detailed attitude time line is now a required part of the flight plan for a lunar mission. The onboard flight plan contains local-horizontal attitudes and inertial measurement unit gimbal angles for every phase of the mission activity from lift-off to landing. Included in the flight plan are illustrations of critical attitude-dependent activities (such as landmark tracking procedures, photography procedures, and command and service module (CSM) and lunar module (LM) high-gain antenna (HGA) pointing requirements) and other aids that serve as reference for the crewmen during every phase of the mission.

The CSM and LM crew procedures manuals are more detailed than the flight plan. The CSM and LM documents contain a description of each step in the procedural techniques that have been defined for every phase of the mission. Specific attitude requirements are intrinsic in most of these procedures. Although some attitudes can be computed on board, many of the attitudes cannot. Also, the onboard solutions are not always used because these attitude computations are used to solve for a specific case. (In most attitude-pointing problems, usually there are many solutions that will satisfy the attitude constraints.) The onboard solutions also do not include consideration of a total attitude and maneuver sequence. For this reason, the procedures documents contain many attitudes computed preflight that are optimized for communications, minimum maneuver requirements, and visual cues.

The attitude time line is used in communications, thermal, and navigational analyses. The time line also has been used for trajectory dispersion analyses, such as the modeling of venting effects, waste dumps, and the direction and magnitude of translational velocity increments that result from uncoupled attitude maneuvers (attitude maneuvers using unbalanced thrusting). The final attitude time line therefore must be the result of much detailed planning to minimize maneuvers and to meet all tracking, thermal, and communications requirements and to meet any other spacecraft-attitude requirements during all phases of the mission.

REQUIREMENT FOR A COMPLETE ATTITUDE TIME LINE

A detailed attitude time line did not exist for Mercury, Gemini, or early earth-orbital Apollo missions. The first lunar-orbital mission (Apollo 8) was the first mission for which an attempt was made to produce a detailed attitude time line. Some phases of the early missions did have preflight planned attitudes, but this preflight attitude planning was limited to specific experiments or tracking exercises. The limited attitude planning was possible for several reasons. For an earth-orbital mission, no major attitude problems occurred that involved communications because high-bit-rate telemetry and good voice communications could be obtained by the use of the CSM and LM omnidirectional antennas. However, for lunar distances, high-bit-rate communications necessitate the use of the CSM high-gain antenna or the LM steerable antenna (SA). Many operations require the use of attitudes that conflict with pointing these antennas at the earth; therefore, the flight crew and ground controllers must know the exact spacecraft attitude profile for each tracking period so that the high-bit-rate communications requirements can be scheduled. In earth orbit, no major thermal problems occurred. For a lunar mission, almost all of the translunar and transearth coast phases are in direct sunlight. To maintain even heating from solar radiation, an attitude and turning rate that allows passive thermal control must be established. Also, specific attitude guidelines are established for thermal constraints during crewmember rest periods in lunar orbit.

In lunar orbit, the time line is more time critical and event critical than during other mission phases. If a particular section of the crew activity time line were not completed on a pass during earth orbit and the flight plan had to be delayed one revolution, the consequences would not be as severe as for the same situation during lunar orbit. Although the earth-orbital missions were involved and detailed, no requirement existed to maintain a continuous detailed attitude and pointing time line for all mission phases. The lunar-landing mission planning is based on many time-critical considerations, such as Manned Space Flight Network communications coverage, experiment activities, crew rest/work cycles, spacecraft housekeeping requirements, and lighting conditions at the lunar landing site. An example of a time-critical and event-critical time line is as follows.

For the Apollo 11 mission, the lunar-orbit time line on the day of descent was the result of months of concentrated effort. The effort involved almost every major group at the Manned Spacecraft Center (MSC). The basic problems were to accomplish the following objectives.

1. To activate and check out the LM

2. To perform landmark tracking for descent targeting

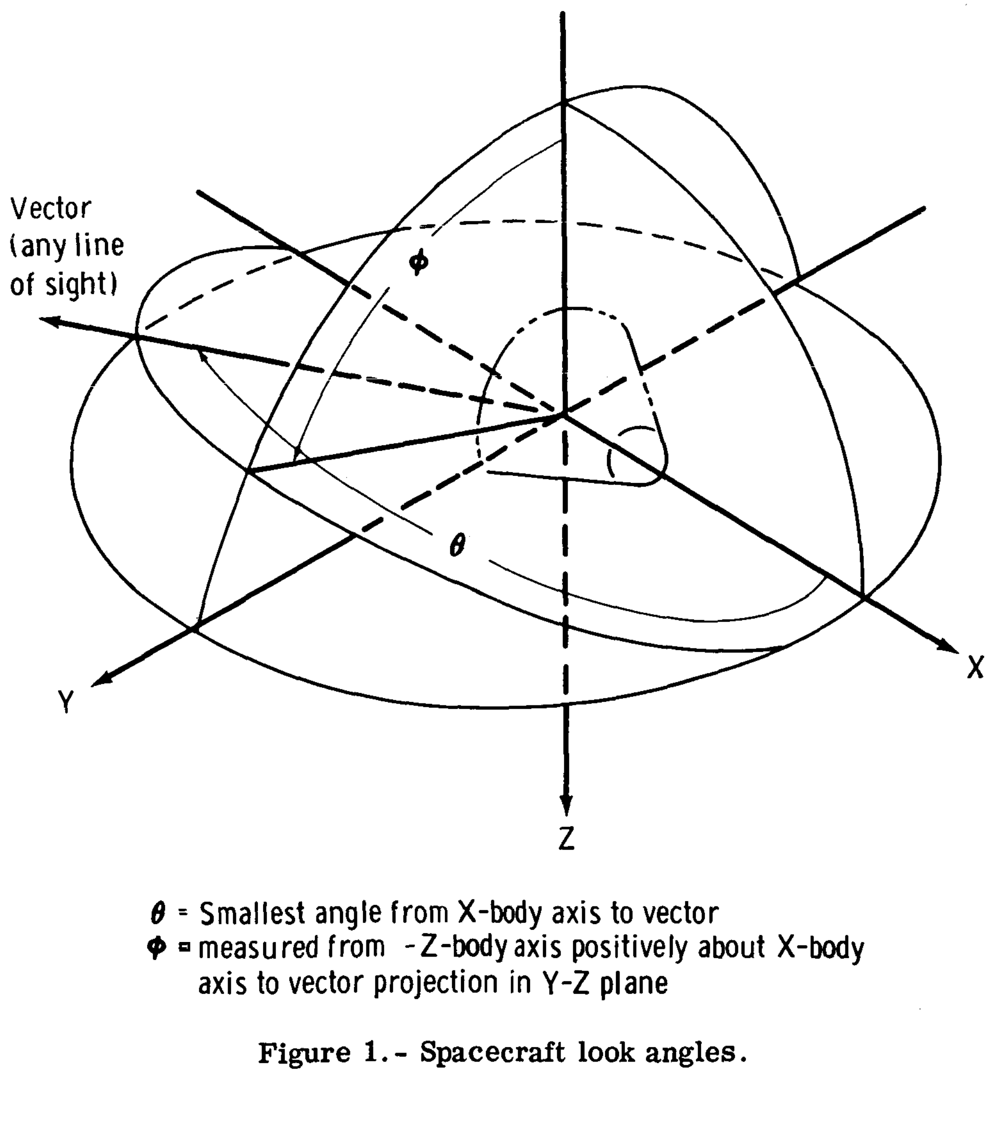
3. To undock, perform descent-orbit insertion, then perform powered-descent initiation one-half revolution later

4. To perform all these activities within a time frame that would permit extravehicular activity after landing

Initially, these problems did not seem to be particularly difficult, but closer examination resulted in unexpected problems. Most of the LM checkout period required continuous LM high-gain SA coverage, the landmark tracking necessitated the use of attitudes and maneuvers that were incompatible with SA pointing coverage, and a sequential scheduling of these activities resulted in an unacceptable crew workday (more than 20 hours). The only solution was to schedule sections of the LM checkout with an attitude for good communications and then accept a break in high-gain-antenna communications during the setup and execution of the landmark tracking. All these steps were time critical because the landmark tracking exercise is a precise operation that involves specific attitude and pitch rates and the consequence of not completing the LM checkout or of not performing the tracking would be to delay the landing for one revolution or more. This situation would be undesirable because the descent targeting would have to be updated and an additional fuel cost would be required. During this period, many other activities (such as undocking, LM inspection, rendezvous-radar checkout, and burn monitoring) required particular attitudes. All of these requirements imply that, for highly complex missions, it is not desirable for the crewmen to determine the proper attitude for communications, undocking, or other maneuvers. The conflicts should be resolved preflight, and the inertial measurement unit gimbal angles and other associated data should be provided as a part of the onboard data file.

BACKGROUND DEVELOPMENT — CONSTRAINTS AND BASIC ANALYSIS

Many specific and systems-critical constraints were established in the planning for a lunar mission. These constraints applied to all phases of the mission; that is, at any time during the mission (a rest period, in cislunar space, or in lunar orbit), specific attitudes are necessary to meet thermal, communications, or other requirements. The determination of these attitudes necessitates a complete attitude time line, which, in turn, requires a compiled set of all the attitude requirements for all phases of the mission. The initial effort in this compilation was a thorough review of the CSM and LM Operational Data Book and the joint MSC/Marshall Space Flight Center Joint Reference Constraints document. The constraints were often poorly or improperly worded and sometimes were out of date. Also, many constraints were not presented in a usable manner; for example, many were delineated in terms of X-, Y-, Z-body coordinates that were extremely awkward to use. The first step was to convert all of these constraints to a coverage envelopment in a consistent coordinate system. The coordinate system used was the θ-, ϕ-system (fig. 1), which is believed to be the most usable system for attitude work. The angle between any line of sight and the X-axis of the spacecraft (either CSM or LM) is θ, and ϕ is the angle between the -Z-axis of the spacecraft and the projection of that line of sight into the spacecraft Y-Z plane. This simple coordinate system was a versatile tool that could be used to define uniquely any line of sight in the spacecraft body system. For example, if there were a pointing requirement to establish a line of sight directly along the +Y-axis of the vehicle, the corresponding θ, ϕ angles would be $\theta = 90°$, $\phi = 90°$. This system also provides an easy method of examining several requirements at once by overlapping the coverage contours. For example, assume that there was a requirement to view the earth through the hatch window and to maintain HGA lock-on simultaneously. Overlapping the coverage contours of the window and the HGA would easily show whether any line of sight to the earth could meet both requirements.



θ = Smallest angle from X-body axis to vector
ϕ = measured from -Z-body axis positively about X-body axis to vector projection in Y-Z plane

Figure 1.- Spacecraft look angles.

The collection and documentation of these constraints were not easy to accomplish. Often, data were not available and contacts had to be made with the proper MSC group to have the data generated. For example, the data books would contain information on the field of view of all five CSM windows, but these fields of view were based only on data on views from the couch. Data were needed for fields of view 12 inches from the window, 6 inches from the window, and so forth. Another example was the extent to which the LM blocks the CSM optics when the vehicles are docked. The data book blockage contours were only approximations of the real blockage. Detailed blockage contours were generated because many of the landmark tracking profiles required exact data to define when the landmark was in an acceptable viewing region.

Often, old constraints were invalid or overly conservative. Some constraints that had originated during testing in early spacecraft development phases (Block I spacecraft) had remained only because they had never been challenged. An example was the CSM environmental control system (ECS) radiator constraint for lunar orbit. The constraint was worded as follows.

"The ECS radiators impose restrictions upon the orientation of the CSM in lunar orbit. For convenience of expression, the effective surface area of the radiators may be expressed by 'chordal planes' defined as two planes parallel to the X-axis of the CSM, each containing the circumferential extremeties of the respective radiators. These planes must be within 25° of the local vertical when the CSM is within 25° of the subsolar point on the moon. A deviation from this constraint is admissible for a maximum of three consecutive orbits for a total of eight times per mission."

Operationally, this constraint was untenable. Compliance would have required that one crewman be awake at all times, and the attitudes would have conflicted with other activities during the crew work periods. The conflict that resulted from this constraint was discussed, and a request was made that the spacecraft contractor and MSC reexamine this constraint for Block II spacecraft. The constraint was found to be not applicable for a Block II spacecraft and was deleted. Many conflicts occur between operational requirements and data book constraints, and these problems had to be negotiated as the mission profile changed.

GENERATION OF THE ATTITUDE TIME LINE

Theoretically, the result of the initial effort would be a complete set of attitude requirements that would be the design criteria for a lunar mission. A mission designed within this framework would involve minimal reaction control system usage by minimizing all attitudes and maneuvers for a mission while meeting all thermal, communications, navigational, and photographic requirements. However, in practice, numerous compromises are necessary to meet various secondary objectives (such as television coverage). For this reason, the development of an attitude time line is an iterative process, the result of which is an optimization of all attitudes for all phases of the mission without sacrificing simplicity of operation, crew preference, or mission flexibility.

The first attitude document was prepared for use on the Apollo 8 mission. This effort was difficult for several reasons. One problem was that a similar document had never been prepared before and the effort was not a part of the required mission documents or included on any schedule. Another factor was that, in the past, many groups had been determining attitudes for their own particular segment of the mission. For instance, the LM procedures document contained basic attitudes for undocking and a few other phases. No attempt had been made to produce a complete attitude document for use during earth-orbital missions because the attitude-generation team did not exist. The data priority effort was a factor contributing to the acceptance of one group as the official source for all attitudes. Meetings were held to define the mission techniques for all phases of the mission and were supported by all the major planning groups. In the discussion of the lunar mission techniques, it became evident that the complexity of the attitude planning effort (for all the reasons mentioned previously) was an order of magnitude greater than for earth-orbital missions. The most complete list of all requirements was compiled by a group of engineers who had been planning this type of effort for some time, had anticipated the need, had collected the requirements, and through computer program developments had designed the tools needed to perform the required analyses. Therefore, the entire task was given to this group, who also had quick and complete access to the trajectory data.

The development of an attitude time line for a lunar mission requires a close interface with many groups, including the crewmen, flight planners, flight procedures personnel, and flight control personnel. These people define the general requirements (such as photography and landmark tracking) for a mission in the form of a flight plan. These mission requirements are then integrated into a detailed attitude time line for the mission. Considerable interaction in this process occurs because the events scheduled in the flight plan often are attitude dependent. Therefore, development of the attitude time line for each mission is an evolutionary process that has input from simulations, from priority designations (when conflicts arise), and even from crewmember preferences.

The groups who develop, use, and verify the attitudes must analyze the time line to determine whether the attitudes satisfy constraints that are associated with particular systems. The result is an operational attitude time line that is distributed widely to real-time support personnel, that can be used with confidence that no attitude-dependent problems will be encountered, and that tracking requirements will be acceptable for all phases of the mission.

CONCLUDING REMARKS

The attitude time line generation for lunar missions became a recognized required effort. This work became increasingly important as the missions became increasingly complex. The advanced lunar exploration provided by the J-series lunar missions includes plans for a large number of experimental packages that are used in lunar orbit for further exploration of the moon. These experiments have precise pointing requirements and operational constraints. These experiments, their operation and scheduling, and the conflicts that arise require a thorough operational attitude and pointing constraint analysis if the highest and best return is to be realized for the mission.

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