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Space Guidance Analysis Memo #11

To: SGA Distribution
From: Richard H. Battin
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Subject: SGA Studies Presently Underway

The following list by category describes briefly the studies presently underway in the SGA division:

AGC Housekeeping Programs and Studies

1. Overall Computer Functions
   Determine, in a broad sense, all functions which must be performed by the AGC.
2. Scaling
   Determine range of all variables to be carried in AGC. Determine units needed internally to facilitate computation.
3. AGC Interpreter Revision
   Revise features of the interpreter as necessary to make it compatible with the 1024 word erasable memory and 12,288 word fixed memory with switchable banks.
4. Improve AGC Executive Program
   The executive is a program which directs the operation of sub-programs in the AGC on the basis of assigned priority. It is being revised to eliminate certain deficiencies and to update it in terms of memory configuration.

5. Elementary Functions

   Develop algorithms which allow minimum time to compute elementary mathematical functions. Note that the unusual operation repertoire of the AGC precludes use of some standard techniques.

6. Storage Allocation

   Determine the optimum arrangement of programs within storage and the optimum assignment of erasable memory to each such program. Consider in this determination the effects of the AGC bank switching scheme.

7. AGC Diagnostics

   Develop programs which isolate computer faults on a module level and indicate such faults to allow in-flight repair.

8. Error Detection and Handling Techniques

   Evolve a plan for treatment of errors in the AGC. Design programs which implement this plan.

9. Adaptive Programs

   Study the effects on the normal computational flow of failures in a portion of a subsystem (e.g. one line of sight of SXT). Pinpoint areas where AGC can continue to function by adapting its computational plan to such a failure.

10. Recovery from Failure

    Determine requirements for a program which re-initiates computation in the AGC after loss of erasable memory. If up-telemetry is available and is useful for this function during certain phases of the mission, then integrate this effort with telemetry studies.

11. Computer-System Interface

    Determine all input/output requirements for AGC. Design general sub-programs to facilitate communication with the outside world.

12. Display Requirements

The question of vehicle computed variables to display so as to enable the pilot to monitor the operation of the guidance system will be studied.

13. Documentation

Design a system for documenting AGC programs which is easy to understand and which facilitates changes in the program with a minimum of confusion. Such systems should be as automatic as possible.

AGC Mission Programs and Studies

1. AGC Trajectory Calculation Technique

Develop a technique for on-board trajectory calculation using methods applicable to any Apollo mission.

2. Approximation to Position and Velocity of Moon for AGC

Develop polynomial approximations valid over a two week period.

3. Approximation of Orientation of the Moon for AGC

Develop transformations suitable to keep track of lunar orientation over a two week period relative to a fixed equatorial coordinate frame.

4. Lunar Landmarks

Determination of the inertial location of lunar landmarks within AGC.

5. Determination of Star Directions with AGC

Determine the requirements for storage of accurate star data within the guidance computer.

6. Reentry Calculations for AGC

The guidance equations and control logic will be approximated and modified so as to minimize the on-board computing requirements. The required computation iteration rates, scaling, input sampling rates, etc. will be determined.

AGC Simulation on H 800

1. AGC Simulator

   Prepare H 800 program to simulate the action of the basic orders of the AGC with provision for checking and diagnostic information. This program is to be used as part of a detailed guidance simulation and must be compatible with MAC-language programs. To aid in communication between the AGC simulator and the simulated environment, a communication or buffer program is required and is also in preparation.

2. Launch Erection Simulation

   Prepare MAC-language platform routine as a step in the development of the AGC-guidance simulation.

Trajectory Calculation

1. Circumlunar Trajectory Program Improvement

   Improve the circumlunar trajectory program by incorporating a new method for piecing conics which avoids convergence problems in the calculation of a precise integrated path.

2. Trajectory Calculation to Achieve a Specified Lunar Orbit

   A method of analysis, based on pieced conic approximations is being used to study the possibility (or impossibility) of achieving specific orbital planes in moon space by direct injection from an earth orbit. The desirability of making a maneuver near the sphere of influence in terms of fuel management is also considered.

Thrust-Guidance Studies

1. Velocity-to-be-Gained Computation

   The satisfactory control of the thrust vector during periods of powered flight require attention to speed and accuracy in the computation of the velocity required for cut-off. Methods of computation of this quantity, compatible with the boost and injection problem, are being developed.

2. Saturn-Apollo Compatibility

   A program to insure guidance compatibility between the Apollo vehicle and the Saturn booster is beginning. The following are problem areas:

   a) requirements for satisfactory launch solutions in terms of the translunar injection, or rendezvous, if applicable;
   b) coordination with MSFC on compatibility of path adaptive equations for Apollo vehicle boost;
   c) signal interface with booster;
   d) interchanging of guidance equipment under failure conditions during boost into parking orbit.

3. Injection Guidance

   A digital simulation is being written to study guidance logic for an explicit translunar injection scheme. This simulation has the following objectives:

   a) to define tolerances on the parameters which define the parking orbit;
   b) to test various steering equations for accuracy and fuel management;
   c) to investigate the requirements for safe abort during the injection phase;
   d) to test the system of equations being developed for the velocity to be gained computation.

4. Phantom-Target Midcourse Guidance

   A technique is being explored which permits pseudo-explicit midcourse velocity-correction determination.

5. Explicit Guidance into Lunar Orbit

   An explicit method of calculating the velocity-to-be-gained for transfer to lunar orbit from a translunar trajectory is under study.

6. Lunar Landing Window

   A method of providing a large launch time window for direct return from the surface of the moon is under study. The method consists of fitting a conic section from the launch point to a tangential "rendezvous" with a reference return trajectory.

<u>Atmospheric Entry Guidance Studies</u>

1. Midcourse Interface

   The requirements imposed by midcourse guidance on reentry guidance and vice-versa, as well as the transition phase, are being examined.

2. Trajectory Determination

   a. A technique to select a trajectory on the basis of minimizing the effects of uncertainties in the measured or computed inputs to the system is being developed.

   b. Optimization procedures to ascertain ultimate capabilities of the reentry vehicle are under study. These include "steepest descent" methods as well as others.

   c. Analytic flight paths that are flyable enable better range prediction. A study is underway which examines the feasibility of controlling to a flight path angle as a function of time or velocity.

3. Error Studies

   Several sources contribute to the error or target miss of the reentry guidance. These are:

   a) IMU inaccuracies

b) AGC approximations and round-off effects

c) Ability to control the reentry vehicle.

These effects along with initial condition uncertainties are being studied.

4. Optimum Navigation

   The problem of achieving a statistical best estimate of state variables from a combination of inertial navigation procedures and prior knowledge of the character of the atmosphere is being studied.

5. Controller Design

   The logic necessary to maintain the vehicle on the computed path during the various phases of the trajectory is being designed, with consideration of the trade-off between roll-rate capability and corridor width. Control configurations will be evaluated on the basis of fuel expenditure, vehicle heating, and acceleration loading. The simple analytic formulae to predict range-to-go and time of flight are being improved.

6. Terminal Phase Control

   Control logic and range prediction studies are being made for the terminal phase assuming that position information has been updated and/or the vehicle has radio contact with the landing site. Both the feasibility and need for such control are under study.

7. Orbital Mission and Abort Entry Control

   A control configuration compatible with the prime-mission configuration will be developed.

<u>Midcourse Navigation Error Studies</u>

1. Determine the effect on midcourse navigational errors of

   a. Supplementary or backup ground tracking data

   b. Star occultations

c. Non-optimum measurements

d. Errors in application of velocity corrections

e. Minimum allowable time between measurements.

2. Orbital Navigation Technique

   a. Investigation of required tracking rates during orbital midcourse guidance

   b. Study of the effect of multiple observations of a single landmark with the tracking telescope.

   c. Consideration of star-horizon or occultation measurements as a supplement or backup to landmark observations.

3. Attitude Maneuvers

   Determination of optimal roll-pitch-yaw maneuvers to enable a desired measurement to be made during midcourse.

<u>Lunar Landing and Rendezvous</u>

1. Lunar Orbit Operations

   a. Optimize mission profile with respect to orbital altitude, powered descent, and guidance equipment requirements.

   b. Conduct error studies to determine lunar orbital conditions after deboost from midcourse.

   c. Choice of landing site relative to lunar orbit for varying stay times.

2. Landing

   a. Examination of guidance equations for the landing maneuver and their use with the proposed equipment.

   b. Investigation of flare-out portion of trajectory to provide manual control as well as automatic maneuver resulting in acceptable hover conditions.

   c. Determination of radar requirements for landing as well as rendezvous.

3. Lunar Ascent

   Determine a technique for guidance of the vehicle during lunar ascent in order to achieve rendezvous. Assistance from mother ship may be included.

4. Rendezvous and Docking

   a. Develop rendezvous guidance technique, utilizing a fully automatic system, or one with strong dependence on astronaut control.

   b. Investigate various docking techniques.

5. Simulation

   Preliminary investigation of simulation requirements for lunar landing and rendezvous to be accomplished using combined analog-digital equipment as well as the incorporation of manual control through tie-in to display and control equipment.

Abort Considerations

1. Reentry Errors Following Midcourse Abort

   An error study is under way to calculate the sensitivity of position and flight path angle at reentry to position and velocity errors at various points along abort trajectories.

2. Midcourse Two-Impulse Aborts

   An engineer's thesis is being written which treats the two-impulse midcourse abort situation. This scheme may be capable of providing improved reentry ground track and earlier landing time relative to the single-impulse abort in some cases.

3. Abort from Lunar Landing Maneuver

   Aborts from several phases of the lunar landing maneuver to accomplish a successful rendezvous with the parent vehicle are under study.