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COLOSSUS Memo # 174

TO: Distribution
FROM: Gerald M. Levine
DATE: April 25, 1969
SUBJECT: Transearth MSFN State Vector Updates.

The current F/G mission techniques dictate that periodically between the first transearth midcourse correction and 30 hours prior to entry a new state vector may be uplinked to the CMC. This state vector will be used as initial conditions for the on-board midcourse navigation (P23) in the event of communication loss. If the uplinking of the entry-minus-30-hour state vector is accomplished, then P23 will not be used even if communication is subsequently lost. The question that has been raised is how much difference should there be between the current MSFN best state vector and the older on-board state to justify a state vector update ? In other words, how much error can be tolerated so as to avoid the uplink procedure ?

In my opinion the question should not be asked. I recommend that there be a state vector update every 12 hours automatically with no difference check even being made.

Actually, for a moon to earth transfer of about 60 hours, there is no update to be avoided since no more than 15 hours exists between the correction and the 30 hour point, and it takes MSFN about 10 hours to obtain a state vector after the maneuver. As the transearth coast period increases, potential updates between the midcourse correction and entry minus 30 hours come into existence at the rate of two per day of increased transit time, assuming 12 hours as a reasonable period between updates.

If I were an astronaut returning from the moon on a three or four day trajectory, I would first of all be doing midcourse navigation. Since this is not planned, I would certainly desire the best state vector possible in the on-board computer for contingency use. I do not understand the objection to an automatic twice-a-day state vector update procedure which can be made absolutely safe by the use of the CM and LM state vectors and the special transfer verbs (commonly called ZAP and UNZAP).

Notwithstanding my opinion, there still exists the philosophy of updating the CM state vector only if the new state would be a "significant" improvement, thus requiring a periodic critical decision as to whether or not to uplink the new state. The remainder of this memo is concerned with developing a criterion for determining the significance of state vector differences.

The only simple way to discuss the question is under the very pessimistic assumption that P23 will merely maintain the current state vector accuracy level. In other words, the fact that P23 will be used and will improve the state is ignored, and only the extrapolation of initial errors to entry are considered. The conclusions will therefore be conservative. This assumption that P23 does nothing might cause state vector updates to occur more often than necessary (but, twice a day at the worst). The reason for making the assumption is that it allows a relatively simple discussion of the question since the P23 capability is very dependent on the various assumptions which must be made (for example, entry constraints, SXT accuracy, measurement schedule). The discussion will be concerned with the following entry initial error sensitivity table:

	$\frac{1}{2}^{\circ}$ $\delta\gamma$		200 f./s. $\delta\dot{R}$	
Hours Prior To Entry	δR (n. mi.)	δV (f./s.)	δR (n. mi.)	δV (f./s.)
30	27	0.93	7.7	0.47
40	31	0.78	6.9	0.31
50	37	0.69	6.1	0.23
60	43	0.64	5.5	0.18

In the table, $\delta\gamma$ is the error in knowledge of what the entry angle of the current trajectory is. Note that it is possible to know the entry angle perfectly without having perfect state vector knowledge. In particular, if the only state vector error is in time (i.e. the path is known perfectly but the estimate of the location of the spacecraft on the trajectory is in error), then $\delta\gamma$ is zero even though there is a position error and a velocity error at any given time. The other quantity, $\delta\dot{R}$, is the error in the knowledge of the altitude rate that will exist at the time the spacecraft actually arrives at entry.

These two parameters, $\delta\gamma$ and $\delta\dot{R}$, are the two critical parameters for the entry guidance. The assumed limits consistent with safe entry are:

$$\delta\gamma \leq \frac{1}{2}^{\circ}$$

$$\delta\dot{R} \leq 200 \text{ ft./sec.}$$

which explains the top line of the table. The entries in the table indicate the magnitudes of the position error (δR) and the velocity error (δV) at a given time prior to entry which will produce the limiting values of $\delta\gamma$ and $\delta\dot{R}$. For example, 40 hours prior to entry, a 31 mile position or 0.78 ft./sec. velocity uncertainty will yield $\frac{1}{2}^{\circ}$ $\delta\gamma$, while a 6.9 mile position or 0.31 ft./sec. velocity error will cause 200 ft./sec. $\delta\dot{R}$.

This table was constructed from data obtained using a 99 hour trans-earth trajectory. Faster trajectories will cause the numbers to change, particularly those near the bottom of the table. In addition, the position and velocity errors must be in specific directions in order to cause the $\delta\gamma$ and $\delta\dot{R}$ indicated in the table. Ignoring this last fact and merely considering the total position and velocity errors simplifies the discussion and also makes it more conservative.

From the table it is clear that $\delta\dot{R}$ is the more sensitive parameter. Applying what is, in my opinion, a reasonable safety factor to the last two columns in the table, I recommend that a state vector update be made every 12 hours if either

$$\delta R > 1 \text{ n. mi.}$$

or

$$\delta V > 0.1 \text{ ft./sec.}$$

where δR and δV are the magnitudes of the differences between the new and old position and velocity vectors, respectively. Now, since these limits are so small, and almost surely will be violated each time, perhaps the check shouldn't be made at all, and the state vector updated automatically every 12 hours.