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DANCE Memo # 67

TO: Distribution
FROM: George W. Cherry
DATE: April 15, 1968
SUBJECT: MIT Comments on GAEC Software Discrepancy Reports

This memo is a summary of MIT/IL comments on the GAEC "Software Discrepancy Reports."

Bob Gardiner of NASA directed GAEC to report everything peculiar witnessed during their CCA765 in a Discrepancy Report whether the source of the problem was software, hardware or elsewhere. GAEC has so done and we consequently have some "Software Discrepancy Reports" which are not software problems. There are 23 GAEC generated "Software Discrepancy Reports." They are all commented on here, some for the first time. In some cases a previous comment, such as DANCE Memo #41 by Jim Kernan, Phyllis Rye, and Bill Widnall or my AG letter #105-68, is simply referenced here. In some cases a previous MIT/IL comment in a reference, such as DANCE Memo #41, is herein slightly modified or amplified.

DISCREPANCIES (GAEC Generated)

- No. 1 Restart Protection: See DANCE Memo #41. (Problem was not in LGC program.)
- No. 2a See page 12 of this memo.
- No. 2b See DANCE Memo #41. (Problem was due to an operator procedural error.)
- No. 2c See DANCE Memo #41. (Problem was a programming error in Rev. 251 which was fixed in Rev. 254.)

No. 3 Description See DANCE Memo #41 which states that MIT will fix the problem. The description of the problem is that the vehicle attitude error diverges during X-axis translation if there is an undetected jet failure. The discrepancy was genuine. With one X-translation RCS jet failed (undetected) the unfailed "translation" jet produces prodigious angular acceleration, and the rate derivation suffers a consequent degradation. (Incidentally, an undetected jet failure is a double failure - a failure of the jet and a failure of the failure detection system.) Bill Widnall gives a qualitatively sound analysis of the problem in DANCE Memo #41, and his prediction that MIT/IL would fix the problem was based on this analysis. Bill tells me, however, that his analysis is quantitatively erroneous because it does not take into account the non-linear (up-down counter) filtering used in the rate derivation. The changes made to the DAP therefore do not result in stability for any magnitude of unmodeled disturbing angular acceleration. The problem has been fixed to some extent now so that it only occurs for the very lightest IM vehicle.

Recognition While in P41 or P47 and performing X-axis translation the astronaut can recognize the problem of an undetected X-axis jet failure by two symptoms: (1) The VX term in N85 of P41 (or the DELTA VX term in N83 of P47) will not decrease (increase) as it should. (2) Furthermore, the attitude of the spacecraft will diverge from the commanded attitude (increasing attitude error on the FDAI error needles).

Correction Procedure The astronaut can stop the attitude divergence immediately by releasing the translational hand controller. He can then try switching from system A jets to system B jets and using only two jets for X-translation (in case he was

using four). He does this by selecting R03 via V48E and then modifying the contents of window B in N46.

Another procedure would be to try to isolate the failed jet by operating the jet isolation switches until the symptom disappears. As soon as the astronaut isolates the failed jet the DAP will behave properly yielding both translation delta V and good attitude control.

Disposition Work around given above is necessary. On the SUNDANCE missions (missions D & E) there are no plans for unmanned light ascent burns. Therefore, crew safety is not affected by this phenomenon and no work around is required. MIT/IL considers this discrepancy closed for the SUNDANCE mission.

- No. 4 See DANCE Memo #41. The phenomenon observed at GAEC never re-occurred at GAEC and could not be reproduced at MIT/IL. We consider this discrepancy closed.
- No. 5 Revision 258 had a JETLIST bug in it which caused the high rate amplitude limit cycle alluded to. The bug was removed in Revision 271.
- No. 6 This discrepancy report concerns the false GDA failure indication. The software must be absolved of any allegation of a discrepancy because it complies with the interface specification. Nevertheless, a PCR has been generated to change the software because of the approximately 1 Megabuck cost to fix the hardware.

No. 7 See DANCE Memo #41. The error in the ball angle display routine noted by GAEC in Rev. 263 was fixed in Rev. 264.

No. 8 This was a GAEC simulator hardware problem. GAEC concedes this and we consider the discrepancy closed.

No. 9 Description In Rev. 271 the Verb 43 option could not be performed without obtaining "operator error" unless fresh start or restart is performed.

Disposition Jim Kernan fixed this in Rev. 272.

No. 10 See DANCE Memo #54.

Description GAEC reports an attitude error divergence with the CSM-docked DAP when a horizontal jet fails on in Rev. 271. This was the same bug which stimulated IM Mission Simulator Comment #11 on DANCE revisions 270 and 272. The CSM-docked DAP was firing feeble short pulses under certain circumstances due to a coding error.

Disposition The SPS backup DAP coding error was fixed in Rev. 273 and the discrepancy is considered closed.

No. 11 See end of this memo.

No. 12 Description If the major mode is P00, P30, P32, P33, P34 or P35 and a re-start occurs, an IMU CDU ZERO is performed to make sure that the CDU counters in the LGC contain correct representations of the IMU gimbal angles. The IM DAP must, of course, be turned off

while the CDU's are being zeroed, are held at zero and are counting back to the correct values. GAEC alleges that the roughly 12 seconds of DAP inactive time "could be catastrophic in certain critical mission phases such as docking."

MIT Comment We do not consider the observed phenomenon to be a software discrepancy since the software was explicitly and expressly designed to work the way it does. Furthermore, docking should be done in P47, a program which does not permit an IMU CDU ZERO, and not in P00, a program which does permit an IMU CDU ZERO. If station keeping or manual maneuvers or docking were done in P00 rather than P47 the IM state vector would be degraded. MIT/IL believed that the DAP was not essential during P00 and the FXY targetting when the re-start philosophy was determined.

Despite these comments there is merit in what GAEC states if we are really concerned about re-starts. For example, R62, the Crew Defined Maneuver Routine is used in P00 only. If the crew has defined a high rate maneuver in R03 and the rate has been achieved in R62 and a re-start occurs, the spacecraft would rotate for about 12 seconds at the high rate without the DAP. This is evidently not desirable. A simple ad hoc fix for this would be to set the IMUSE bit during R62 operation. I am generating a PCN to do this.

Why does the program do an IMU CDU ZERO following a restart at all? It is believed that whatever causes the re-start might cause the CDU registers to be incorrect. It is obvious that counter increments can be lost during a restart and that multiple re-starts could cause several, perhaps many, counter increments to be lost. I do not believe that we are particularly interested in multiple re-starts, however; the astronaut is likely to be very suspicious of a multiple-restarting LGC and switch to AGS anyway. The point is that a single restart does not necessarily signal anything wrong with the CDU's.

Should an IMU CDU ZERO be done, then, following a computer re-start? Many causes of a re-start do not make an IMU CDU ZERO necessary.

It is interesting to note that just as a computer re-start does not necessarily signal a CDU problem and the need to ZERO, an event which causes a CDU problem and a need to ZERO does not necessarily cause a computer re-start. An IMU CDU ZERO at the beginning of a burn program might be a good idea, then. An IMU CDU ZERO following a re-start in POO when R62 is operating may be a bad idea.

I believe the program is all right the way it is. I don't believe there is a crew safety problem - since every mission phase which has a crucial attitude control requirement has the IMU CDU ZERO following a re-start inhibited. However, the way the program is may not be, probably is not, optimum. The way the program is has this to say for it - it is finished, it is documented, and it involves no new crew procedures.

Here is another approach to IMU CDU ZERO for what it is worth. I do not recommend it but it is worth discussing. It puts more burden on the crew but in the event of a re-start when the DAP is in use, it does not create a hiatus in the PGNCs attitude control. Suppose that the RESTART routine looks at the Mode Select Switch Inbits and Guide Select Switch Inbit to find out whether the DAP is in use (Mode Select not OFF and Guide Select in PGNCs). If the DAP is in use no IMU CDU ZERO is performed; otherwise an IMU CDU ZERO is performed. After the Re-start light appears the astronaut does an IMU CDU ZERO (V4ON20) when he doesn't mind a 12 second period of DAP inactivity. Perhaps he does a V4ON20 a couple of other times (even if there is no re-start) just to be sure of his CDU's.

Disposition Closed. Can be opened by the approval of a PCR which describes a better scheme to everyone interested and involved.

No. 13 DAP Instability with Undetected Jet Failure, Revisited. See No. 3 in this memo.

No. 14 Description The GAEC report describes a high rate amplitude limit cycle for the light ascent vehicle when there is a mass difference between the LGC and the real world (the simulator). GAEC states the phenomenon occurs, when the LGC mass is 20% higher than the real world mass.

MIT Comment We believe that many effects observed on the GAEC simulator are due to lags in the tilt-table response. Bill Widnall, to confirm this hypothesis, had some runs made on our digital simulator with the jet-on delay (time lag between electrical on signal and RCS thrust) increased from 20 milliseconds to 50 milliseconds. We then began to see effects similar to those seen at GAEC.

GAEC spent about 1.5 Megabucks to fix this kind of problem in their AGS and believes we ought to spend a couple of man-days on analyzing the problem at MIT.

Dick Goss has made some powered light ascent runs with a mass mismatch of 73%. That is, the LGC mass was 73% higher than the true mass. No high rate amplitude limit cycles were witnessed. These runs were with the normal jet-on delay of 19 milliseconds. Thus, the system works very well and is very forgiving with respect to mass errors in the light powered case. Dick has a very interesting explanation and some interesting graphs of why the system works this way.

Todd Schmidt has explored the light ascent vehicle DAP performance and behavior during drifting flight.

Todd was able to provoke an eight degree per second limit cycle by a constellation of bad conditions.

1. A jet-on delay of 55 milliseconds rather than 19 milliseconds.
2. A LGC mass of 7000 lbs versus a vehicle mass of 5202 lbs.
3. An impossibly low vehicle I_{ZZ} of 1444 slug-ft² which is below the unmanned dry I_{ZZ} of 1538 slug-ft².

Todd ran another case which converged to a minimum impulse limit cycle. This case had a 15% mass error but the proper jet delay. The conditions were

- a. A jet-on delay of 19 milliseconds.
- b. An LGC mass of 6000 lbs versus a vehicle mass of 5202 lbs.
- c. An LGC inertia of 2146 slug-ft² versus a true inertia of 1444 slug-ft², an inertia error of about 50%.

I do not want to make light of the GAEC "discrepancy report." In LUMINARY the interrupts will grow and lengthen somewhat and delay our outputting a computed jet time. The system is sensitive to delays whether they are in the computer, the simulator or the RCS thrusters.

Avoidance Procedure The crew can avoid the high rate limit cycle during drifting flight with the light ascent vehicle by loading through RO3 the minimum weight which that routine will accept - about 4840 lbs. This is less than the dry, no-crew LM weight of 4938 lbs and yields an I_{ZZ} inertia of 1220 slug-ft² as compared with the absolute true minimum of 1538 slug-ft². This load will make any tendency toward high rate amplitude limit cycles virtually impossible.

Disposition With respect to SUNDANCE, this is closed from MIT's viewpoint. However, we ought to do some analysis for LUMINARY (where there are more interrupts) to assure ourselves that computation delays and other delays cannot be as great in the real lunar landing LGC and LM as they apparently are in the GAEC FCI Lab. I am also, with respect to LUMINARY, requesting Bill Widnall to consider using a 10% to 20% lower weight for computing inertias during drifting flight.

No. 15 Description Excessive Cross Coupling in Rate Command with Detected Jet Failure.

MIT Comment The explanation and the corrective measures or avoidance are described in AG letter #105-68.

Disposition Closed since DAP is adequate for SUNDANCE. An improvement for LUMINARY based on AG letter #105-68 would be a reasonable consideration.

No. 16 Description No Rate Command/Attitude Hold during Powered Ascent.

MIT Comment Yes. In fact, no Rate Command/Attitude Hold during Powered Descent either. Manual modes during powered flight are not Mission D or E requirements.

Disposition Closed. No manual modes during powered flight required for SUNDANCE.

No. 17 Description Large Cross Axis Rates during Ascent Engine Burns.

MIT Comment Same as No. 15.

Disposition See No. 15.

No. 18 Description Lack of Flexibility in Inertia Curves.

MIT Comment We are somewhat puzzled by the "Discovery Circumstances" which states "Investigation of SUNDANCE listing Rev. 271 in preparation for DAP verification testing..." and the "Description" which states "There are polynomials provided within the LGC to calculate as a function of mass; 1. one jet angular accelerations, and 2. X_{cg} during powered descent. The polynomial constants are in fixed memory..." Well, we believe that they are hyperbolas and that the discrepancy report is somewhat of an hyperbole.

Disposition Closed. GAEC states that the unmanned APS burn will be incorrect with respect to inertias because we have not arranged in our curves for the astronauts' absence. The errors in inertia so caused amount to about 10%. This is quite tolerable.

No. 19 Description Excessive RCS Jet Impingement on the Descent Stage.

MIT Comment PCR's 135 and 144 help in this area. GAEC is also concerned about the DAP's firing RCS jets a lot because Maxwell's deamon shifts the fuel causing large C.G. shifts and moment unbalances. A small help here might be a wide RCS DAP deadband during the low thrust C.G. trim maneuver.

Disposition Closed from MIT/IL's viewpoint. DAP meets specs in respect to RCS jet firings.

No. 20 Description While performing coarse align in P40 and then doing an IMU CDU ZERO, GAEC believes that they observed BIT6 of IMODES33 stay set so that the DAP was not turned back on.

MIT Comment Ed Grace, MIT/IL, has been working with Clint Tillman, GAEC, on this one. Ed does not see how this could happen and GAEC has not reproduced the problem.

Disposition Open pending further information from GAEC. The procedure of coarse align during P40 should be avoided.

Action GAEC to pursue this by adding additional information. MIT/IL (Ed Grace) to await GAEC information and continue to investigate.

No. 21 Description Reduced Control Boundary in Powered Ascent. GAEC states, "In powered ascent, the control system should be capable of counteracting a pure roll or pitch moment unbalance of 2200 ft-lbs. However, with the system as designed, only 1774 ft-lbs could be controlled before the system went unstable."

MIT Comment MIT/IL believes the GAEC observed reduction in the control boundary may be partially due to the tilt-table dynamics. We observe negligible reduction in the theoretical control authority. Runs by Dick Goss at MIT/IL show the DAP stability virtually equal to the theoretical possible. Furthermore, the specification for the maximum moment unbalance is, I believe, about 778 ft-lbs.

Disposition Specification on moment unbalance for IM ascent guarantees stability and IM DAP is stable to the virtual maximum possible moment offset anyway.

No. 22 Description GAEC states that the CSM-docked DAP performs erratic R60 maneuvers when the maneuver rate specified in R03 is 10°/sec.

MIT Comment Correct. Even the 2°/sec maneuver option in R03 should be avoided. The IM-docked CSM DAP which is a primary autopilot in the CM avoids maneuver rates higher than 1°/sec. Of course, the SPS back-up DAP must be similarly restricted.

Avoidance Astronaut must select the 0.5°/sec or 0.2°/sec maneuver rates in R03.

Disposition Closed.

No. 23 GAEC concedes that this was a FCI Lab simulator problem. Closed.

No. 2a The reported problem did not re-appear. It must have been a transient problem which existed in Rev. 251 only. GAEC has not been able to re-produce the problem. Closed.

No. 11 Description GAEC notes that in the event of a complete RCS system failure, an attempt to translate in the plus or minus Z direction would result in a program alarm (2001) and no translation.

MIT Comment This is not a software discrepancy but a deliberate design feature. Indeed, reference to Figure 1 shows that pure $\pm Z$ translation is theoretically impossible when a whole system such as System A (jets A1F, A2A, A3R and A4R) are off.

Example. Suppose system A is off and that the astronaut requires +Z translation. The only jet left which "translates" in the +Z direction is B3A. But this jet also provides a + yaw torque. For every millisecond of B3A's "translational" thrusting there must be one millisecond of thrust from B4F or B1L in order to maintain the attitude desired by the astronaut. If B4F is used the translation provided by B3A is exactly cancelled out and nothing results but RCS propellant wastage. If B1L is used to buck out the yaw torque provided by B3A the spacecraft translates in the diagonal direction between +Y and +Z without loss of attitude control. However, the +Y translation, which was not commanded, cannot be taken out because both minus Y translation jets, A3R and A4R, are out. Thus, the astronaut drifts in the +Y direction with no resource for coming back. This seems so undesirable we do not consider it a useful design.

If the astronaut does want the DAP to translate in the diagonal direction between +Y and +Z he can with the whole system out. But he must command +Y and +Z simultaneously.

I believe that the policy of translating in the +Y direction when the astronaut commands +Z is unacceptable. Expecially, this policy seems incorrect when we recognize that the astronaut has no way of cancelling out the unauthorized translation.

Disposition Closed pending further direction from NASA. We believe that the mechanization in SUNDANCE is superior to the one suggested by GAEC.