M E M O R A N D U M

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From: J. Sampson

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Subject: LM-1 Trip Report at MSC - Flight Support and Debriefing

(Please note that the observations herein are those of the author and do not necessarily reflect the position of MIT or NASA)

I. Introduction

I accompanied J.S. Miller of MIT to MSC to support the LM-1 mission from the software point of view. In previous unmanned flights, the ground had only limited capability to change the flight plan (i.e.: state vector updates), however the BURST120 flight program for the LM-1 mission was programmed to allow the flight controllers the capability to retarget burns, change the order of burns, terminate LGC activity, issue commands to the vehicle via the LGC UPLINK, and even to turn off the Digital Autopilot.

Dr. Miller and I were in the Flight Dynamics Staff Support Room in the Mission Control Center during the flight as well as for the Network Simulations two weeks before the flight. Officially, we were there to support both the Guidance and Control Officer and the Guidance Officer who were in the Mission Operations Control Room across the hall.

II. Mission Support

The desired cold soak gimbal angles were achieved to within $\pm 0.2^{\circ}$. The Digital Autopilot (DAP) held these desired gimbal angles to within $\pm 10^{\circ}$. Since the deadband was $\pm 5^{\circ}$ and since the mission rule agreed on was not to schedule a burn if the DAP could not hold attitude to

within ±10°, we and the Guidance and Control Officer became concerned. Then we realized that the DAP holds attitude within a deadband defined along control (vehicle) axes and that the IMU gimbal axes around which the mission rule criteria was based are not generally orthogonal. The bigger the IMU middle gimbal angle, the bigger the apparent difference between the desired and actual CDU angles. Some quick calculations showed that with an MGA of 60°, the DAP could be holding attitude to within 5° around control axes, yet this would show up as a 28° attitude error around CDU axes. Since the MGA during the cold soak was -33°, we recommended that the mission rule be changed. The fact that the G&C officer decided to ignore the rule completely and instead rely solely on the mission rule that limited CDU rates to ±10°/sec led us to believe that mission rules are not very stringently enforced.

We were especially pleased with the DAP limit cycle during the cold soak. It was firing a jet (minimum impulse) about every 2 minutes to hold attitude.

LMP commands 254 and 255 were sent to the LM Mission Programmer via the LGC uplink at 1:35:10 G.E.T. to close the RCS Manifold Crossfeed Valves. We could not immediately determine why this was done.

Four seconds (erasable memory constant) after the DPS1 guidance program commanded the engine on, the LGC ΔV monitor program failed to detect enough compensated PIPA counts to satisfy the minimum descent stage threshhold criteria of 45cm per 2 seconds (fixed memory constant), and it consequently commanded the engine off and immediately scheduled the mission idling program, resulting in Program Alarms 1405 (ΔV monitor alarm) and 315 (FORGETIT). First indications via telemetry showed that a slow leak that had been present since launch had allowed the ullage pressure in a fuel tank to drop from a nominal 153 psi to a level of 100 psi, causing the thrust to build up slowly. Since we heard that it might have taken 7 seconds for the tank to pressurize after the engine was commanded on, we informed the Guidance officers that the 4 second criteria of the ΔV monitor program could be increased by changing a number in erasable memory via the uplink.

The Flight Director immediately chose to implement Alternate Mission Plan C, which included PRA (Program Reader Assembly) sequence III. Essentually, this involved repositioning a tape recorder onboard which when started would command the following fixed-attitude sequence: a DPS burn with the first 26 seconds at 10% thrust and the last 2 seconds at maximum thrust, a 30 second coast, a second DPS burn

immediately followed by a Fire-In-The-Hole and a short APS burn. They planned on terminating the sequence before the "canned" second APS burn to fuel depletion so that they could attempt to let the LGC control the APS2 burn.

Executing PRA sequence III meant switching control from PGNCS to AGS (although the Abort Guidance System was not onboard in any total sense). Evidently the Flight Director felt that there was no adequate ground coverage to transmit the required UPLINK commands necessary to retarget and reschedule the DPS1 burn or even to let the PGNCS control the DPS2/FITH/FIPS1 burns. We heard a rumor that George Low at KSC favored Alternate Mission Plan L - retargeting and scheduling DPS2.

Since the AGS onboard only contained rate gyros for rate control, the alternate mission plan required using the attitude maneuver program and the DAP in the LGC to re-orientate the vehicle for the PRA sequence III (most humiliating from a PGNCS standpoint). The Guidance Officer loaded the predetermined desired CDU angles into the specified erasable memory locations and requested the attitude maneuver program (KALCMAN3) via a VERB 30 UPLINK command. The LGC maneuvered the vehicle to the desired attitude and left the DAP in a minimum 0.3° deadband. Using KALCMAN3 from the ground was suppose to be a post-mission test and requires an LGC erasable (ATTCADR) to be reset to +0 if the LGC is ever to command a subsequent attitude maneuver, because KALCMANU was designed to be used only under LGC control.

After the PRA sequence III was carried out under AGS control, they switched back to PGNCS so that the DAP could hold attitude and so the Guidance Officers could begin setting up the LGC for the APS2 burn. We strongly recommended that the valve of MASS in the LGC be immediately updated to reflect the current ascent stage mass and that the DAP deadband be reset to maximum 5°. We pointed out that the DAP knew that the vehicle had staged, but was still using the full descent mass and inertias to compute jet firing times, etc. For some reason they ignored our advice and proceeded to perform an LGC state vector update (the LGC had not been keeping track of the ΔV acquired during the PRA sequence III). Meanwhile the DAP was firing jets rapidly and RCS fuel was being used up very quickly.

Telemetry data soon indicated that the fuel in the RCS B system was depleted. The Guidance and Control Officer wanted to shut off the fuel in the A system to force the DAP to give up, but we informed him that it would not work because the DAP will only give up if it had been informed that all

the jets required to hold attitude had failed. Shutting off all the fuel to the jets would only cause the DAP to vainly keep trying to hold attitude. We kept pleading with the flight controllers to update the LGC mass and/or switch the DAP from a minimum to a maximum deadband. Instead they chose to update the ΔV monitor criteria from 4 to 60 seconds (??). When we asked why they did not want to update the mass, they replied that they were trying to figure out a valve with which to update. We informed them that any rough guess was better than the valve presently in the LGC, but they replied that they were losing command capability and would update MASS at Carnarvon acquisition.

When they were able to command again, they sent some LMP commands to feed some of the fuel from the other tanks into the B system. They were able to update the LGC valve of MASS but were not able to switch to a wide deadband before they lost acquisition again.

The Flight Directors then decided not to use the PGNCS for the APS2 burn, but instead use PRA sequence V. This meant that the second APS burn to fuel depletion would be carried out under AGS control. The reason given was there was insuffiecient ground coverage available during the next orbit to uplink all the required data and commands to get the LGC prepared for the APS2 burn, and also that there was not enough RCS fuel left to wait for good coverage.

They eventually initiated the PRA sequence V and lost acquisition half way through the burn. The last telemetry data showed that all the vehicle rates were "off scale" and the IMU gimbal angles were:

$$\begin{aligned} \text{IGA} &= 260^{\circ} \\ \text{MGA} &= 100^{\circ} \\ \text{OGA} &= 103^{\circ} \end{aligned}$$

The inner (pitch) gimbal angle was changing so fast that they believed that the vehicle was tumbling. The Gimbal Lock and NO ATT lights were on.

Ain Laats thought that the IMU must have gone through gimbal lock (85°) with such a high rate that when the IMU dropped automatically into the coarse align mode, it could not stop the MGA from going through 90° and the platform from tumbling.

We received intermittent telemetry indications that showed that the DSKY must have looked like a Christmas tree with the IMU fail, CDU fail, Gimbal Lock, NO ATTITUDE, and PGNCS fail indications present. The last indication before they lost telemetry for the last time was that the vehicle was

tumbling at a rate of one revolution/sec (and with such a large MGA, the platform could have been tumbling at 100 times that rate). They were unable to re-acquire tracking because they had no way of knowing which way the vehicle had been thrusting.

A press conference we monitored after the flight pointed out the following observations:

1. 11½ of the 12 overall mission objectives were achieved. Only the long duration DPS burn was not.

2. The Flight Director did not hesitate to use Alternate Mission Plan C because he was most interested in achieving the critical Fire-In-The-Hole objective.

3. NASA feels that the LM is man-rated. To be sure, the first time the engines are ignited with a man on board, they might keep the LM coupled to the CSM.

4. We have a very smart guidance computer onboard that abides by the mission rules very strictly. Had there been a man on board, he might have hesitated and given the engine a few more seconds to achieve the command thrust.

We met with the NASA people responsible for putting out the one-hour report. Officially it was stated that the LGC terminated the burn because it determined that the thrust was not up to a predetermined threshhold within 4 seconds after commanded ignition.

As we returned to our motel rooms about 3 a.m., we couldn't help but feel disgusted that the flight plan and tracking coverage allowed no opportunity to reschedule the DPS1 burn one orbit later. Evidently the whole trajectory was planned for a nominal mission. The LGC flight program contained a very flexible mission scheduling capability and we were disappointed that it was not utilized.

III. Post Mission Analysis and Debriefing

The next day we attended a number of meetings to discuss the mission results. As we anticipated, there were a number of questions on everybody's mind:

1. Why do we have a ΔV monitor?

   The guidance must ensure that there is sufficient ΔV present before it starts steering (i.e.: the Time-to-cut-off calculation in DPS1 guidance divides by ΔV).

2. Why does the ΔV monitor have to cut off the engine if it doesn't detect thrust? Why doesn't it just wait for thrust before starting to steer?

   a. The guidance cannot wait forever for thrust to build up. It has to do something.

   b. The DPS2 preburn guidance scheme involves a complicated engine-on algorithm that computes the time of ignition in order to achieve the stringent DPS2 end conditions. If thrust is not attained shortly after commanded ignition, the end conditions might never be met and the burn should be terminated.

   c. When we incorporated the ΔV monitor into the flight program some 18 months ago, we were led to believe that if thrust did not occur shortly after the engine was commanded on, the build-up of pressure in the Descent Propulsion System due to the explosive mixture might cause the engine to explode or rupture.

3. Why did MIT chose 4 seconds for the time after which the ΔV monitor would shutdown the engine?

   a. Again, when the ΔV monitor was originally incorporated into the flight program, we were lead to believe that when ullage was terminated ½ second after commanded ignition, there was a chance that the engine might explode if thrust did not occur immediately.

   b. At one time we were working under the assumption that the engine would produce the commanded 10% thrust within 50 ms. after commanded ignition. Just before program release we were informed by Grumman that the spedification was around 2 seconds. We were so confused about such a long time that we took the 4 second criteria constant out of fixed memory and put it into erasable so that it could be changed.

Since we felt that at that late date it would be impossible to inform all the people who were running LM-1 simulations about a new erasable that had to be initialized, we decided to initialize the erasable (STARTDVC) from fixed memory in the Fresh Start Program. That way it could be changed in the erasable load that follows, or left at the 4 seconds that Fresh Start initialized it as. (There are 7 other erasables that are initialized from fixed memory in Fresh Start, 3 of which are changed in the K-START tape erasable load which follows).

c. MIT sent an action item to NASA asking them to approve the 4 second criteria and NASA replied that MIT should use it.

4. Why did NASA approve the 4 second value when it should have been obvious that a slightly under-pressurized engine could not have possibly built up thrust within that time?

a. The Software Branch looked up the specifications and saw that a nominal engine should have built up full thrust in 2.7 seconds. Unfortunately they did not ask the Propulsion Branch what was the worse-case delay.

b. The specifications stated that the difference between a slow and a fast build-up of thrust for a nominal engine was about 100 ms.

5. Why didn't anybody simulate the effect of low pressurization at ignition on the ΔV monitor?

Grumman, which has prime responsibility to verify the interface between the vehicle and the flight program, claimed that they ran a simulation less than a month ago with the latest engine characteristics (but with nominal pressurization at ignition) and the thrust build-up just passed the ΔV monitor. However they felt that they were having trouble with their PIPA simulator.

6. Will there be a ΔV Monitor on the manned flights?

There will be one, but it will not shut off the the engine during the critical descent, FITH, and ascent burns above the actual lunar surface. Instead it will just display an alarm if thrust is too low. However, for all the burns on the earth orbital missions and the Lambert-targeted burns of the lunar mission (i.e.: Rendevous, DOI, etc.), the ΔV monitor is presently programmed to shutdown the engine as it did on LM-1.

The following needs to be decided:

1. What happened in the Descent Propulsion System? (May require an after-the-fact prediction)

2. What did MIT and Grumman expect of the engine from the Propulsion people at NASA?

3. What ΔV did the LGC detect before it shut the engine down?

The following needs to be done in the future:

1. Determine the minimum acceleration threshhold required for stable guidance control (to lower the ΔV threshhold)

2. Propulsion: Determine the minimum ullage on the tanks which can produce an engine start.

3. Based on the minimum possible ullage for satisfactory engine performance, determine the LGC cutoff command maximum time.

Early Conclusions

1. There is a serious lack of coordination between the propulsion people and the Software Control Branch at NASA. The program did not know how the engine performs, and visa versa.

2. The constants in the LGC programs should be reviewed more carefully by NASA.

3. The failure of the G&N test objectives to be achieved was a result of a combination of unfortunate circumstances.

   a. The DPS tanks were only partially pressurized at DPSI ignition.

   b. There was inadequate ground coverage to complete the mission under PGNCS control

   c. There was no man on board to reschedule the burn.

4. Even if more people had been aware of the 4 second ΔV monitor criteria, it is doubtful that it would have been changed before the flight.