NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MISSION OPERATIONS REPORT

APOLLO 13

APRIL 28, 1970

PREPARED BY

FLIGHT CONTROL DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

MISSION OPERATIONS REPORT

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SECTION I

INTRODUCTION

INTRODUCTION

This mission operations report contains the story of the Apollo 13 flight operation as seen in realtime. An attempt has been made to describe the situations, the various alternatives available, the decisions made, and the reasons for those decisions. No data is used except that available in realtime even in those cases where post-mission data shows the real-time data to be in error.

The basic mission narrative is contained in Section III (Flight Director's Report) and identifies the teams by color. The corresponding flight directors are:

White	- Eugene F. Kranz
Black	- Glynn S. Lunney
Gold	- Gerald D. Griffin
Maroon	- Milton L. Windler

There are several aspects of the mission which deserve special note although these do not appear in the narrative. First of all, the procedures used in recovering from the anomaly were, in a great many instances, fairly well thought out premission. For example: The LM jettison sequence and time, the LM operation at minimum cooling, the midcourse alignment technique, and the procedure to separate the LM and the Saturn S-IVB stage communication frequency to name a few. When new procedures were required or when existing procedures had to be reviewed, the core of the premission planning team was used. This resulted in well coordinated, quickly defined procedures.

Another important aspect is that premission work with LM systems and CSM systems in minimum power configurations contributed greatly to the ability to provide suitable systems configurations for the Apollo 13 case. This work also provided an additional capability that was available through minimum duty cycles. Fortunately this was not required, but the point should be made that there was a level of operations availabe that would have resulted in LM water and battery power usage rates well below the final stabilized rates obtained.

Also, a conscientious effort was made to let the crew set the rest/ work cycles. This resulted in the Mission Control Center holding many non-critical procedural items until the correct crew member was available.

The total flight control team for this mission had been built around a four shift operation. This worked out very well in that the team which had prepared for the entry phase (simulations, checklist review, etc.) could be taken out of the normal rotation and devote full time for two days to the new timeline and procedures for entry. These same people then executed this highly critical phase.

Finally it should be obvious that the simulation personnel in both the Flight Control Division and the Flight Crew Support Division played a very important role in preparing both the crew and the ground team for abnormal operational modes.

SECTION II

SUMMARY

SUMMARY

The Apollo 13 flight was essentially following the nominal flight plan prior to 55 hours 53 minutes elapsed time. The center engine on the S-II stage of the Saturn launch vehicle shut down about 2 minutes early, but this had no effect on insertion into Earth Orbit or on Translunar Injection. The Saturn S-IVB stage had been successfully targeted toward the planned lunar impact area near the Apollo 12 seismometer. The launch vehicle debriefing with the crew had been completed, and entry into the Lunar Module had been made about 3 hours early to inspect the supercritical helium pressure in the descent propulsion system. This pressure was satisfactory, and no further action was contemplated.

At 55+53 GET, a Command Module computer restart was observed, followed by a report from the crew that a main bus B undervoltage had occurred about the same time as a "loud bang." There was a short period during which the Control Center and the crew sorted out the false indications from the true anomalies, but it quickly became apparent that one of the two cryogenic oxygen tanks and two of the three fuel cells had been lost. The Command Module systems were configured to protect the entry capability. Efforts were concentrated on attempting to save the remaining oxygen tank. These efforts proved to be futile and at 57+35 GET, the CDR and LMP were entering the Lunar Module (LM) to establish communication and life support functions. The LM guidance system was powered up and aligned to preserve a maneuver capability and at 58+40, the CSM was completely powered down. About 20 amp hours had been used from the total of 120 amp hours available in the CM entry batteries.

Once the systems situation had stabilized, the Control Center's attention turned to the trajectory plan. The current status was that the spacecraft was on a nonfree return trajectory which would require a significant maneuver to change to satisfactory entry conditions. A direct return to earth with landing time of 118 hours GET was possible only by using the Service Module propulsion system and jettisoning the LM. This option was unavailable for obvious reasons and reduced the considerations to either: (a) Execute a immediate 40 fps midcourse correction to a free return trajectory (landing at 152 hours GET in the Indian Ocean). There would then be an opportunity to reduce the trans-earth coast time by making a maneuver about 2 hours after flying by the moon.

or (b) waiting to make the first maneuver until about 2 hours after flying past the moon.

The plan adopted (and which was essentially unchanged) was to execute an immediate midcourse correction to a free return trajectory, evaluate the consumables with the intention of keeping the LM guidance system powered up thru the major maneuvers if at all possible, and executing a major LM descent engine burn about 2 hours after passing the moon (79+30 GET).

The primary effort for the remainder of the mission was directed towards establishing the various procedures required for the many non-standard operations, i.e., CM battery charging from LM batteries, CM LiOH cannister use on LM environmental control system, no-optics alignment for maneuvers, water transfer from CM and portable life support system tanks to LM tanks, Service Module jettison, and many others.

The consumable situation continued to improve and stabilize to the point where it was feasible to leave the LM guidance system powered up until the descent engine maneuver with every expectation that the systems could easily be managed to stay within the consumable quantities available. This proved to be the case and after the major maneuver at 79+30 GET, the usage rates had dropped to be clearly compatible with the landing time. Sufficient workaround procedures had also been established to provide margins should there be subsequent loss of batteries, water tanks, or oxygen tanks in the LM.

There were several options available for the maneuver at 79+30 GET (2 hours after lunar flyby). These included jettisoning the Service Module before the burn and burning the descent engine to near depletion. The comsumables status did not justify going to either of these extremes, and the maneuver was targeted to reduce the landing time from 152 hours GET to 142 hours GET and change the landing area from the Indian Ocean to the Pacific Ocean. This allowed a comfortable propellant margin for future midcourse corrections.

The transearth coast portion was devoted to getting the ground developed procedures up to the crew at the proper times and in executing two small midcourse adjustments to the trajectory. The consumable status had continued as predicted, and the LM was powered up early to help warm up the crew and allow them a better chance to rest. This early power up also allowed a LM Primary Guidance and Navigation System alignment which was later transferred to the CM Guidance System saving several minutes in the critical preentry phase.

The SM was jettisoned about 4-1/2 hours prior to entry interface (EI) and the CM power up procedure started at EI - 2 hours 30 minutes. The CM Guidance System was fine aligned and the LM was jettisoned at EI - 1 hour. All CM Systems functioned properly during entry and the landing could be seen from TV on board the recovery ship. The crew were recovered in 45 minutes and were in good condition.

SECTION III

FLIGHT DIRECTOR'S REPORT

MISSION OPERATIONS REPORT

SECTION III

FLIGHT DIRECTORS REPORT

FOR APOLLO 13

Eugene F. Kranz - White

Milton L. Windler - Maroon

Glynn S. Lunney - Black

Milton L. Windler for

Gerald D. Griffin - Gold

FLIGHT DIRECTORS REPORT

Apollo 13

Prelaunch:

The major precount activity started when the Black Team came on duty at 2:00 a.m. CST with the clock holding at T-9 hours, and the network count to liftoff at T-11:20[1] and counting. The only network problem was the Honeysuckle MSFN Station command computer which was occasionally faulting. There was no estimate on the problem, but we were still GO without a command computer at Honeysuckle. (This problem continued to exist until 56+47 GET when a temporary fix was made to a chassis and the problem never returned.) Balloon and landing point prediction processing was normal throughout the count with no land landings even for the negative Emergency Detection System limits. At T-7:32, the weather report included an area in the Atlantic with 28 knot winds and 8-10 foot seas. This represented abort times from 6 minutes 30 seconds to 8 minutes 10 seconds Ground Elapsed Time (GET) and was considered acceptable. At T-5:34, the Vanguard MSFN Station central data processor was reported "red--cannot support." This affected the low and high speed radar tracking, however, the Bermuda MSFN Station coverage was adequate to proceed. A temporary fix was attempted, but the processor never was usable.

There was a problem with coordinating the use of the longline for patching the Cape Kennedy test channel 214 to the MCC. This should be addressed again prior to the next mission to assure that all parties know and agree to the plan.

About this time (T-2:00), a weather report of about 16 foot swells on both sides of the previously defined marginal weather was received.

[1] All times are hours and minutes unless otherwise noted.

After considering this for a time, and the possibility of a 2° (20 minute) launch azimuth slip, another weather report was received with a movement of the marginal weather significantly to the south. After some discussion, it was clear that there was nothing to be gained by slipping the azimuth, and the worst weather area was now down to an abort GET of 7 to 8 minutes with the same 8-10 foot seas and 28 knot winds. There were other reports from the area not as bad as this, and we elected to continue.

The Maroon Team came on shift at T-2:00, and the only other anomaly prelaunch was a procedural error in failing to console select the BSE for commanding the launch abort check sequence at T-1:55.

Launch, Translunar Injection, and LM Extraction:

Liftoff occurred at 1913:00 GMT as scheduled. All functions were nominal until the Saturn S-II center engine shut down at 5 minutes, 31 seconds (about 2 min 12 sec early). This presented no flight control problems and the rest of the stage performed nominally. There was no doubt about being GO for Translunar Injection (TLI), and the flight was normal through TLI although some instrumentation was inoperative on the Saturn SIVB.

Transposition, docking, and LM extraction were normal with satisfactory TV coverage. The Entry Monitoring System ΔV bias measurements were taken and the results incorporated in the midcourse maneuver pad. The Midcourse Correction at 30+40 GET was expected to be nominal; and, as planned, the MCC-1 (at 11+41) was not executed.

SIVB Lunar Impact:

The SIVB lunar impact maneuvers were executed successfully as planned. There was a question whether the SIVB Attitude Propulsion System (APS) MCC-1 at 6+00 GET should be based on the Bermuda tracking vector instead of the preburn vector with a nominal TLI profile applied. However, these two vectors were similar; and since the tracking after the APS MCC-1 indicated that the SIVB would land within the target area, it was decided not to attempt further midcourse corrections. The SIVB telemetry and attitude control was lost at 19+34, but there was no difficulty in tracking the S-Band beacon. An apparent ΔV impulse was observed about the time of telemetry and control loss, but this appeared to make the landing point closer to the target. The landing point varied slightly as the tracking data was obtained. However by 36+00 the point stabilized.

Translunar Coast:

The Gold Team came on duty at 6+00 and all flight plan items were accomplished normally until it was time to establish Passive Thermal Control (PTC) at approximately 7+30. The first attempt to establish PTC resulted in a very wide and diverging coning angle, and the PTC had to be reestablished. Several problems were detected in the first attempt--the major ones being that in order to get a final roll rate of .3°/sec, the Digital Auto Pilot (DAP) must be loaded with a rate of .375°/sec, and all thrusters must be enabled in roll. Although GNC stated that this was the same as Apollo 12, neither the checklist nor the flight plan reflected the DAP load; and the crew was not apparently aware that "overloading" the DAP was required. The thruster enabling was a late pen and ink change to the checklist. After the crew was advised of the proper PTC procedures, PTC was established with very good results. At 9+10, GNC reported that the Service Module Propulsion System (SPS) oxidizer tank pressure was slowly decreasing but that it was expected and was attributed to helium absorption. At 9+24, GUIDO reported that the CMP had entered a V37 into the Command Module Computer (CMC) at an improper time during the P-23 navigation sightings and that certain bits had not been set properly in the computer. A corrective procedure was read to the crew with a caution on how to avoid any similar occurrences in the future.

The White Team came on duty at 13+51 with PTC in progress and the crew asleep.

FIDO pointed out that MCC-2 was presently scheduled for 30+41 GET and would be approximately 23 fps. GNC pointed out that the gyro drift was running about 1.5 meru and would eventually require updating. EECOM reported no anomalies and all consumables were plus. He also pointed out that fuel cell sharing with the split bus configuration was running about as expected.

At 15+38, two questions were received from the Mission Director relative to the SII early engine cutoff during the launch phase. These questions were passed on to the CAPCOM to be uplinked at the nominal time in the flight plan for the booster performance debriefing with the crew.

At 18+31, EECOM reported that fuel cell 3 condenser exhaust temperature was fluctuating 1.5°F about every 70 seconds; however, this sort of thing had been seen on previous missions and was not expected to creat a problem. This trend continued until after the MCC-2 at which time the fluctuation increased to 6.4°F about every 31 seconds.

At 20+01, RECOVERY reported a tropical storm in the South Pacific, and then worked with RETRO to make the necessary adjustments to the 25 and 35 hour abort landing areas.

The Black Team came on duty at 22+00 with the crew asleep. The flight plan activity for this shift was highlighted by the following.

1. The Saturn Launch Vehicle debriefing questions.

2. MCC-2 (which was a transfer from the free return to a hybrid trajectory.)

3. P-23 navigation sightings.

4. Comet Bennett photos.

The P/T transducer on quad D was operating correctly at this time but was determined to give inaccurate readings at high SMRCS usage rates. Available SMRCS propellants were slightly above the flight plan projections. On the EECOM side, cryos were above the redlines; a suit pressure transducer was biased low; glycol flow rate was 10#/hour lower than expected from previous missions; two offline meetins were scheduled to plan for the LM supercritical helium (SHe) readout procedures and to review final changes to the lunar orbit photo plan.

At 22+46, the potable H_2O transducer dropped to 79% for a short time and returned to 100%. This was concluded to be a transducer problem of the same kind as seen on previous missions. The crew called in at 23+11 and started battery B charge. They had stowed their dosimeters on the suits, and the CMP dosimeter would be available later. The SURGEON understood and accepted that situation, knowing the other readouts would be available when the crew suited up at the moon.

At 24+41, the LM/CM ΔP confirmed a close-to-nominal decay rate in the LM. At 25+11, the Saturn debriefing was conducted and all questions were answered. (Further discussions on the LM SHe were leading to the conclusion of an early entry into the LM, about GET 55+00 hours, while the pressure readings for various courses of action were still being firmed up.) At 28+45, preparations began for the MCC-2 burn with spacecraft television on. The 23.2 fps MCC-2 was performed at 30+40+49 and all burn parameters were normal.

The Maroon Team came on duty shortly after the MCC-2, and at 32+00 an attempt was made to photograph comet Bennett. However, this was not possible due to the sun shafting on the CM optics. This shafting was expected, but the attempt was made since the comet would be considerable dimmer on the transearth leg when no optics problems were expected.

PTC was initialized at 32+25, but had to be stopped and reinitialized at 33+20. Apparently the DAP commanded a jet to fire to slow down the roll rate causing divergence. The second PTC was initialized successfully.

A CSM Master Caution and Warning (MC&W) alarm came on after the crew went to sleep due to H_2 tank #1 dropping below MC&W limit before the heaters cycled on. This did not happen again although the pressure came within 1 pcm count of tripping the alarm on several other cycles.

The Gold Team came on duty at 40+00 with the crew asleep. At 43+00, the landing point for the 60+00 abort point was moved to 153°W in order to avoid tropical storm Helen. At wake-up (47+00) the crew was requested to cycle the cryo fans per the normal procedure. When the crew cycled the fans in O_2 tank #2, the gauging system in that tank failed off scale high. A readout of the onboard gauge confirmed an off scale high reading. Loss of this gauge was of no great concern at this time since the tank status could be followed by monitoring pressure, temperature, and the status of O_2 tank #1. GNC noted a slight jitter in the optics Coupling Data Unit shaft readout and the crew was advised of the anomaly. A similar jitter was noted on Apollo 12 and was of no concern. The crew was advised to turn off the optics power except when the optics were in use.

Anomaly Period to Midcourse Correction (to Free Return):

The shift handover to the White Team was completed at 49+00 GET. There were no major open items; the Flight Plan contained the original LM activation, SHe pressure verification, a TV pass, and establishment of

PTC. The MCC-3 maneuver scheduled at 55+25 was deleted since the MCC-4 was only 4 fps. The major flight control activity was directed toward establishment of a plan to avoid a cryo H_2 tank #2 low pressure C&W during the subsequent sleep period.

The heaters in H_2 tank #2 had been turned off at 47+00 in an attempt to see if the H_2 tank #1 heaters would control the pressure at a higher level. By 49+40 the H_2 heater cycles on tank #1 had shown this to be true. (The heater came on at 233 psi, and the C&W limit was 224.5). The plan then was to unbalance the H_2 so that tank #1 was about 3% higher than tank #2 for the sleep period. Tank #1 heater would be left in auto for the sleep period and tank #2 heater would be left off in order to avoid MC&W's during the sleep period.

At 50+30, the crew was briefed on the changes to the Activation Checklist in order to allow them to read out the SHe pressure.

At 51+00 the crew was requested to stir both cryo's in order to monitor the H_2 balance prior to commitment to our sleep plan and in order to maintain a better track on the O_2 since we had lost the tank #2 sensor.

At 52+15, a new trajectory update was made that indicated MCC-4 would be less than 3.6 fps; all systems were normal, and the Battery B charge was initiated. The MCC-2 Service Module Propulsion System data was reviewed and it was noted that the thrust chamber pressure seemed about 4% below the preflight prediction. At 53+27, the crew was cleared to ingress the LM about 1 1/2 hours early, and LM press began at 53+34. A review of the analog playback of the O_2 tank #2 gauging problem with EECOM showed that the quantity went through 4 cycles, averaging about $\pm$2% about 80% quantity, then went to 100% quantity, and subsequently remained there. It was assumed that the transducer failed. A hardcopy of the analog data was requested.

The detailed SHe procedures were reviewed with SPAN, including the procedures for the DPS "Burp" if it became necessary. The crew completed the SHe verification at 54+40 with the pressure 710-720 psi,and no further action required. At 54+59, the LM power was terminated and the TV was initiated at 55+00. The High-Gain Antenna (HGA) would not work properly in AUTO or REACQ. (The crew tried both the primary and secondary electronics and lockup was finally obtained in manual. A maneuver to the PTC attitude was prescribed, and as the maneuver was initiated, the HGA locked up in REACQ and narrow beamwidth, and worked correctly. However, it was not understood how this maneuver caused the HGA to operate correctly in REACQ.) Limited troubleshooting was attempted.

The TV was very good, and was terminated at 55+46. The battery B charge was terminated at 55+50, and the battery was essentially topped off with 40 AH. Further isolation of the HGA anomaly began by verifying cockpit switches and HGA pitch and yaw readouts. These proved to be normal and no further investigation was made due to the O_2 anomaly. The crew was advised to stir the cryo H_2 and O_2 for the last time prior to the sleep period. A status check was run to verify proper configuration on LM closeout and start of the PTC and rest period. Everything was normal; the hatch was being closed, and the LM heater current was cycling properly.

NOTE: The following pages discuss the anomaly and are derived primarily from the air-to-ground and flight director loop voice tapes. Times are only approximate.

At 55+55, the Guidance Officer indicated that he had observed a Command Module Computer hardware restart. In rapid succession, the crew identified, "O.K., Houston, we have a problem. Main B undervolt."

"Right now, Houston, the voltage is looking good; we had a large bang associated with the C&W, and I recall Main B was the one that had a 1 amp spike on it." The telemetry indicated many discrepancies, and EECOM identified we may have had a major instrumentation problem. INCO identified that we had a switch from narrow to widebeam.

> NOTE: At this time, I felt we had had a major short circuit that knocked much of the instrumentation offline, and that it might be related to the HGA anomaly that occurred earlier.

The crew gave a quick summary of their C&W indications, and several of the Reaction Control System (RCS) flags associated with the helium and propellant isolation valves indicated closed. EECOM, at 55+58, indicated the crew was apparently attempting to reconfigure the fuel cells. At 55+59, EECOM had enough confidence in the TM to give a quick status: "We got Main A volts, no Main B volts. Attempt to connect fuel cell #1 to Main A, fuel cell #3 to Main B." This was attempted by the crew with no success and they reported that the fuel cell (FC) #1 and #3 talkbacks were grey (normal), but there were no reactant flows.

Prior to the anomaly, Main bus B was configured to drive inverter 2 and power AC bus 2. When the main bus B was lost, the AC bus 2 was lost. The GNC had monitored a decay in SMRCS quad D manifold pressures, and believed that the quad helium isolation valve was closed. The crew was requested to reopen the D He isolation valve.

INCO came back shortly after GNC and identified that the HGA switched beam width at 55+55+04, and I believed that the HGA could have been the cause; due to concern on switching into a shorted system and my concern on the instrumentation reliability, I became quite cautious on further configuration changes.

The main bus A seemed to be holding up although the voltage was below the undervolt warning light. The EECOM recommended attempting to configure FC #1/main bus B, FC #3/main bus A, which would bring a different set of overload and reverse current sensors and motor switches into action. However, I decided not to take that course until I had a better feel for the problem.

The crew then provided us several readouts at our request:

FC #1 N_2=0 psi

FC #2 0_2=13 psi

The telemetry on main bus A current indicated 53 amps which was about normal, but the max that the FC can sustain. We were discussing putting a battery on main bus A at about the same time the crew brought battery A onto main bus A.

Throughout all of the above, the spacecraft was relatively stable in attitude due to the crew exercising corrective attitude control, but now it was starting to drift and we started omni switching. Fortunately, we were able to obtain good High Bit Rate data from the 210-foot MSFN site at Goldstone. The Guidance Officer noted that the spacecraft was moving in attitude and this was confirmed by GNC when he confirmed usage of about 25# of SMRCS fuel. I then became concerned that we had an SMRCS problem that may have precipitated the electrical problem. The GNC was requested to come up with a minimum RCS fuel usage configuration.

NOTE: Somewhere along here, I requested Glynn Lunney to advise center management that we had a major systems problem.

The TELMU advised that LM heater current had become static; I was not concerned on this item and advised him to come back later on.

GNC shortly thereafter advised me that the crew had turned all RCS thrusters off. By this time, the crew had given us the requested FC N_2 and O_2 readouts; and after discussion with EECOM, he recommended that fuel cell #1 should be open-circuited. This recommendation was taken by the crew at about 56+08--about 13 minutes after the initial problem.

The crew advised that the cryo O_2 tank #2 quantity read zero. This was the quantity transducer that had been lost previously, and was of no particular concern since it could also be related to the AC 2 loss. (AC 2 powers the instrumentation.)

At 56+14, the crew reported that they had looked out of the hatch window and they were venting something. All positions were requested to check their systems for any venting.

I then requested EECOM to call in their backup people, and identified the possibility of going to the LM as a lifeboat.

NOTE: This is the first time that I considered that we were probably in a survival situation, and I started moving in the direction of safing the CSM while trying to maintain enough main bus A power to allow a controlled CSM powerdown.

At 56+15, the GNC had an RCS configuration to move quad C to main A, and place B3 and B4 on main A also. At the same time, we were drifting close to gimbal lock.

The crew performed the RCS configuration as requested and advised they were seeing the vent through window #1.

An emergency powerdown was initiated at EECOM request at 56+15 per Crew Emergency checklist, page E 1-5. This would make an initial power reduction of 10 A from main bus A. Shortly thereafter, the GNC suggested we might attempt establishing the PTC before we powered down further since the sun was approximately normal to quad A. This recommendation was discussed, and due to the venting and the fact I didn't think we had adequate control or time, this recommendation was not accepted.

The crew continued the power down and at 56+22 had reduced the main bus A power to 41 amps. Subsequently, they advised that the venting was giving them rates in -pitch and -roll, and they were using DIRECT SMRCS to counteract the rates.

At about 56+25, EECOM requested that we power up the AC 2 bus in order for him to look at 0_2 tank #2 telemetry. He also expressed the feeling that we had lost 2 fuel cells and that we didn't have an instrumentation problem. As a result, inverter 1 was configured to supply power to both AC busses. During the emergency power down, the crew advised that per the checklist, they had turned FC #2 pump off, and asked us if we wanted it back on. We gave them an affirmative reply and the pump was placed on AC bus 1.

At around 56+27, the crew advised they would leave the probe and drogue out until we gave them an O.K. to install it, and FIDO reported that they had seen venting in their tracking data. By 56+25, I had requested the Computer Supervisor to bring up the Dynamic Standby Computer, and standby for telemetry delogs. The network was also brought up to maximum status with dual communication processors and activation of the Parkes 210-foot site. (This was accomplished within 24 hours and excellent support continued until splash.) The GNC was noting sustained firing from SMRCS C3 thrusters to counteract the -pitch and -roll rates from the venting.

The crew requested us to verify that there was not some spurious RCS jet firings. The SMRCS was reconfigured per MCC request to place A3 on main bus A.

At 56+31, EECOM, after reviewing the data, identified that 0_2 tank 1 pressure was at 318 psi and decaying, and that he wanted to power down further prior to bringing the cryo heaters on. The crew powered Body Mounted Attitude Gyro (BMAG) 2 to OFF, lights to minimum, (still per Crew Emergency Checklist--additional items powered down as required); and at MCC request, open-circuited fuel cell #3.

At 56+33, we had used about 70# of SMRCS fuel; the usage was tapering off, and we recommended turning quad B off, and quad D to main bus A. This would better balance the quads and eliminate concern that quad B was causing the attitude problem.

Between 56+34 and 56+35, EECOM recommended removing battery A from the main bus A, and also isolating the surge tank to preserve the entry oxygen supply. At 56+36, the battery was off-line, and the main bus A could sustain the 5A load increase from the 0_2 tank #1 heater. The current apparently increased at 56+38 indicating the crew placed the heater ON. Subsequently, EECOM recommended isolating the repress pack. I asked the AFD to get one of his backroom personnel to keep a coherent spacecraft configuration listing as we passed it up to the crew. Similarly, 24-hour LM Flight Controller manning was initiated.

By 56+40, we had seen no increase in 0_2 tank pressure and the crew was requested to turn the tank 1 cryo fans to ON and check the cryo circuit breakers on Panel 226. The fans did not arrest the 0_2 pressure decrease. Both the GNC and crew identified that the vehicle had stabilized considerably, and the venting had essentially stopped. The EECOM advised at 56+41 that he did not think he could save the fuel cell #2, and that we should consider using the LM. Subsequently, I requested the LM personnel to start establishing a minimum power profile to get home on.

At 56+45, at G. Lunney's suggestion, we requested the crew to survey the spacecraft displays and controls and give us the readouts. The EECOM advised me that we had about 2 hours remaining on the fuel cell prior to depletion of the cryo 0_2 tank #1. At 56+46, BMAG 1 was turned OFF.

At this time the spacecraft was on a non-free-return trajectory with a 62 n.m. pericynthion. The crew had an abort pad onboard which required an SPS burn of 6079 fps at 60+00 to land in the Pacific Ocean at 118 hours.

At 56+48, the Flight Dynamics team was advised to initiate all of the return-to-earth planning based on going around the moon, and assuming use of the LM descent engine and LM RCS, and that we would not use the SPS except as a last ditch effort.

Shift handover to the Black Team occurred at 57+05. The White Team moved to room 210 of the MCC to review the telemetry delogs and propose a LM power profile.

Although there was some possibility that the problem was being magnified by a loss or shift of instrumentation due to an electrical problem, it rapidly became evident that the following situation existed.

1. A loud bang was reported at the time of the main bus B undervolt and observed venting from the SM was causing vehicle rates.

2. 0_2 tank #2 pressure had gone to zero and was considered a confirmed failure. 0_2 tank #1 was decreasing in pressure.

3. Fuel cell #1 and #3 were not supplying any current and had been open-circuited.

4. Main bus B and AC bus 2 were essentially zero (both fed by fuel cell #3). Although AC bus 2 had been repowered by main A, as noted above with normal operation.

5. Fuel cell #1 reference N_2 supply was essentially zero, although other pressures looked all right.

6. Considerable reconfiguring had been performed to get the thrusters on main bus A, and the propellant isolation valves in quad C were indicating closed (similar to previous flights at pyro separation times). They could not be reopened without main bus B power.

7. The surge tank was isolated and the repress pack was not yet confirmed to be isolated.

With the vehicle rates essentially under control and a reasonable RCS configuration, our attention was focused on trying to save what we could of the CSM cryo-fuel cell capability. By this time, O_2 tank #1 was reading about 255 psi and it was apparent that whatever started the problem, was causing O_2 tank #1 to also lose pressure. The reactants to fuel cell #3 were closed about 57:06 to attempt to isolate a possibility of an O_2 leak within that cell. O_2 tank #1 continued to drop. At about 57+14, we recommended closing the reactant valves in fuel cell #1. Again the O_2 continued to decrease.

By 57+35, the CDR and LMP were making their entry into the LM. At this time we had one good fuel cell (#2) but the O_2 pressure was still dropping. The fans in O_2 tank #2 were turned on from 57+39 to 57+55 in the final hope that this would raise the pressure; however, no change was seen. Initial activation of the LM was designed to get the Environmental

Control System, batteries, and communication/instrumentation system configured for use. The initial LM signal was received at 57+57. Establishing LM communications was made somewhat more difficult due to the SIVB S-Band beacon being on the same frequency as the LM S-Band communications. However, contingency procedures had been developed by NETWORK and INCO to drive the SIVB slightly off frequency while locking up the LM carrier. These procedures were utilized with minor modifications and all communications functions were satisfactory. At about this juncture, we decided to try to get a CM inertial alignment transferred to the LM Guidance System since some propulsion maneuver was going to be required. At 57:54, we had the CMP start powering as much down as he could while leaving up the CM Guidance System; e.g., FC pumps, etc. Fuel cell #2 was used to charge battery A for a short time prior to putting the battery on the main bus. Because of the decreasing O_2, we were watching to see a degradation in fuel cell #2 in order to know when to put a CSM battery on. We intended to stay up in the CSM until a LM Guidance System alignment was made;and once on battery A (58+04), we wanted to minimize the number of amp hours withdrawn from it since we did not know if we could charge it from the LM umbilical because we were not certain of Main Bus B. During the period of transferring the alignment, we made what I consider our one error in this time sequence. For a few minutes, we had an airborne configuration with no attitude control system on. This was quickly corrected as soon as recognized and power was turned off the CSM busses at 58+40 with the O_2 tank #2 pressure essentially gone and fuel cell #2 gone (about 20 amp hours were used from battery A before the CSM was completely powered down).

The ascent O_2 tank #2 valve had a known leak and by 58+52 the higher pressure of the descent O_2 tank had raised the pressure in ascent O_2 tank 2 to the point at which it was felt necessary to use some O_2 to reduce the pressure. Consequently this tank was used until 59+59 after which the descent O_2 tank was again selected. This same procedure was used again from 63+52 to 65+20.

At 58+54, the pilots reported a lot of particles and no ability to recognize any constellations for an alignment, which strengthened our resolve to save the reference for the present until the maneuver plan and consumable picture became more clear. At about this juncture, we had time to confer with the personnel surveying the return-to-earth options. It was obvious that we were committed to going around the moon rather than performing a direct abort because the large ΔV could have been supplied by the SPS only if the LM were jettisoned, but that was out of the question. Now our attention, in the period between 59 and 60 hours, was focused on the consumables needed for such a return which involved a total trip time of approximately 152 hours. At about 59+50, the LM water was the critical item. The initial water usage rate with the LM Primary Guidance and Navigation System (PGNS) up would have resulted in H_2O depletion in 34 hours; i.e., at 94:00. Although this high usage rate of H_2O was to some degree charged to the initial load of cooling the entire loop down (including the fluid), it was severe enough to force us to entertain how to keep an alignment up with the LM Abort Guidance System (AGS) while powering the PGNS down until it was needed again. The power was projected to last 67 hours; i.e., 127+00 GET, at the current rate of 35 amps.

At 59+41, the crew suggested rigging the backup urine dump on the side hatch to save urine heater power on the primary system. This suggestion was approved by MCC at this time and again at 61+40 when it was mentioned again. These exchanges led the MCC into thinking that the crew was dumping urine as required (although the postflight debriefing showed this to be incorrect).

In the time period from about 60+00 to 60+15, we had time to consider our maneuver options which were essentially the following two:

1. Do a midcourse correction quickly to reestablish free return and then power down.

2. Power down immediately and plan on powering up for a maneuver about 2 hours after passing pericynthion (PC+2).

It was quickly determined to take the option to get on the free return as soon as practical as long as all systems were up. If the consumable situation did not improve, the trajectory would already be established toward a safe Indian Ocean landing at 152. At 60+23, we suggested a time of execution for the midcourse burn of 61 hours, which the crew suggested moving to 61+30 to assure proper checklist procedures. In about the remaining hour, the flight crew called out each appropriate sequence of the 2-hour LM Activation Checklist as the vehicle was prepared for the 40 fps MCC with the descent engine. All burn parameters were nominal and the postburn doppler tracking confirmed the maneuver. The doppler confirmation was also important in that it verified the alignment transferred from the CSM.

Midcourse Correction to PC+2:

Once the burn was performed, an attempt was made to set up a PTC, with the usual difficulty with a new vehicle/procedure as with the LM/CSM docked configuration. At 63+05, MCC passed a preliminary pad for a PC+2 hour maneuver of about 890 fps designed to land at the MPL at 142+40 (compared to the free return coast landing time of 152).

By 63+20, the current output was 27 amps, and the usage rates had settled down to something more like nominal for the power load. The projected profiles were coming more in line with keeping the PNGS up to PC+2 time (79+30) and then powering down to a life support/comm mode after the maneuver. Midcourse maneuvers were budgeted at 104 and 140.

Projected ahead at an average 25.6 amps:

EPS would last to 142+00 GET

H_2O would last to 138+30 GET

O_2 would last to 233+00 GET

Powering to 15.4 amps after 80 hours:

EPS would last to 163+00 GET

H_2O would last to 155+00 GET

This picture gradually began to improve. At about 63+32, the consumable of concern was the CO_2 removal, and people were already working on the problem of how to use the CSM cannisters.

At 63+47, we began to review the requirement for the CM Guidance System heaters. The first recommendation was to try to turn the heaters back on using LM power. However, we were reluctant to try to establish the required electrical configuration until all three pilots were up because of the required switch procedures; although this was a configuration which we felt we would definitely want to establish at some time for other purposes; e.g., charging battery A. Subsequent discussion of the heaters indicated that it would be satisfactory to leave these heaters OFF until power up for entry.

By 63+50, the dynamic PTC was given up because of the difficulty in setting it up,and a LM yaw schedule of attitude holds 90° apart every 1 hour was instituted. Among other items, the power amplifier was taken offline to save the 2.5 amps; as a result the comm had a lot of background noise, but was readable.

As the PTC attitude hold and vehicle systems stabilized, we began looking ahead to the darkness opportunities for a Guidance System alignment (P-52) while in the moon shadow and/or an earth-sun P-52 technique for either checking the present alignment or realigning for the burn. Consideration was also being given to the minimum power mode for P-52 using the LM Alignment Optical Telescope (AOT) which required moving the rendezvous radar antenna, etc. Also the CSM optics were being considered as another way to check the LM alignment.

For the crewmen sleeping in the CM, MCC advised the crew to take the long CDR suit hose and put it in the tunnel to force circulation down into the CM. The crew reported extending the hose with the vacuum hose to aid in this. The MCC passed a procedure for using a small amount of surge tank O_2 to obtain CM potable water for drinking.

SPAN was already considering the pros and cons of jettisoning the service module and burning most of the descent fuel to get an earlier landing time of 118+00. The primary concern was the cold environment to which the heat shield and CMRCS would be exposed and the fairly small amount of descent fuel that would be left. The White Team's recommendation based on their understanding of the current state of the relative advantages of dropping or keeping the Service Module was to keep the Service Module. There was no real urgency to decide that issue at that particular time and, along with the descent propellant budgets, this subject was highlighted for consideration by the next shift.

During the period after the burn, MCC recommended keeping one crewman on duty at all times. This was done except for the times of maneuvering and the crew took short rest periods throughout the rest of the flight. The LMP took a rest period from about 63+00 to about 69+00, with the CDR and CMP scheduled for a rest period when the LMP awoke.

By 67 hours, the LM spacecraft lifetime projections were reasonable and were based on the following plan.

Stay powered up until PC+2 at 79+30 GET.

Then power down to about 15 to 18 amps.

Two hours of power up time for each MCC (at 104+00 and 140+00 GET).

The following issues were identified as open.

1. Selection of return time option with question of jettisoning the SM.

2. Find a suitable method for checking or realigning prior to the burn.

3. The CSM/LM umbilical procedure had to be finalized and available, but should be implemented with all 3 crewmen awake.

4. Consumables studies need to be refined.

5. Need a procedure for CO_2 removal with CSM cannisters.

6. Consider comm duty cycle for power conservation.

7. Need procedure for moving rendezvous radar out for using AOT.

8. Possibility of transferring PLSS H_2O to LM ascent H_2O tanks.

The Gold Team came on duty at 67+00 and in all respects, the performance of the flight control team during this period was exemplary. At the start of the shift, the FAO was instructed to begin working on a flight plan assuming a descent engine burn at PC+2 hours with a landing time in the Pacific at 142 hours. At the time, this plan was tentative but appeared to be the strongest option. At 68+00 hours, TELMU was instructed to get the post-PC+2 LM powerdown checklist in shape. At 68+18 FIDO reported that the point of closest approach to the moon was holding steady at 135 n.m. SPAN reported that the procedure to use CSM LiOH cannisters in the LM was in preliminary form and being reviewed by all areas. CONTROL reported at 68+40 that he had a procedure available for redesignating the rendezvous radar antenna out of the way of the Alignment Optical Telescope (AOT) for use in making an alignment. At 68+45, the crew was told to remove the used CM LiOH cannisters from the loop so that they would not swell up and get stuck. The crew acknowledge this request, but it was not clear when this procedure was carried out. At 69+30, a meeting with all the managers was convened in order to finalize the overall mission plan. The results of this meeting were as follows.

1. The PC+2 maneuver would be performed with the descent engine for approximately 850 fps, giving us a Pacific Ocean landing at 142+00 GET.

2. An AOT check of the sun would be performed at 74+00 to check the present alignment of the LM platform. If the AOT check was within $\pm 1^{\circ}$, the present alignment would be acceptable for the PC+2 burn. If the AOT check failed, then a sun-earth platform alignment would be performed prior to going behind the moon; and an AOT star check would be performed while in darkness.

Other options available at this point were as follows:

1. Perform a PC+2 hour abort burn with the Service Module Propulsion System for a landing at 118+00 in the Pacific Ocean. This option was rejected unanamiously as being too risky since no data was available as to the structural integrity of the Service Module. This option was put into the category of "last ditch".

2. Jettison the Service Module and perform a descent engine PC+2 burn to provide a landing at 118+00 in the Pacific Ocean. This plan was rejected because it would require burning the descent engine very close to depletion, would require uncovering the heat shield of the CM for many hours and thereby reaching the hazy area of thermal limits, and because of the uncertain alignment of the LM platform could require a very large midcourse correction to get back into the corridor.

3. Do nothing and perform a midcourse correction sometime after pericynthion in order to get back on the free return corridor for a landing at 153+00 in the Indian Ocean. This plan was unacceptable since such a trip time would push the LM consumables very close to depletion. In fact, it was not clear at this point that there was enough water in the LM to fly that long. This option would also require landing in an area with a relatively poor recovery posture. (Although the Recovery Coordinator and DOD had established that there were 4 U.S. destroyers in the area and retrieval equipment could be flow in before splash.)

4. A final option was not discussed but was available, and the crew was already updated (at 59+00) with a pad to make the burn if required. This option was a DPS burn to very near depletion with the SM still attached.

This option would provide a landing at 133+00 in the Atlantic Ocean. This plan had obvious drawbacks, but was given to the crew in the case of a loss of communications and consumables usage too high to stay on the free return.

The final overall plan was passed to the LMP at 70+53. He confirmed that he understood the plan and concurred and that he would brief the CDR when he woke up. At 71+42, RETRO reported that the latest tracking showed that at 90+00 a 4 fps maneuver would place the spacecraft in the center of the corridor. The crew was updated with the detailed AOT sun check procedure at 72+30. The rendezvous radar (RR) redesignate procedure was also read up at this time in order to move the RR antenna out of the way of the AOT detent required for the sun check. At 73+12, the RR was redesignated and at approximately 73+50 the AOT sun check was made with excellent results. The check indicated a platform misalignment of approximately $1/2^{\circ}$. With this result, a subsequent sun-earth alignment was not required and preparation for the PC+2 burn were begun.

The shift handover to the White Team was completed at 74+00 GET.

The major flight control activity on this shift pertained to completion of the PC+2 maneuver. The ground rules established for this maneuver were:

1. If no maneuver, stay on free return trajectory with an Indian Ocean landing at 152:02 GET after a small MCC-5 of approximately 4 fps at approximately 93+00 GET.

2. No PC+2 maneuver trims were required.

3. If a shutdown occurred during the PC+2 maneuver, a subsequent MCC would be required with earliest possible execution time of PC+4.

4. If the maneuver had to be delayed, a PC+4 maneuver would be performed at a ΔV cost of 24 fps with a Pacific Ocean landing at 142:46:30 GET.

At 75+35 GET, a PC+2 Maneuver Pad was updated, and the State Vector and Target Load were uplinked.

At 76+00 GET, a MCC Mission Rules Review was conducted for the PC+2 maneuver.

1. The shutdown criteria for the maneuver were:

a. Thrust chamber pressure = 85 psi on the ground or 77% thrust onboard.

b. Engine inlet pressure = 150 psi on the ground or 160 psi onboard.

c. ΔP fuel/oxidizer greater than 25 psi (based on a ground call-out).

d. Attitude rate limit, except start transients, 10°/sec and attitude error limit 10°.

e. An engine gimbal light.

f. Inertial reference system warning light plus computer program alarm.

g. A LM guidance computer warning light or control electronic systems DC power failure light.

h. An inverter light after switching inverters.

2. If an early shutdown occurred, for reasons other than above, the LM descent engine was to be restarted by ullaging, depressing the engine start pushbutton and turning on the descent engine command override switch.

At 76+16, PTC was terminated and an AOT star check was satisfactorily completed indicating the platform was still reasonably aligned.

At 76+49, the crew started V49 maneuver to burn attitude and an AOT start check at burn attitude was accomplished satisfactorily.

Moon occultation caused LM loss of signal from 77+09 to 77+34.

At 77:56:27, the Saturn SIVB impacted on the moon and was recorded by ALSEP I instruments.

At 77+59, the final PC+2 Maneuver Pads were passed to the crew.

At 78+12, LM power up was begun, and it was determined that to maintain a burn configuration in the LM, it would take approximately 38 to 40 amps. Also, the crew was advised that PC+2 maneuver ignition time was not time critical.

Previous planning for PTC was based on the free drift mode to conserve water, RCS propellants, and power. SPAN did not concur that this was an acceptable PTC mode and further planning on a free drift mode of PTC ceased at 78+49.

PC+2 ignition occurred at 79:27:38.30 and the burn was nominal. The PGNS residuals were:

R_1	+00010
R_2	+00003
R_3	+00000

Transearth Coast:

At 79+34, LM power down was initiated except those functions necessary for PTC. Also a report was received on the radiation environment. The solar flare activity was reported to be relatively low and no problems were anticipated from a radiation standpoint.

At 79+52, CAPCOM read up a detailed procedure for establishing PTC in an attitude of LM roll 0°, pitch 90°. This attitude was held until rates nulled to .1 degrees/sec in all axes at which time a yaw maneuver was initiated. While maneuvering to establish PTC, the crew reported sighting several pieces of material apparently from the SM. Considerable time and effort was expended in establishing PTC due to cross coupling between the roll and yaw axes. However, by 81+17, rates were low enough to complete the PTC procedure.

Crew changeover to the Maroon Team was completed by 82+00, and the LM was powered down to about 12 amps at 82+37. The consumables status (except for LiOH) for the first time was clearly compatible with the landing time including reasonable margins. The consumable status at 84+00 was:

	Water	0_2	Batteries
Total Usable	205.8#	43.25	1454 amp hours
Rate	3.0#/hr	.25#/hr	12.1 amp
GET Depletion at Present Rate	152+36	257+00	204+00

Three hours after the PC+2 maneuver the crew still saw loose metal and particles coming out of SM area. Camera settings to take pictures of these items were passed up, but few opportunities were expected since it would have meant waking up the CDR and CMP who were asleep after a long day.

The SURGEON recommended extending the CO_2 partial pressure limit from 7.6 mm to 15.0 mm. This was accepted and it was decided to let the LM primary cannister stay on until this level after which we would start using the LM secondary cannister. The improvised CM cannisters had been ground tested and would then be used to verify the configuration.

The FAO was able to keep a rough check of the PTC attitudes by plotting the earth-moon motions through the Landing Position Display.

However, it was planned to accept whatever PTC motions ensued unless the comm loss became intolerable.

A maneuver pad was passed up to the crew for execution at Entry Interface (EI)-8hours for a loss of communication case. The time was picked to allow as much time as practical for reestablishing comm before the maneuver. The MCC-5 alignment procedure (in general terms) was also passed up for the first time. This procedure was about the same as that proposed for Apollo 8 backup and Lovell remembered the general philosophy.

By 87 hours, the following emergency procedures were available, although most of them were held in the MCC until needed or until a suitable time was available for the read-up. (This usually depended on which crewman was awake).

1. Water transfer from CSM to PLSS to ascent tank.
2. Main B power-up and integrity check.
3. Entry power-up.
4. CM entry battery charging.
5. CM LiOH cannister fix.

The Black Team came on duty at 90+00 with the CMP and LMP in rest period.

The consumable picture remained in good shape and the LM current was down to about 11-12 amps.

All water sources for LM cooling were being researched and a CSM checklist (launch) was in work to assure that all components were off the main busses and to provide a starting point for the entry checklist.

The MCC-5 time was being changed to 104+00 vice an earlier selected 118+00 time to allow more tracking after the burn.

At 90+09, MCC started reading up the CSM cannister fix to the CMP and LMP, now awake. Several personnel were going to the checklist meetings for the MCC-5 burn and PTC procedures. I advised them of our interest in getting these checklists early and that the burn checklist should be read to the crew at least 5 hours before the scheduled MCC-5 which entailed the new earth terminator alignment technique. At 91+10, it was suggested that we arrange to try the PLSS water feed early to avoid getting into this new procedure at the end of the flight where things would be busy. This was a good idea, but the procedure called for emptying both ascent H_2O tanks first (would take 30 hours). Also, there was a concern that the descent stage was getting cold and the descent water might freeze by 140+00 GET. This later turned out to be not so, but there was enough justification based on present consumption to decide not to try the PLSS water transfer which really was not guaranteed to work anyway (maybe not enough ΔP to force the transfer).

At 91+20, EECOM advised that North American Rockwell would have a recommendation in two hours on whether to close the motor switches which tie the battery busses to the main bus. The CM electrical system would then be controlled with the circuit breakers. Their concern was that the motor switches might not work at low CM temperatures. Without any evidence as to the "realness" of this concern, I personally considered this to be a high priority--very important subject. Expecially since it could be done with no attendant disadvantage except the time to do it. I also felt that this was more important at this time than a main bus B check. It was easy to check both busses when closing the motor switches, but we did not have any real evidence of a main bus B problem, per se.

At 91+53, MCC started to read up the modified launch checklist. At about this time, RETRO discussed his options for moving the target to avoid any potential weather problem and we tried to reschedule the reconnaissance airplanes to get another report by GET 98+00, but their schedule did not permit it.

At 92+07, control reported that the SHe burst disk would probably relieve somewhere around 107+00. This was of interest in scheduling MCC-5 because it was assumed that this event would disrupt any established PTC.

At 92+46, the CMP finished copying the modified launch checklists and went over to the CM to establish the configuration. By this time 92+52, both EECOM and SPAN reported that they wanted to activate the motor switches. Again, I personally was anxious to do this to assure CM power for entry. At 93+00, the LMP asked about storing urine in the condensate containers. We should have recognized and reopened the question of dumping urine at this point, but did not. At 93+28, the CO_2 partial pressure was about 7.6 mm,and MCC advised the LMP to configure the suit loop to use the CSM cannisters. The hoases were extended--LMP hose to front of LM, CDR hose to tunnel, and CO_2 was scrubbed down by 94+00. The LiOH considerations immediately disappeared except for later discussions on when to change cannisters.

At about 93+50, we had another conversation about the landing weather. Based on the fact that there was no real storm organization, no real consistency in winds, and the location was forecast to be 5^{O} (300 miles) away, we concluded that no weather avoidance maneuver was required.

At 94+30, MCC advised crew of 2 more CB's to be opened for the modified checklist and the procedure for closing the motor switches and checking both busses. The CMP reported one of his own deviations to the configuration as read and that was leaving the H_2O accumulator valve on Panel 382 in the OFF position; MCC concurred.

The CMP reported 32.3 V on main A, 37.0 on B, and zero battery currents. At 94+19, the voltages were consistent with the existing state of charge on the batteries and the zero current verified the proper CSM switch configuration. The circuit breakers were pulled and the motor switches left closed.

At 94+36, MCC read up the configuration necessary to readout the DPS propellant tanks because of the concern for a cooling descent stage.

TELMU reported a change in O_2 flow rate up to 6.0#/hr at 94+44 and an apparent glitch in the demand regulator A. The crew reported no change of that switch and cycled it closed and back to cabin at MCC request. The O_2 flow rate subsequently remained at the previous value of .2 to .3#/hr.

The Recovery Coordinator and the Department of Defense representatives made a survey of additional forces available in the Pacific landing area and at 95+00 had decided to implement a plan augmenting the premission forces. This new landing area array included another ship which was positioned at the landing area for the backup entry monitoring systems and increased the HC-130H aircraft support from 2 aircraft to 4.

Starting at about 95+00 GET, the MOCR operators summarized their considerations on the MCC-5 time:

FIDO and RETRO felt they had as good a vector at 104+00 as at 118+00 and wanted to execute MCC-5 as early as practical and maximize the tracking after the MCC.

CONTROL felt the SHe burst disk might relieve anywhere from 105+00 to 108+00 and probably should not effect the PTC.

Slightly after 96+00 GET, it was decided to try to schedule the MCC-5 in the early range of times under consideration and near the SHe burst disk time. Our thought was that the vent might upset the PTC and it would be preferable to have both the MCC-5 and the vent over while the LM Abort Guidance System control system would still be up from its use for the MCC-5. We also wanted to minimize the Abort Guidance System powerup time because of the consumables.

At 95+03, the crew reported another good "jar" coming out of the other side of the SM down below window #5. At 95+12, MCC advised the crew of the expected SHe vent around 107+00 and read up the procedure for powering the CSM from the LM. This procedure was read up to have onboard for probable subsequent use and in case of loss of LM communications. The crew reported the PTC wobble was getting worse,but no corrective action was deemed necessary.

By 95+47, MCC read up procedures for using the condensate containers to store urine. By about 96+00 GET, it was evident that there was a strong interest in obtaining some CSM High Bit Rate telemetry for insight into the CSM thermal conditions. Twelve amps were expected to be required since there would be a MSFN station with a 210-foot dish available at 97+30.

A typical hourly summary is listed below.

<u>As of 96+00 GET</u>

	H_2O	Oxygen	Battery
Total Usable	173.4#	39.2#	1312AH
Present Rate	2.5#/hr	.25#/hr	11.8 amps
GET Depletion at Present Rate	165+12	252+00	207+00

Two MCC's would cost about 5 hours of both H_2O and battery power so that H_2O remained the critical consumable with a predicted depletion at about 160+00 GET.

Again in the timeframe around 96+00 to 96+30, I asked TELMU if there were any single point failures associated with the LM to CSM power procedure which would leave the descent batteries deadfaced and unavailable. I asked this to assure that any changes we made in this all important area were well considered. As a matter of fact, I asked three different TELMU's this question and got an unquestioning affirmative. Therefore, I became very reluctant to move into this configuration at this time, and said so several times on the loop. (It was later determined on the next shift that the procedure could be modified such that the worst result of a single point failure would be that ascent battery #6 could not be removed from the bus.)

At about 97+00, EECOM reported that calculations showed that the CSM H_2 tanks would start venting about now and that was possibly what the crew reported earlier. He also reported that, based on 6#/man day, the potable water in the CSM was depleted. These facts were reported to the crew as they reported particles now from the descent stage although we could see nothing to correlate with it on telemetry.

At 97+24, the crew reported that the CSM optics were clear and usable. Within MCC, we discussed the other potable water sources--(15# in CSM survival kit, 15# in both PLSS units, 1.5# in Liquid Cooled Garment [LCG]), and people were working on procedures for drinking the PLSS water. This water was chemically pure, but not sterile; however, the surgeon was prepared to allow the crew to drink it, if necessary. At 98+07, CONTROL reported that the descent stage was not cooling down as quickly as had been postulated.

In handing over to the next shift, the checklists were promised for readup to the crew by 98+40.

The Gold Team came on duty at 98+00 with the major planning for MCC-5 finished. The burn was scheduled for 105+30 and was approximately 7.0 fps. It was also planned to power up the CSM telemetry for a short burst of data to analyze the temperature in the CSM. Another consideration to power up the LM for MCC-5 was the SHe pressure in the descent stage. The trend of the SHe pressure rise rate was such that it appeared that the low range of the burst disc would be reached around 105+45. This was good from the standpoint that we would already be powered up for MCC-5 and that the vent might take place while positive attitude control was available. This later proved not to be the case as the rise rate decreased, and the decision was made to go ahead and get MCC-5 behind us and let the SHe vent during PTC. At approximately 98+30, all crewmen were awake. The crew reported that the SM venting had ceased at 98+34. A readout of the CM repress pack at 98+48 was 820 psi. At 99+49, master alarm and battery malfunction on LM battery #2 was illuminated. The battery voltage and current were normal. TELMU suspected a battery overtemp and requested the crew to take battery #2 offline. At 100+00 the procedure for MCC-5 was read to the crew. It was a derivation of the 30 min Activation Checklist. At 100+16, TELMU stated that he was fairly sure that the battery malfunction was a sensor problem but that he wanted to leave the battery off for approximately one hour. At the end of the 1-hour period the battery was again placed online and the battery malfunction and master alarm reappeared. Since a real overtemp condition would have cooled in this time, TELMU was convinced that the temperature sensor was failed closed. The battery was left online and continued to function normally for the remainder of the mission, although the alarm continued to reappear sporadically.

At 101+08, the CSM telemetry power up checklist was read up to the crew, and at 101+38 the CMP commenced the CSM power up. Approximately 10 minutes of data was collected and the CSM was again powered down. All voltages and pressures appeared to be in expected limits; and temperatures, in general, were warmer than expected. TELMU suggested at 103+52 to place the suit temperature rheostat to the full cold position. This decreased the flow of glycol to the suit heat exchanger. Normally this glycol is warm and heats the 0_2; since the LM was so cold, the glycol was actually cooling the oxygen coming out of the 0_2 tanks. Going to full cold decreased the flow of cold glycol to the heat exchanger and did increase the cabin temperature slightly. Although MCC-5 was scheduled to occur at 105+30, the crew was ahead of the timeline;and since the execution time was not critical, the crew was given the go-ahead to perform the burn early. The burn was complete at approximately 105+18.

The Maroon Team came on duty at 106+00 and PTC was established in a gross fashion using the LM Abort Guidance System. The communications were satisfactory and any motion at all satisfied the thermal experts.

At 107+00 hours, the spacecraft was within ascent stage capability (assuming using PLSS 0_2 and water to supplement).

The SHe was predicted to burst at times between 107 hours and 110 hours. This became a concern in that it might exceed the maximum gauge reading and visibility into the pressure status would be lost. Procedures for venting the SHe were being developed when the disc ruptured at 1937 psi

(108+54 GET). This caused no problem other than reversing the PTC roll direction and inparting a slight pitch motion. Since the motions were not critical from a thermal standpoint, they were allowed to continue.

The roll rate went up from 18 min/rev to 2 min/rev which caused frequent antenna switching. The crew was given an option to not switch and allow data dropout, but they apparently chose to continue switching.

At 112+11, the battery A charge was initiated with all currents and voltages as expected. The CSM meter was used to monitor the charge status.

The Black Team came on shift at 113+00 with the tracking data showing an entry flight path angle (γ) of -6.25° (the corridor was -5.25° to -7.4° with -6.5° desired).

The LMP and CMP were resting and the CDR was on watch duty, soon scheduled for a rest.

At 113+15, MCC advised the crew of the need to tape another CSM LiOH cannister in front of the ones already in use. Both were rigged by 113+56 and the CDR was off duty for a rest. Voltage and current readouts on the battery A charge were requested every 30 minutes and the crew provided those from the CM guages. The consumable picture had long since stabilized and, even with the additional 8 amps for battery charging, the situation was good.

As of GET 114+00

	H_2O	Oxygen	Batteries
Total Usable	124#	34.72#	1084.7 AH
Percent	2.5#/hr	0.26#/hr	19.2 amps
GET Depletion at Present Rate	163+00	247+00	169+00

This was a typical hourly update and subsequent ones stayed very close to that throughout the mission.

At 114+30, the FAO reported that the stowage plan was to proceed from the present configuration and minimize required changes. Another team of people was working the entry checklist problem and the simulator runs.

At 115+00, there was some discussion about the lack of urine dumps. I assumed that some previous discussion had addressed not using the CM side hatch or that it had frozen. In retrospect, this was not correct and we should have advised the crew to use the urine dump.

At 115+40, the CDR relieved the watch and had no questions. The BAT MAL on descent battery #2 began blinking, and we advised the CDR. At 117+00, MCC requested another readout on the descent propellant tank temps, and CONTROL reported that no more were needed since the descent stage was thermally in good shape. MCC also advised the CDR of the upcoming quantity lite on descent water at 16% and recommended he reset it. At 117+55, CDR reported it was too cold to sleep in the CM. He later reported that he and the LMP were wearing their lunar boots and that he, the CDR, had on a second pair of underwear. At 118+38, TELMU noted a change in the suit relief valve position. The CDR put it back in CLOSE and reported that the hoses apparently bumped it.

By this time, it was clear that the ASPO/thermal team wanted some more CSM High Bit Rate telemetry and that was projected when the MSFN 210-foot dish coverage started sometime after 121+40.

The Gold Team came on duty at 120+00, and the crew was briefed on the overall plan for the entry power-up sequence at 120+22. After a general discussion of the entry sequence, the crew added that they would prefer to fly the entry unsuited, which was concurred with by the ground.

At 121+51, the changes to the LM and CSM stowage lists for jettison and entry were updated to the crew. The CMP powered up the CSM telemetry at 123+06 for approximately 10 minutes in order to give the ground another "snapshot" of the CSM data. The CSM continued to look as expected with temperatures showing a slight drop from the previous data. At 125+00 the crew was advised of the camera plan for obtaining pictures of the SM after jettison. The CMP reported that the CSM potable water tank was empty at 125+19. At 125+34, the readup of the CSM powerup and entry checklist was initiated. The readup was temporarily delayed by reproduction problems, and was reinitiated at 126+15. During the checklist delay, battery A reached full charge (about 20 amp hours had been restored), and it was decided to go ahead and charge battery B back to full charge. At 126+03, battery B charge was initiated. The CMP reported that the windows in the CM were coated with water and that he would try to clear them the best he could prior to SM photography. At the end of the shift, latest tracking indicated an entry flight path angle of -6.05, requiring a MCC-7 of 2.7 fps.

The Maroon Team came on duty at 127+00 and read up LM procedures for power-up and entry.

At 128+05, the LM was switched to ascent water tanks which fed properly and the crew was told that they could drink from the descent tank.

At 130+00, the stowage was reported to be satisfactory with a resulting L/D of .29 (.31 was nominal). It was decided to add CM S-Band power amp to entry list (post-blackout) to allow recovery HC-130's to track at altitude (Cost -.3ah.).

It became obvious the crew was unable to rest due to the cold temperatures and a decision was made to power up the LM early (133+24). At the time, the battery and water margin showed a 6.9 hour pad at a power level of 40.7 amps. The possibility of also using LM window heaters was discussed, but the crew reported heavy frost on the panes and window heaters were not used due to the possibility of cracking.

After LM power-up there was time to accomplish a LM Primary Guidance and Navigation System (PGNS) alignment using the sun-moon technique which was done with little difficulty.

The White Team came on at 135+03 to conduct the entry. The crew was in the process of reading out the V06N93 torquing angles at the completion of their alignment. The MCC-7 maneuver was computed to occur at 137+39+48 GET (EI-5 hrs), and the ΔV was -3.35 fps. The LM systems looked good, the LM Guidance Computer (LGC) erasable memory was verified and the entry, SM sep and LM jett data was voiced to the crew.

At 136+12, the maneuver load was uplinked to the crew, and the DAP weights for the CSM and LM were loaded.

The crew initiated CM RCS preheat using LM umbilical power through CSM Main Bus B to heat Ring 2. CM battery C power was provided to Main Bus A to provide power to heat Ring 1 and to CM RCS instrumentation to monitor the preheat.

At about 136+45, we recommended to the crew that we would perform MCC-7 using the PGNS.

NOTE: This was a change in our overall strategy for the burn. We had intended to use the PGNS to provide a monitoring and backup attitude control capability. After looking at the system, there appeared to be no reason not to use the

PGNS for MCC-7. It would provide a slightly better maneuver execution capability. It should be noted that this maneuver was relatively insensitive, however.

The consumable status at this time was excellent.

LM H_2O	54.8# remaining 4#/hr usage 13.7 hrs remaining
LM Power	641 AH remaining 38 AH/hr usage 16.5 hrs remaining
RCS	37% usable remaining Predicted 25% remaining at LM jettison

The crew cycled through Program-30 and 41 in preparation for their burn. In maneuvering into burn attitude, they used PGNS AUTO, which appeared to have an unusually high duty cycle. We requested them to use PGNS MIN IMPULSE for maneuvers and PGNS AUTO only for the burn.

After the maneuver to burn attitude, we advised the crew to perform an Abort Guidance System (AGS) body axis align. At this time, the crew advised that the PGNS roll and yaw error needles did not null after completion of the maneuver. At Ignition - 15 min, after discussions with LM CONTROL and CAPCOM, I decided to return to the original plan and use the AGS for MCC-7.

NOTE: The prime reasons for returning to AGS was the unexplained problem with the PGNS error needles and the higher than expected PGNS RCS usage.

The crew selected AGS, accomplished an AGS to PGNS align, and accomplished the burn at 137+39+48, using the PGNS P-41 for monitoring.

After MCC-7, the spacecraft initiated the attitude maneuver to S/M separation attitude. At 137+57, the CM RCS was activated and a hot-fire test was accomplished on all thrusters on both rings.

S/M separation was accomplished at 138+02+00, using .5 fps with the +x thrusters followed by S/M separation; then .5 fps with the -x thrusters. The crew then initiated a pitch up maneuver to obtain photographs of the S/M.

The crew returned to the S/M separation attitude and remained there.

NOTE: The original alignment procedure was developed in case we could not see stars through the CSM optics. It required 2 LM maneuvers to place the CSM optics field of view on the moon and then the sun. I believed that this procedure would work; however, I believed that it was worthwhile to first accomplish a reverse docked coarse alignment, then attempt a CSM normal P-52. Additionally, the docked coarse alignment by itself would be adequate for entry.

At 138+00, the RCS usable remaining was down to 19% and we advised the crew to minimize further usage. It should be noted that there is a 13% unusable/uncertainty in our capability to gauge the RCS. The onboard quantities were reading about 32% at this time.

The CMC was powered up and placed to standby at 138+21. At this time we were still about 2 hours from powering up the Command Module. Some minor trouble shooting was accomplished to find a CM Main Bus A load of 2 amps that was not expected. The entry, weather, and recovery data was voiced to the crew.

At 139+15, LM battery 3 was removed from the line. Its current output was about 1 amp, indicating it was essentially depleted. Battery 4 was past its spec lifetime of 400 AH at 139+34 per our computations.

At 139+46, the coarse align gimbal angles, based on the SM jettison attitude were passed to thecrew.

LM umbilical power was removed at 140+10, and the CM power up for reentry was initiated. CM telemetry was activated at 140+24. Due to the spacecraft attitude, the voice and High Bit Rate telemetry data was very broken. Several configuration changes were made; however, we were unable to maintain High Bit Rate data. The Low Bit Rate data was selected to obtain a better signal margin, and at 140+30, ground command loading of the CMC was initiated. Five command loads were required to prepare the spacecraft for entry. These updates took longer than normal since we did not have High Bit Rate. The erasable memory was dumped, and fortunately the remote site copied one full iteration of the dump.

The crew completed the coarse alignment of the CM Guidance System and proceeded into the fine alignment which was complete at 140+55. At this time we cleared the spacecraft to move into the LM jettison attitude. The CSM GNC Controller identified that he was concerned with the injector temperatures on the -yaw thrusters on Rings 1 and 2 of the CM RCS. I decided not to take action on this request because we would be separating within 30 minutes, and because the crew had completed transfer to the CM.

NOTE: The LM was holding an attitude close to the CM gimbal lock attitude. I was concerned about any attitude perturbations that would cause the LM thrusters to start a high duty cycle

(LM -x impingement on the CSM). We should have examined the LM jettison attitude more closely to avoid being close to CSM gimbal lock.

At 141+06, the Retro Officer advised that the LM was not in the correct orientation for separation. The telemetry indicated that we were yawed 45° North instead of 45° South of plane. The X axis was properly aligned along the positivie radius vector. I was not concerned, because the separation was a minimum of 4,000 feet at entry interface and was probably going to be 8,000 feet or greater. Even though the initial lift would take the spacecraft North, subsequent modulating lift would be away from the LM orbit plane. Therefore, no attempt was made to change the attitude.

The tunnel was vented down to about 2.2 psi at 141+19 and pyro arm and jettison occurred at 141+30. The CM almost went into gimbal lock at LM jettison and the crew had to use DIRECT RCS to keep the CM under control.

The crew performed the sxt star and EMS checks at 141+40, and the entry pad was read to the crew. Tracking data indicated the reentry flight path angle had changed slightly to -6.2 degrees; however, we were still below the lift vector orientation line and we would not have to perturb the initial crew procedures; i.e., heads down for initiation of entry.

At 142+00, the final computer loads were transmitted to the spacecraft. The current state vector, Z pipa bias and a clock increment update were loaded, and the spacecraft then went to the moon check attitude. The Primary Glycol Evaporator was brought on line, the Entry Monitor System was initialized, and the crew went to their normal entry checklists at Entry Interface - 20 min when they selected Program 61 in the CMC.

All spacecraft systems were GO; the moon check was satisfactory, and the power profile was nominal at loss of signal at Honeysuckle MSFN station at 142+39.

Voice contact was obtained via the Apollo Range Instrumentation Aircraft at 142+45; drogue deploy was monitored at 8,000 feet, and main chutes were sighted via TV at 142+50.

Splashdown occurred at 142+54+47, the recovery proceeded very rapidly, and the crew was onboard the Iwo Jima at 143+39+00.

SECTION IV

ACRONYMS

ACRONYM LIST

AC	Alternating Current
AFD	Assistant Flight Director
AGS	Abort Guidance System
A/G	Air to Ground
AH	Ampere Hours
AMP	Ampere
AOT	Alignment Optical Telescope
ARIA	Apollo Range Instrumentation Aircraft
BSE	Booster Systems Engineer
CAPCOM	Capsule Communicator
CDR	Commander
CES	Control Electronics System
CM	Command Module
CMC	Command Module Computer
CMP	Command Module Pilot
CONTROL	Guidance, Control, and Propulsion Officer for the LM
CSM	Command and Service Module
DAP	Digital Auto Pilot
DC	Direct Current
DPS	Descent Propulsion System
DSC	Dynamic Standby Computer
EECOM	Electrical, Environmental, Sequential Systems Engineer for CSM
EDS	Emergency Detection System
EI	Entry Interface
EMS	Entry Monitoring System

FAO	Flight Activities Officer
FC	Fuel Cells
FD	Flight Director
FIDO	Flight Dynamics Officer
FPS	Feet Per Second
GET	Ground Elapsed Time
GNC	Guidance, Navigation, and Control Systems Engineer for the CSM
GUIDANCE	Guidance Officer (CSM and LM software)
H_2	Hydrogen
HBR	High Bit Rate
HGA	High Gain Antenna
HSK	Honeysuckle USB Tracking Station
INCO	Instrumentation and Communications Officer (CSM and LM)
IP	Impact Point
ISS	Inertial Subsystem
IU	Instrumentation Unit
LCG	Liquid Cooled Garment
LM	Lunar Module
LMP	Lunar Module Pilot
MCC	Midcourse Correction
MC&W	Master Caution and Warning
MOCR	Mission Operations Control Room
MPL	Mid Pacific Line
MSFN	Manned Space Flight Network
NETWORK	Network Controller
NR	North American/Rockwell

O_2	Oxygen
PC	Plane Change
PC	Chamber Pressure
PCO_2	Carbon Dioxide Partial Pressure
PLSS	Portable Life Support System
PNGS	Primary Navigation and Guidance System
PROCEDURES	Operations and Procedures Officer
P/T	Pressure/Temperature
PTC	Passive Thermal Control
RCS	Reaction Control System
RETRO	Retrofire Officer
RR	Rendezvous Radar
S/C	Spacecraft
SHe	Super Critical Helium
SLV	Saturn Launch Vehicle
SM	Service Module
SPAN	Spacecraft Planning and Analysis
SPS	Service Propulsion System
SXT	Sextant
TCE	Fuel Cell Condenser Exhaust Temperature
TELMU	Electrical, Environmental, Extra Vehicular Systems Engineer for the LM
TIG	Time of Ignition
TLM	Telemetry
TM	Telemetry
TV	Television
VAN	Vanguard USB Tracking Ship

SECTION V

SUMMARY FLIGHT PLAN
(54:00 GET through Entry)

FLIGHT PLAN

Time	CSM CMP		LM CDR	LM LMP	
54:00		MSFN	CLEAR TUNNEL OF CM HATCH INSPECT TUNNEL & DOCKING LATCHES REMOVE PROBE & DROGUE		
:10					PTC P 90, Y 0
:20	TEMPORARILY STOW PROBE & DROGUE		ACTIVATION CHECKLIST	OPEN LM HATCH RECORD AND REPORT DOCKING TUNNEL INDEX ANGLE (-2.0°) IVT TO LM	
54:30					PTC P 90, Y 0
			IVT TO LM	ASSIST CDR	
:40					
:50	CM POWER TO LM-OFF			LM POWER-ON	PTC P 90, Y 0
55:00			LM FAMILIARIZATION	LM FAMILIARIZATION	

MCC-H

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE

FLIGHT PLAN

CSM CMP	TIME	LM CDR	LM LMP	MCC-H
	55:00		LM POWER-OFF	
CM POWER TO LM-ON				
	:10	LM FAMILIARIZATION	LM FAMILIARIZATION	
QUADS C&D DISABLED	:20			
	55:30 (TV; MSFN)			
			IVT TO CSM	
	:40	IVT TO CSM		

CSM

QUADS C&D ENABLE
CLOSE LM HATCH

TERMINATE BATT B CHARGE
CMC RESTART LT.
MAIN B BUS UNDER VOLT (55:55:20)
MAIN A BUS UNDER VOLT (55:58:25)

[FLIGHT PLAN] MNVR TO R 60, P 90, Y 0

FIRST INDICATION OF SYSTEM MALFUNCTIOI

:50

56:00

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE

FLIGHT PLAN

Time	Station	Activity
56:00		CMP: INSTALL CM HATCH LM TUNNEL VENT VALVE - LM/CM ΔP BUS TIE AC-ON OMNI C
:10		FUEL CELL 1 OFF LINE OMNI B
:20		EMERGENCY POWER DOWN TO DELTA OF 10 AMPS INVERTER 1 ON BOTH AC BUSES OMNI C
56:30	MSFN	BMAG 2 OFF FUEL CELL 3 OFF LINE BATTERY A OFF OXYGEN SURGE TANK ISOLATED
:40		O_2 TANK 1 HEATER & FANS-ON
:50		BMAG 1 OFF
57:00		OMNI B

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE

57:00	MSFN	FUEL CELL 3 REACTANTS OFF
		OMNI C
		RCS THRUSTER CONFIGURATION VERIFIED
:10		
		REPRESS PACKAGE ISOLATED
:20		FUEL CELL 1 REACTANTS OFF
		INITIALIZE ERASEABLE DUMP - V74
		CHARGE BATTERY A (57:26)
		WASTE WATER DUMP HEATER-OFF
57:30		QUADS A&C SM RCS PROP ISOL VALVES CLOSED
		LM POWER UP (57:36)
		CM POWER TO LM OFF (57:38)
:40		
:50		BATTERY A-OFF
58:00		

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE

FLIGHT PLAN

MCC-H

Time	MSFN	Activity	MCC-H
58:00			
		DOCKED COARSE ALIGN (58:03)	
		V06N20E (CSM)	
:10		V06N20E	
		FINE ALIGN (58:12) POWER DOWN CMC & IMU (CSM) MISSION TIMER ACT	
:20		PRIMARY GLYCOL LOOP ACT	
		FDAI POWER-ON	
		RCS HTRS-ON	
58:30	MSFN	RCS PRESS DAP LOAD 30120 LM IN ATT HOLD	
:40		CSM POWERED DOWN	UPDATE TO LM GYRO TORQUING ϑ's
		IMU FINE ALIGN	
:50			
59:00			

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE

FLIGHT PLAN

MCC-H

59:00

PQGS, HEATER & EPS DISPLAYS - ALL CIRCUIT BREAKERS OPEN

UPDATE PC+2 DPS ABORT PAD (59:02)

:10

LGC CLOCK ΔT - V55E

VERIFY ASCENT FEEDS - CLOSE

:20

UPLINK TO LM
PTC REFSMMAT
T EPHEM

59:30

MSFN

:40

:50

60:00

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE

FLIGHT PLANNING BRANCH

FLIGHT PLAN

GET	MSFN	CMP	CDR	LMP
60:00	MSFN	DESCENT O_2 (60:02)		
		P30 PAD UPDATE (60:53)		
61:00		DPS PRESS & C/O (61:12)		
		DPS MNVR GET: 61:30		
		POWERDOWN PGNCS		
62:00		FLIGHT PLAN UPDATE (62:34)		
63:00		ATT HOLD LM POWER DOWN PC+2 P30 MNVR PAD UPDATE (63:05)		
64:00				REST PERIOD (6.0 HOURS)
65:00		YAW <u>90°</u> TO NEXT PTC ATT		
66:00				

GET	MSFN	CMP	CDR	LMP
66:00	MSFN	YAW <u>90°</u> TO NEXT PTC ATT		
67:00				REST PERIOD (6.0 HOURS)
68:00		YAW <u>90°</u> TO NEXT PTC ATT		
		EAT PERIOD	EAT PERIOD	
69:00				CREW STATUS REPORT
				EAT PERIOD
70:00				
71:00		REST PERIOD (6.0 HOURS)	REST PERIOD (6.0 HOURS)	
		RENDZ RADAR PROCEDURE UPDATE		
72:00				

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FLIGHT PLANNING BRANCH

FLIGHT PLAN

Time	CMP	CDR	LMP
72:00	P52 IMU ALIGN		
74:00			AOT SUN CHECK
75:00	2 HR ACT. CONT. CHECKLIST UPDATE		
	P30 PC+2 PAD UPDATE		
76:00	CREW STATUS REPORT		
	EAT PERIOD	EAT PERIOD	MISSION RULE UPDATE (LM BURN)
77:00			AOS/LOS, SR/SS UPDATE AOT STAR CHECK
78:00			

MSFN

Time	CMP	CDR	LMP
78:00	POWER UP LM SYSTEMS P30 EXTERNAL ΔV ALIGN AGS TO PGNCS CSM MNVR ENTRY UPDATE STATE VECTOR UPDATE		S-IVB LUNAR IMPACT
79:00	PC +2 — TIG: 79:27:38.30; BT: 4 MIN 24 SEC; ΔV2: 861.5 FT/SEC; ULLAGE: 2 JET 10 SEC		
	BURN STATUS REPORT		
80:00	UPDATE POWER DOWN & PTC PROCEDURE		
	CO_2 MASTER ALARM		
81:00	ESTABLISH PGNCS PTC		
	EAT PERIOD	EAT PERIOD	EAT PERIOD
82:00	PGNCS POWER DOWN CREW STATUS REPORT POWER DOWN LM SYSTEMS		
	REST PERIOD (8 HOURS)	REST PERIOD (3 1/2 HRS)	
	PHOTO UPDATE	(TARGETS OF OPP. FOR SM JETTISON)	
84:00			

MSFN

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FLIGHT PLANNING BRANCH

FLIGHT PLAN

Time	MSFN	CMP	CDR	LMP
84:00	MSFN	REST PERIOD (8 HOURS)	REST PERIOD (3 1/2 HRS)	
85:00				LM LiOH CANNISTER CHANGE (85:30)
86:00			LM BIOMED OFF COMM CK EAT PERIOD	EAT PERIOD
87:00		LM MCC BURN PROCEDURE UPDATE P30 NO COMM MCC-7 PAD		
88:00				
89:00				REST PERIOD
90:00				

Time	MSFN	CMP	CDR	LMP
90:00	MSFN	PROCEDURE TO FAB LiOH HOOKUP EAT PERIOD		
91:00		CREW STATUS REPORT		REST PERIOD (5 1/2 HRS,
92:00		PROCEDURE UPDATE CM CONFIG	EAT PERIOD	
93:00		CO_2 MASTER ALARM		EAT PERIOD
94:00		LiOH CANNISTER CHANGE	REST PERIOD (6.0 HRS)	
95:00		PROCEDURE UPDATE LM POWER TO CM EAT PERIOD		EAT PERIOD
96:00				

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FLIGHT PLAN

Time	CMP	CDR	LMP
96:00		REST PERIOD (6.0 HOURS)	
98:00			BIOMED ON LMP
98:30		CREW STATUS REPORT	
99:00		EAT PERIOD	ADDITIONAL PROCEDURES FOR LM POWER XFER TO CM
99:30	PWR AMP ON FOR HBR LM BATTERY 2 ALARM		
100:00	PASSED UP PROCEDURES FOR LM MCC BURN		
101:30	CSM POWER PROCEDURES FOR TELEMETRY		
102:00	CSM POWER-UP FOR TELEMETRY		

MSFN

Time	CMP	CDR	LMP
102:00	CM POWER DOWN EAT PERIOD	EAT PERIOD	EAT PERIOD
104:30	P30 MANEVUER PAD VOICED UP		
104:50	POWER UP LM SYSTEMS		
105:18	MCC-5 — TIG: 105:18:28, BT: 15.0 SEC, ΔV: 7.8 FPS; PGNCS DPS		
106:00	ESTABLISH PTC - AGS POWER DOWN LM SYSTEMS PA-OFF	BURN STATUS REPORT CREW STATUS REPORT	
107:00	REST PERIOD		REST PERIOD

MSFN

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FLIGHT PLANNING BRANCH

FLIGHT PLAN

108:00 – 114:00 (MSFN) — CMP | CDR | LMP

108:00

109:00 — SHe DISK BURST

110:00 — REST PERIOD (CMP)

REST PERIOD (LMP)

111:00 — VOICE UP PROCEDURE FOR POWERING CM FROM LM

PROCEDURE VOICED UP FOR CHARGING BAT A
PROCEDURE VOICED UP FOR REMOVING BAT A
PROCEDURE VOICED UP FOR CM POWER REMOVAL
SELECT HBR
TRANSFER LM PWR TO CSM

112:00

CHARGE BATT A

LiOH CANNISTER CHANGE

113:00 — PROCEDURE VOICED UP FOR LiOH CANNISTER UTILIZATION

REST PERIOD (2 1/2 HRS) (CDR)

LiOH CANNISTER ADDED

LiOH CANNISTER ADDED

114:00

114:00 – 120:00 (MSFN) — CMP | CDR | LMP

114:00

115:00 — REST PERIOD (2 1/2 HRS) (CDR)

116:00

117:00

REST PERIOD (IN LM) (CMP)

REST PERIOD (LMP)

118:00

119:00

120:00

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE

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FLIGHT PLANNING BRANCH

FLIGHT PLAN

Time		CMP	CDR	LMP
120:00	MSFN			
		PA-ON VOICED UP PROCEDURES FOR MCC-7, SM SEP, & LM JETTISON		
121:00		PA-OFF		
		VOICED UP TRANSFER AND STOWAGE LIST		
122:00		PCM-HBR; PA-ON		
		PCM-LBR		REVISED CM POWER UP PROCEDURES
123:00		TERMINATE BATTERY CHARGE-BATT A CSM POWER UP (TM) - CSM POWER DOWN BATTERY CHARGE BATTERY A		
124:00			REST PERIOD	
			VOICED UP PHOTO DATA FOR POST SM SEP PHOTOGRAPHY	
125:00		REST PERIOD		
126:00		VOICED UP PROCEDURE FOR BAT B CHARGE		

Time		CMP	CDR	LMP
126:00	MSFN	TERMINATE BATT A CHG START BATT B CHG READOUT BATT B VOLTS & CHARGE AMPS ENTRY PROCEDURES UPDATE TO CREW		
127:00				REST PERIOD
128:00		TERMINATE BATT B CHG SW TO ASCENT H2O DOCKING TUNNEL INDEX -2.1°		
129:00				ENTRY PROCEDURES UPDATE
		POWER AMPS-OFF		
130:00		REST PERIOD	REST PERIOD	
131:00				REST PERIOD
132:00				

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE

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FLIGHT PLAN

CMP | CDR | LMP

132:00 – 138:00 (MSFN)

POWER UP LM SYSTEMS

START MISSION TIMER

AGS ACTIVATION & BODY ALIGN

MCC-H UPLINK LM S.V. & REFSMMATS, V66 (SUN-MOON)

P62 - LM IMU REALIGN, OPT 1

LM E-MEMORY DUMP

MCC UPLINK: MCC-7 TARGET LOAD
MCC UPDATE: MCC-7 MNVR PAD
CM/SM SEP PAD
LM JETT PAD

P30 - TARGET MCC-7
P41-RCS THRUSTING
COMPLETE CM RCS PREHEAT
MNVR TO BURN ATT
AGS BODY AXIS ALIGN

MCC-7 (EI-5)

TIG: 137:39:48.39
ΔVR: 3.1 FT/SEC
BT: 23 SEC
(4 JET RCS, +X)

MNVR TO SEP ATT

CMP | CDR | LMP

138:00 – 144:00 (MSFN)

CSM HOT FIRE
SM JETTISON 138:02

SM PHOTOGRAPHY & DESCRIPTION

MCC UPDATE: ENTRY PAD
RECOVERY WEATHER REPORT

MCC UPDATE: CM COARSE ALIGN ∢'s

POWER UP CM SYSTEMS
MCC UPLINK S.V., REFSMMATS, ENTRY TGT
CM COARSE ALIGN
CM P52 IMU ALIGN, OPT 1
LM MNVR TO JETT ATT LM (FDAI): R 228, P 125, Y 12.4
LM CLOSEOUT
PRESSURIZE TUNNEL
HATCH INTEGRITY CHECK

LM JETTISON 141:29:56

MNVR TO ENTRY ATT: R 0, P 91.3, Y 0
SXT STAR CHECK
MCC UPDATE ENTRY PAD & S.V.
MOON CHECK

EI - 142:40:39

SPLASHDOWN - 142:54:56

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE

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FLIGHT PLANNING BRANCH

APPENDIXES

APPENDIX A

Booster Systems Engineer (BSE)

GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

Memorandum

TO : M. L. Windler, FC

DATE: April 21, 1970
MSFC/PM-MO-F/121/70

FROM : Manager, MSFC Flight Control Office,
PM-MO-F

SUBJECT : Apollo 13 BSE Position Report

REFERENCE: 70-FC11-49, subject: Apollo 13 Accident Evaluation Memo #1, dated April 20, 1970.

The referenced memorandum requested Apollo 13 mission reports for each position be supplied by April 24. Enclosed is the BSE position report. This report should satisfy the request in the referenced memorandum. A more detailed report will be published by May 1, but the details in that report are not important to the evaluation of the Apollo 13 accident since they concern only the Saturn launch vehicle. However, copies of the detailed report will be available by contacting Frank Van Rensselaer, extension 2716.

R. Scott Hamner

R. Scott Hamner

Enclosure

cc:
PM-MO-F/Van Rensselaer

MSFC - Form 488 (August 1960)

APPENDIX A

BOOSTER SYSTEMS ENGINEER REPORT

Prepared by: Frank L. Van Rensselaer
Frank L. Van Rensselaer
Booster Systems Engineer #1

Approved by: R. Scott Hamner
R. Scott Hamner
Manager, MSFC Flight Control
Office, PM-MO-F

BOOSTER SYSTEMS ENGINEER REPORT

PRELAUNCH

All prelaunch commands were successful. The S-IC LOX vent valve could not be closed for awhile, but a procedure was established which closed the vent valve. The loss of F4-424 S-IVB LOX chilldown flowmeter was verified.

LAUNCH PHASE

Liftoff was 19:13:00.60 GMT. S-IC burn was nominal. GUIDO reported a step input in the crossrange accelerometer. The center engine on the S-II cut off at approximately 00:05:31 (nominal was 00:07:43). The S-IVB burn duration was approximately 11 seconds longer than nominal to compensate for the S-II engine out. The only other additional problem during launch was loss of F5-404 TM measurement, S-IVB LH2 chilldown flowmeter.

EARTH ORBITAL COAST AND TLI BURN

This phase was nominal. TB6 was initiated at 02:26:08. TB7 was initiated at 2:41:37. S-IVB mainstage burn (STDV to TB7 initiate) was 5 minutes and 51 seconds long ($\sim$5 seconds shorter than prelaunch nominal due to the longer first S-IVB burn). All indications from the crew onboard monitoring, the tracking data, and the LVDC data indicated that the TLI burn performance and trajectory were very good. The burn was approximately 4 seconds longer than the pad data passed to the crew. However, the propellant residuals were comfortably above the 3σ level. The crew reported a vibration during the burn.

TRANSLUNAR COAST

All onboard programmed functions were nominal. A command was sent at 03:03:42 to dump the state vector that was stored onboard the LVDC at TB7 plus 2 minutes and 30 seconds. Spacecraft separation, turnaround, and docking all appeared nominal.

The 80° yaw maneuver was commanded at 04:09:01. This was 5 minutes later than nominal due to a crew request to wait until they had maneuvered so that the S-IVB/IU was in sight. The evasive burn (TB8) was commanded at 04:18:00. All Time Base 8 functions were nominal. The midcourse one (lunar impact) command was uplinked at 05:48:08 and the LVDC stored data dumped back by command at 05:49:10. The midcourse burn was 217 seconds long. Tracking data indicated the midcourse burn resulted in an impact point within the desired 200 KM radius. There was some confusion in real time regarding which vector HOSC should use for targeting the midcourse. In addition, there was some confusion in the MOCR concerning the vector extrapolated lunar impact point. The onboard systems were monitored until the data bacame useless. At ~14:00:00 a 60° pitch change occurred. This was due to an LVDC clock overflow and the method of software implementation. One unexplained occurrence was that the accumulated accelerometer data indicated a gradual increase in ΔV of approximately 5 to 6 meters/second from eleven hours into the mission until the LVDC stopped functioning a little after nineteen hours. This was not confirmed by the tracking data. A second unexplained occurrence was approximately 11 fps ΔV increase at ~19:17:00 reported by FDO from his tracking data. This was after the LVDC had stopped functioning so this could not be verified from the accelerometer data.

After the lunar mission was aborted and the LM was activated, it was very difficult to lock up on the LM telemetry. The LM and IU S-band frequencies are the same. For this mission the IU transponder was active to lunar impact for tracking purposes. Contingency procedures for offsetting the IU frequence were worked pre-mission.

CONCLUSIONS AND RECOMMENDATIONS

The Saturn portion of the Apollo 13 mission was successful through lunar impact. The following anomalies and/or occurrences require further evaluation:

1. The cause of the S-II center engine early cutoff.
2. The difference between the HOSC predicted TLI burn parameters and the actual burn parameters (burn time, propellent residuals, etc.).

3. The confusion in the MOCR concerning the vector extrapolated lunar impact point.
4. The confusion that existed concerning which vector to use for targeting the first lunar impact burn.
5. The gradual increase of velocity indicated by the accumulated accelerometer data after 11:00:00 GET.
6. The approximately 11 fps ΔV increase at ~19:17:00 that FDO reported.
7. I recommend methods be investigated on board and on the ground to minimize CCS/LM communications interference in the event the LM is powered up on the way to the moon.

APPENDIX B

Retrofire Officer (Retro)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

IN REPLY REFER TO: FC5

APR 24 1970

MEMORANDUM TO: Apollo 13 Flight Director

FROM : FC5/Retrofire Officers

SUBJECT : Apollo 13 Postflight Report

I. Problems/Resolutions.

A. Prelaunch - Recovery reported undesirable weather in part of the Mode II area. The decision was made to fly over the bad weather.

B. Launch through MCC-2 (hybrid transfer) - Recovery reported bad weather for LO+25, 35, 60 P37 block data. LO+35, 60 P37 block data was retargeted and updated to the S/C.

C. MCC-2 through PC+2.

1. The CSM suffered a power failure and ECS problems just prior to 56 hrs GET. These problems seriously affected CSM consumables (CSM lifetime), and caused "mission abort" to be executed as a first impulse lunar flyby at 61:30 to return to a free return trajectory, and a second impulse at PC+2 to speed up the return and select the recovery area.

2. The flyby maneuver was executed as a minimum fuel burn with a water landing. However, the roll right backup entry area contained an island. Since the crew had trained for roll left backup entries also, non-execution of PC+2 would merely require a roll left constant g backup entry.

3. The CSM systems problems included an inoperative SMJC. The RFO altered previously developed contingency separation procedures to allow the LM to be used to evade the SM and the LM tunnel pressure for CM separation from the LM.

4. Prior to PC+2, Recovery reported a storm near the MPL. After reviewing the target location, it was felt the weather would be good at landing thus the PC+2 planning continued to the same target.

D. Transearth Coast - Recovery had questionable weather near the target point. The weather was good at the target point and lift during entry could be used to avoid the weather, thus no weather avoidance burn was attempted.

E. MCC-7 through Entry.

1. The initialization of the CMC was hampered by communication problems during powerup. A CMC clock update of 77:26:11.09 was computed during low bit rate TM data. This update was later found to be in error by .06 sec. This error was corrected at EI-45 min along with the state vector update.

2. The CM was 90° out of yaw attitude prior to LM jettison. Instead of being yawed 45° to the south, it was 45° to the north. Since the LM closeout was underway, the RFO advised the Flight Director to jettison the LM in the northerly direction as the inplane separation distance would be adequate.

3. The γ_{EI} jumped to -6.2° from -6.5° when the post MCC-7 RTCC trajectory was updated. After verifying that the trajectory was the best, the final entry pad and state vector were sent to the S/C.

II. Mission Narrative.

A. Prelaunch.

1. During the CDDT, the CMC clock was observed to have a drift. From KSC readouts, the drift for the CMC clock was determined to be .00069 sec/hr fast. The LGC was determined to be .00024 sec/hr fast based on a frequency test. On April 10, 1970, at 10:10 GMT the CMC was biased .02 sec slow in order that the clock be correct at lift-off.

2. Lift-off (T-6) mass properties (wts, cg's, and Aero's) were generated without incident and loaded in the RTCC by T-2:46 (h, m).

3. Recovery reported undesirable weather for Mode II between 67°W (5:10 GET) and 44°W (8:20 GET) for launch azimuths less than 86°. It was decided to overfly the weather if the systems were good.

B. Launch through MCC-2 (hybrid transfer).

1. The GMT of the first motion was 19:13:00.606. The CMC lift-off was 19:13:00.65, which was input to the RTCC as GMTLO.

2. The IMU gyro-compassing error (as expected) caused the CMC to think it was slightly south of the ground track.

3. The crew reported vibration during TLI.

4. The CSM ephemeris was accidently anchored on a pre-TLI trajectory. The FDO corrected the problem shortly.

5. The TLI cutoff trajectory had a resulting perigee of 934 n.m.--later revised to -331 n.m.

6. Recovery reported bad weather in the MPL for LO+25 and LO+35 hr abort RTE block data that was onboard. Present GET was too close to 25 hrs to update the LO+25 hr abort. The LO+35 hrs abort was updated to $\lambda = 155^\circ$W (10° east of MPL) to avoid the weather.

7. The pre-MCC-2 (hybrid) return trajectory.

$\gamma_{EI} = -19^\circ$

GETL = 155 hrs

8. The MCC-2 ΔVc bias from GNC was -0.34 fps for the maneuver pad. The crew EMS ΔV bias check (pre-MCC-2) was 0.45 ΔV/30 sec.

9. The T+24 hr telescope data was generated and shipped to all four stations.

10. The S-IVB predicted moon impact time was 77:51 (h, m).

11. The T+25 RTCC mass properties were run but an update was not needed. (P, Y trims were within .01° of T+6).

12. MCC-2 burn parameters: (Docked, SPS, G and N).

Planned		Actual
Tig	30:40:49.0	30:40:49
ΔTB	3.50 sec	3.49 sec
C/O	30:40:52.50	30:40:52.49
ΔV_T	23.2 fps	23.2 fps
hpc (postburn)	60.22 n.m.	60 n.m.

C. MCC-2 through PC+2.

1. MCC-3 was not required.

2. The DPS "burp" burn for SHe pressure considerations was not needed. DPS trims for this test had been computed.

3. The post MCC-2 TLC trajectory was close to nominal. Therefore, TLC abort ΔV's were like the premission values.

4. The LO+60 abort RTE block data maneuver onboard was updated from MPL to $\lambda = 153^\circ$ due to weather on the MPL.

5. The LOI abort chart update run in the RTCC went well at GET = 37:00. The pitch ∢ changed from 83° to 82° while the ΔV curve was within 10 to 20 fps of the nominal curve. Therefore, the pitch ∢ was all that was required to be updated.

6. About 48 hrs GET, the first RETRO abort/RTE block data status report was passed to the Flight Director.

7. RTCC (LM burn) mass property decks were updated to T+55 decks.

8. The LM crew went into LM early:

53:26 (h. m) - Crew cleared to start ingress.

54:25 - LMP had entered LM.

9. MCC-4 was not very probable at 54:39 GET.

10. Crew Report: -2.0° docking ∢.

+1.047 docking index misalignment

- .953 Δ docking ∢

11. Generated new telescope data with MCC-2 in it for Bldg. 16. Data was at RETRO console ready to pass to Andy Sauliets when CSM accident happened at ~56 hrs.

12. At GET ~55:57 (h, m) the CMC had a restart. A CMC clock check showed the CMC still in sync with GET. Several CSM problems started at approximately this time. Specific mission abort plans began. The first aborts to be looked at were SPS direct aborts with Tign ~58 to 60 hrs because of lunar sphere crossing at ~61 hrs and because SPS capability was still assumed to exist at this time. MPL/AOL fast return direct aborts were passed to Flight for review. A flight controller team change was occurring. The on-coming Retro continued to run abort plans of a lunar flyby and pericynthian +2 hrs fast return nature as docked DPS burns. The off-going shift retired to Rm 210 to debrief; the abort options of a docked DPS flyby and PC+2 fast return nature were presented. Direct aborts were not discussed because GET was at/or near sphere crossing time and we apparently did not have the SPS. The best choice available at this time was to do an MCC in the near future because the present trajectory was non-free return, and because LM Systems to include PNGS alignment could support a burn now and may not several hrs later with as good an alignment. A second impulse (maneuver) was being considered at PC+2 to control landing time within the LM consumables schedule and to select landing area. The consumables budget did not require the GETL = 133 hrs return to the AOL and would allow the 10 hr later landing GETL = 143 in the MPL. By the time this status was reached in the debriefing, activity in the MOCR was already occurring to do a first impulse at ~61:30 to get back on free-return and to be followed by a second impulse at PC+2 (79+30) to speed up the return and select the recovery area.

13. Immediately after the accident, the following trajectory options were computed. The weather and recovery ships of opportunity for these areas were soon made available. The ΔV capability of the docked DPS with the SM was 1994 fps and 4830 fps without the SM. The LM RCS capability with the SM was 44 fps.

Direct Return

Area	Tig	ΔV	ø	λ	GETLC	Weather	Recovery Ships
MPL	60:00	6079	21:05S	153W	118:12	Good	Iwo Jima
MPL	60:00	10395	26:13S	165W	94:15	Good	Iwo Jima

PC+2 with no flyby maneuver for free return

Area	Tig	ΔV	ø	λ	GETLC	Weather	Recovery Ships
MPL	79:30	670	11:35S	165W	142:47	Good	Iwo Jima
MPL	79:30	4657	28:26S	165W	118:07	Good	Iwo Jima
AOL	79:30	1798	22:48S	25W	133:15	Very Good	Some

PC+2 with flyby for free return

Area	Tig	ΔV	ø	λ	GETLC	Weather	Recovery Ships
MPL	79:30	854	21:38S	165W	142:47	Good	Iwo Jima
MPL	79:30	4836	12:24S	165W	118:12	Good	Iwo Jima
AOL	79:30	1997	23:21S	25W	133:15	Very Good	Some
EPL	79:30	1452	22:16S	86:40W	137:27	O.K.	None

14. A PC+2 block data pad assuming no MCC to free return was uplinked at ~59:00 GET. It was a DPS maneuver at 79:30 GET to the AOL with a landing time of 133:15 GET. The DPS trim that was passed to the crew on the PC+2 abort pad was challenged by the LM Control; but, later they agreed with our data. They had used the premission mass properties which was not the best data available.

15. The LGC clock was updated at ~59:00 GET with a -88:59:32.74 sec pad. After this update the LGC was within .05 sec of GET.

16. The options for the free return flybys were computed for several Tig times for minimum fuel return and targeting to the Indian Ocean.

17. The plan that seemed to be most acceptable to all was executing a free return transfer flyby ASAP and then to speed up the return at PC+2. This plan allowed performing the maneuver with the PNGS since it was already up. Also, it provided the option of speeding up the return at PC+2 (79:30) to the MPL with either a 850 fps maneuver landing at 143 hr or a 4830 fps maneuver landing at 118 hr. The PC+2 option decision could be delayed until the lifetime on the lift support consumables could be determined.

18. After the Flight Director decision to do the free return flyby MCC, one more iteration on the maneuver was performed to achieve an impact point in the Indian Ocean. The minimum fuel maneuver had an impact point on Madagascar.

19. The free return flyby MCC was computed as:

TIG = 61:29:42.84, ΔTB = 30.72 sec, ΔV = 38.0 fps

GETEI = 151:45, and ϕ = 20:37S and λ 60:10E

20. The maneuver was computed using a two-jett 10 sec ullage; but, since the DAP was configured for four-jett ullage, we gave a GO to use 4 jett ullage. The MOCR wall clock was several seconds in error; however, the RETRO clock was right and quickly confirmed the LGC and this ended the MOCR confusion.

21. On Tuesday, April 14, 1970, the RFO attended a meeting in the MCC second floor VIP room with the other flight controllers, ASPO, crew representatives, and others. The main topic was what PC+2 maneuver should be performed. The RFO presented the following options for PC+2:

GETI	ΔV	GET landing	Area	ΔV_{MCC} at 105 GET for 1° error at PC+2	SM jettisoned
(PC+1) 78:30	4728	118	MPL	~87 fps	yes
(PC+2) 79:30	845	142	MPL	~22 fps	no
(PC+2) 79:30	1997	133	AOL	~50 fps	no

DPS ΔV without SM = 4726
DPS ΔV with SM = 1977 3σ low

The RFO presented the following options for trajectory speedup after execution of PC+2 of 845 fps:

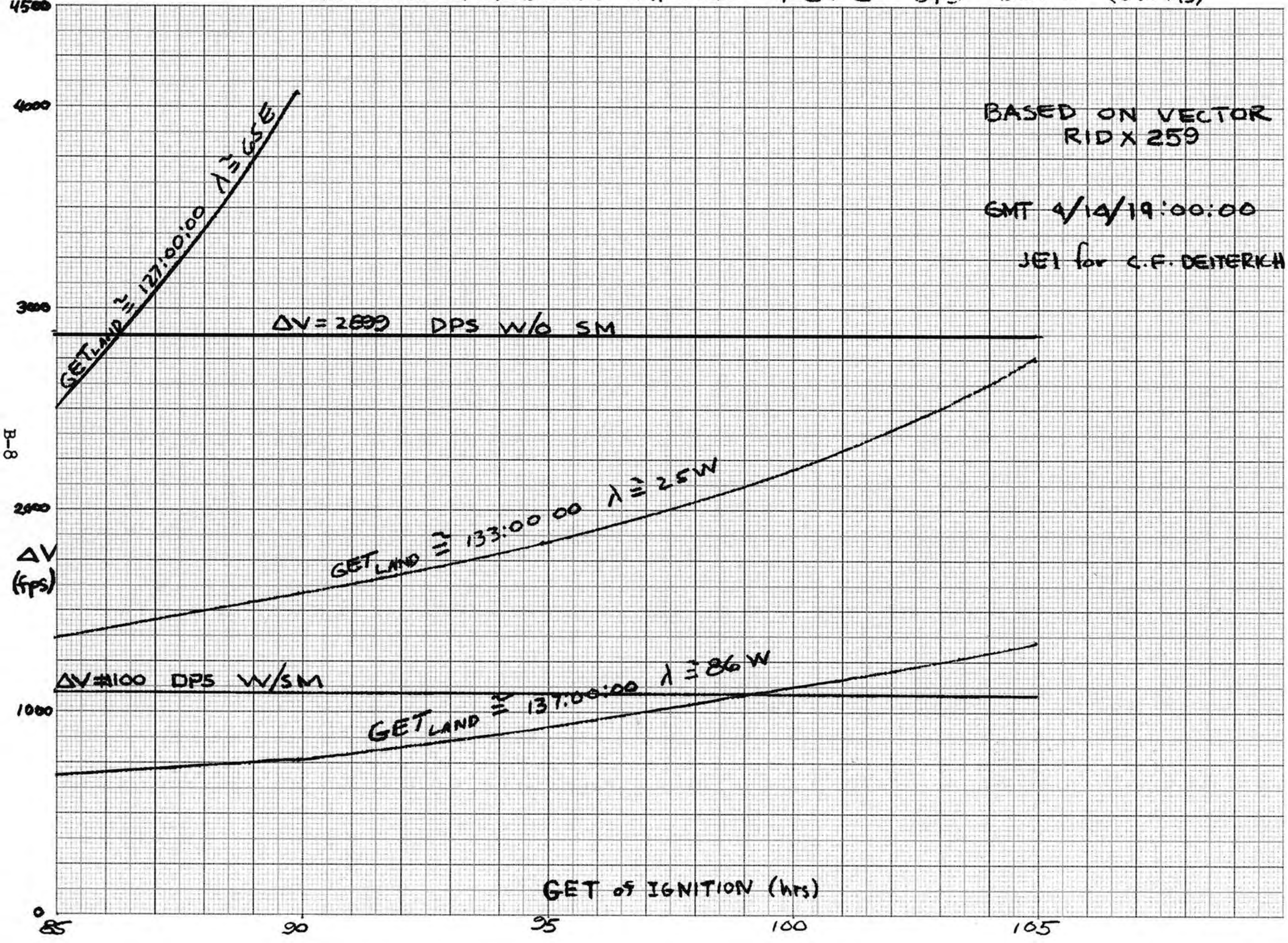
GETI	ΔV	GET landing	Long	SM jettisoned
86:30	2899	127	65°E	yes
99:30	1100	137	86°W	no
105:00	2899	133	25°W	yes

DPS ΔV without SM 2899
DPS ΔV with SM 1100 after PC+2 of 845 fps (3σ low)

The return trajectory would have always been within 4 fps of the entry corridor during the 845 fps PC+2, but was as far as 200 fps away during the 4728 fps PC+2. Based on consumables, uncertainties in S/C characteristics for SM jettison 60 hrs prior to EI, maneuver sensitivities and available speed-up maneuvers, the decision was reached to execute PC+2 with 845 fps. Since a 1° attitude error had a small MCC ΔV, the decision was made to relax the LM IMU alignment accuracy and perform a sun check. A brief description of SM separation and LM jettison sequence was also presented. This sequence was adapted from procedures developed by the RFO's for earlier lunar missions and verified by MPAD. The sequence optimizes separation distances and directions while leaving the entry conditions unperturbed. The proposed SM separation and LM jettison timeline which was also passed to MPAD for verification is as follows:

EI-4 (later revised to EI-5)	a.	MCC-7
EI-3:30 (later revised to EI-4:30)	b.	Align the LM +X out the radius vector and 45° to the south out-of-plane (when SM separation time was revised the out-of-plane was deleted due to change in central angle of travel).

RETURN CAPABILITY AFTER PC+2 DPS BURN (850fps)



c. Perform LM +X 1 fps (later revised to 1/2 fps since earlier separation and to allow SM photography).

d. Perform CM/SM separation followed by LM -X 1 fps (revised to 1/2 fps).

This puts SM to the south and behind the CM-LM; the EI-4 1/2 SM separation puts the SM well behind the S/C at entry.

EI-1 e. Align the CM +X axis out the radius vector and yaw 45° out-of-plane to the south.

f. With the LM holding attitude and utilizing the LM tunnel pressure for jettison ΔV perform LM jettison. ΔV assumed to be 2.5 fps (later updated to 2.0 fps).

g. CM maneuver to entry attitude. This puts the LM south and behind the CM at entry.

MPAD used this sequence and verified the procedure for several ΔV's of separation.

22. Just prior to PC+2, Recovery reported a storm near the MPL. Based on the storm's predicted position at landing, the PC+2 planning was not altered.

23. PC+2.

a. Assuming no PC+2 maneuver, MCC-5 ΔV was ~5 fps to tweak up the free return trajectory.

b. The final PC+2 pad went to crew at 78 hrs based on GYM 289 vector.

c. PC+2 to the MPL (GETL ≈ 143 hrs) was executed on time as a docked, DPS, PNGS burn. The burn was normal with guided cutoff within 0.13 sec of predicted BT. However, subsequent tracking showed hp high (~87.4 n.m.) and a MCC-5 ΔV = 4 to 8 fps at 104 hrs. Postburn tracking after MCC-5 and MCC-7 also showed a consistent trend of hp significantly high.

d. PC+2 burn parameters (docked, DPS, PNGS):

	Planned	Actual	
Tig	79:27:38.30	79:27:38.30	Tig
ΔT_B	4:23.69	4:23.82	ΔT_B
C/O	79:32:01.99	79:32:02.12	Tevent
ΔV_t	861.5 fps		

e. The PC+2 confirmed maneuver showed MCC-5 ΔV at 104 hrs = ~1 fps. However, PC+2 early tracking showed MCC-5 at 104 hrs = ~4 to 6 fps.

D. Transearth Coast.

1. Around 90:00 GET, the weather in the recovery area was questioned. The predicted weather at landing was good but with some degree of uncertainty. However, since a weather avoidance burn would require the LM PNGS as the COAS could not be facing the earth, and since the storm could be avoided with lift during entry; it was agreed not to perform a weather avoidance maneuver.

The uncertainty in the weather was forcing MCC-5 to be possibly delayed until the uncertainty was removed. With the weather resolution, MCC5 was performed as scheduled at 105:30.

2. MCC-5.

a. SHe burst was predicted to occur at ~106 hrs.

b. hp without MCC-5 was ≈87.3 with GDS 250 vector.

c. MCC-5 $\Delta V_{est} \approx (7.83, 7.84)$ at 105:30 (h, m).

d. May do burn within ±30m of nominal Tig for $\pm .1^{\circ}$ $\Delta\gamma$.

e. MCC-5 was passed to the crew based on GDS 253 vector.

f. Crew burned early ~12.29 (m, s).

g. MCC-5 burn parameters (docked, DPS, manual - COAS to earth attitude).

	Planned	Actual
Tig	105:30:00	105:18:31.6
ΔT_B	15 (14 sec DPS + RCS trim)	14 sec + trim
ΔV_T	7.8 fps	7.8 fps

h. The confirmed maneuver showed $\gamma_{EI} = -6.52^{\circ}$.

$\gamma_{EI} = -6.51^{\circ}$ targeted

3. Prior to the SHe bursting, there was some concern that it wouldn't burst. There were several ideas on how to vent the SHe. Some techniques would retain DPS capability others wouldn't. We recommended a plan that was finally agreed upon. The first priority was to minimumize the venting in order to preserve the tracking with no consideration given

to retaining the DPS capability. The trajectory was well within RCS MCC capability. The venting was to be performed in the PTC attitude. If venting in the PTC attitude failed, the next step was to do a vent during a 10 sec ullage maneuver. This maneuver was to be out-of-plane using the MCC alignment technique and aligning perpendicular instead of parallel to the terminator.

4. The G and C requested a cg for the stack weight without the SM in the CSM reference. This data was run offline in the RTCC.

5. On Wednesday, April 15, 1970, the RFO attended a meeting to develop an integrated crew checklist for MCC-7, SM separation, CM powerup, CMC initialization, IMU alignment, LM jettison, and entry. From this 10-hr meeting came the EI-8 hr timeline and crew checklist, which included EECOM, GNC, GDO, RFO, crew representative, and data priority inputs. The RFO presented the separation sequence with MPAD showing their analysis of the sequence.

Since the horizon would be dark until just prior to EI, the RFO suggested that the CM be given a moon check attitude to hold until moonset and then track the horizon. The GDO discussed the CMC IMU align procedure which was also incorporated.

These procedures were then tried by the crew representatives who suggested that MCC-7 and SM separation be moved 1 hr earlier. This was coordinated among the flight controllers and accepted. The RFO, GDO, and FDO ran data and generated the necessary pads for the crew to use in their simulations of the entry timeline. The RFO, GDO, and FDO then ran the timeline in the RTCC area to check their procedures. An error was found in the RTCC entry processor in that it could pick the wrong REFSMMAT for entry. An acceptable workaround was found.

6. MCC-6 (116:00:00 GET).

a. An MCC-6 was not required as MCC-7 ΔV was currently computed as ~3 fps.

b. Telescope data was generated and passed (all four stations) with MCC-7.

c. SM jettison was planned at EI-4 1/2 hrs. LM jettison was planned at EI-1 hr.

d. Final stowage definitions were used to compute entry aerodynamics at GET ≈122 hrs. These entry aeros were loaded in the RTCC as EOM aero's based on mass properties job 27 (L/D = .29052).

7. On Thursday, April 16, 1970, the RFO attended the final checklist review. A few inputs were made, but as a whole the checklist was very close to the one generated on April 15. The checklist was then read to the crew.

E. MCC-7 and Entry.

1. Since the consumables were sufficient, it was decided to bring up the LM PNGS at EI-8 hrs. The LM IMU was aligned to the earth terminator alignment associated with MCC-7 at EI-5 hrs. The RFO picked an alternate target point (50 n.m. downrange from the nominal) which would have to be used if MCC-7 was only partially successful and the γ_{EI} was greater than -6.08° (too shallow) forcing a lift vector down entry.

2. MCC-7 was passed to the crew as a 3.1 fps retrograde burn to correct γ_{EI} from -5.99° to -6.51°. The LM attitude was about 20° out of roll attitude due to error needle confusion. The LM control gave a "GO" on this attitude. The RFO gave a "NO-GO", as the inplane component would have been reduced, and the GDO advised the FD to fly the FDAI to the pad attitude. MCC7 was executed nominally with DSKY residuals of .1 fps.

3. The CM/SM separation was executed with a LM push/pull maneuver at 138:25:00.

4. The preliminary entry pad did not get onboard until 138:46:00.

5. About 140:20:00, the RFO generated a CMC clock update when the CMC TM became available. The proper command load was transferred to the remote site and uplinked. A correction of -.06 sec was required at EI-45 min as the initial update was computed on low bit rate. This update was uplinked with the final state vector uplink. During the CMC initialization at EI-2 1/2 hrs, the entry targets were uplinked to the CMC (lat = 21.66S long 165.37W).

6. The LM maneuvered to a LM jettison attitude which was 45° out-of-plane to the north instead of the south. LM closeout was initiated without a formal "GO", and, when the attitude error was recognized; the hatches were being installed. Since time was critical, the RFO advised the FD to continue LM closeout, and that, although the separation would not be optimum for a roll right constant g entry; the separation would be adequate.

7. At EI-1:10 (141:30:00 GET), the LM was jettisoned and the radar tracking interrupted for processing. The γ_{EI} had changed to -6.2° or a change of .3° from the last trajectory. After verification of the data, the RFO generated a final entry PAD which was sent to the crew as the state vector was uplinked. The RFO advised the GDO that a second uplink might be required if subsequent data refuted the -6.2° γ_{EI}. The subsequent data verified the -6.2° and the G and N was given a GO.

8. A sextant star check was performed to verify the entry attitude and the moon check was successful at moon set.

9. A final γ_{EI} was computed as -6.28°. The S/C was reported to have landed 1.5 n.m. short of the target point.

10. During the recovery, the RFO computed the LM cask IP and passed this data to the AEC. The support to the AEC will be covered in another memo.

III. Recommendations:

1. Observatory telescope data should be transmitted from MCC only by teletype and not by telephone.

2. The RTCC REFSMMAT identifiers should include vehicle nomenclature. Also the entry processors should have the capability to reselect the desired REFSMMAT.

Charles F. Deiterich
Charles F. Deiterich

Charles F. Deiterich for
Bobby T. Spencer

Thomas E. Weichel
Thomas E. Weichel

Jerry C. Elliott
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Enclosure

cc:
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Flight Directors
Branch Chiefs
FS5/J. R. Garman
FC5/J. C. Bostick (26)

RTE MANEUVER SUMMARY

MANEUVER	GETI	ΔV	PREBURN PERIGEE	PREBURN γ_{EI}	PLANNED γ_{EI}	ACTUAL γ_{EI}	GETL	LAT	LONG
FREE RETURN TRANSFER	61:29:43	38	2435	--	-6.53°	-12.52°	151:59:00	20:37S	60:10E
PC+2	79:27:38	861	-101.5	-12.52°	-6.51°	--	142:53:00	21:37S	165W
MCC-5	105:30:00	7.8	87.4	--	-6.51°	-5.99°	142:55:00	21:37S	165:22W
MCC-7	137:39:48	3.1	26.8	-5.99°	-6.51°	-6.28°	142:55:00	21:37S	165:22W

APPENDIX C

Flight Dynamics Officer (FIDO)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

IN REPLY REFER TO: FC5

APR 24 1970

MEMORANDUM TO: Apollo 13 Flight Director

FROM : Flight Dynamics Officer

SUBJECT : Postflight Report

I. Problems/Resolutions.

A. Prelaunch.

1. During the T-5 hr trajectory run, no valid data was received from VAN. The problem was eventually traced to the VAN CDP. An unsuccessful attempt was made to correct the problem by going with the 507 tape. The problem was not corrected.

2. The IP reported a problem with its ALDS interface during the T-5 hr run. No effect of this problem was noted at MCC. It was reported that the problem was procedural and was due to a work-around required to support a sim run. No further action was taken.

B. Launch through MCC-2 (Hybrid Transfer).

1. At T-2 hrs, the VAN CDP problem still had not been fixed. The effect of this problem was that the VAN would not be able to transmit high speed data to Houston. This condition continued through launch.

2. At $\approx$ 5 mins 30 secs into the launch phase the SII center engine shut down early. This caused a subsequent delay in the achievement of SIVB to COI and SIVB to orbit conditions as well as a delay in SIVB shutdown. No other trajectory anomalies were noted.

3. All earth orbit activities were normal with the exception of the tracking sites available for the CSM pre-TLI state vector update. All tracking data was to be terminated at 1:37:00. During this States pass the TEX data was unacceptable due to a "header coding error". The problem was resolved as being a "cockpit error" by the TEX site personnel.

4. The SIVB LOX dump and evasive maneuvers were input to the RTCC at $\approx$ 3:46:00. At this time, the Selects requested that the 2:59:00 zero ΔV maneuver (used for CSM separation attitude definition) be moved back to TLI cutoff. Dynamics was so instructed, however, TLI was moved

instead. This resulted in the ephemeris re-anchoring on the pre-TLI CYI vector. This situation was ultimately corrected by deleting TLI and re-anchoring on CCHU08. (The consequence of this was to "turn on" the RTCC pre-TLI vent model. With this vent on, and unknown, later impact point evaluations with MSFC would not compare. It was not until 24 hrs later that the "vent on" situation was noted as having invalidated impact point comparisons attempted prior to a GET of approximately 6 hrs.)

5. At ~ 5:50:00 MSFC stated they had targeted the first SIVB MCC (Tig ~ 6:04:00) using the BDAX36 vector. The usage of this vector was not as agreed to preflight nor as was done during simulations. It was our understanding that a "reconstructed vector" representing TLI, LOX dump, and the evasive maneuver was to be used for the first SIVB MCC.

6. The Selects reported seeing a small "glitch" in the SIVB tracking that had occurred at about 13:42:00. No explanation of this is available.

7. At ~ 24:38:00, MILX99 showed the SIVB impact to be 0.21°N, 31.79°W with impact at 77:58:37. At ~ 19:17:00, the Selects noticed another "glitch" in the data. MILX99 represented all data after this occurrence. A vector comparison of the pre and post "glitch" vectors yielded:

a. $\Delta\dot{u}$ = 5.45 fps.

b. $\Delta\dot{v}$ = -2.65 fps.

c. $\Delta\dot{w}$ = -9.80 fps.

No real explanation was available for this glitch, but it was theorized that the SIVB expended a significant amount of energy from perhaps an unscheduled vent.

C. MCC-2 through PC+2.

1. During the second day of the mission, the command computer at HSK/NBE went "red" which necessitated using 30-foot sites as two-way when the Pacific triad was in view. Although the command computer did not go "green" until the fifth day of the mission, HSK/NBE continued to support as a three-way site. (See the Network Controller's postflight report for further details.)

2. After the spacecraft contingency arose and the crew transferred to the LM, a problem was found in receiving IU and LM tracking data simultaneously. A premission plan with modifications was initiated with the results being that valid LM data was received. (See the Network Controller's postflight report for further details.) It should be noted that it took approximately 4 hrs to obtain satisfactory LM data.

D. Transearth Coast.- The SHe vent caused considerable effect to the spacecraft PTC mode, but had little observable effect on the doppler residuals. Three hrs later, however, a .1 fps maneuver was input to the MPT in an attempt to model the SHe vent to facilitate data processing.

E. MCC-7 through Entry.

1. The SM separation maneuver, executed at $\approx$ 138:02:00, was to have imparted zero effective ΔV to the LM/CM combination by usage of the "push/pull" sequence. However, the "pull" maneuver "netted" ∿ -1 fps to the LM/CM.

2. Just prior to LM closeout, and subsequent jettison, the crew was to have maneuvered the LM/CM to an attitude which would have resulted in jettisoning the LM "up" and to the "south" (relative to the CM). The crew did not have the stack in this "desired" attitude but a check on the relative separation of the CM and LM at EI showed sufficient downrange clearance though the LM would then be to the north of the CM. This was not as desired, but was acceptable, and mention was made to the FD but not to the crew.

3. The vector utilized to generate the final entry PAD data was GWMX307 which included only those data after MCC-7. This vector indicated an entry flightpath angle to -6.2°, thus confirming the "shallowing" trend that was observed following MCC-7. However, as early as the PC+2 maneuver, this constant "shallowing" of the entry angle was observed. This forced MCC-5 as well as MCC-7. No known explanation is available but with the crew's report of continual "streaming of particles past the window" it is probably that a continual "vent" was in progress. Additionally powering up of the LM required the LM water boiler, which is "propulsive" in operation. Further, all attitude maneuvering was accomplished by using the LM translational jets. Considering these possible perturbations, it seems reasonable to assume one or all could have been responsible for the shallowing of the flightpath angle.

II. Mission Narrative.

A. Prelaunch.

1. The prelaunch phase was essentially non-eventful. The 5-hr trajectory run was good with the exception of VAN and an IP problem which was caused by a procedural error in preparing for the sim run.

2. A second run was planned to exercise the VAN but was scrubbed because the VAN was still down and the IP problem was satisfactorily explained.

3. The remainder of the prelaunch phase went as planned with no significant problems.

B. Launch through MCC-2 (Hybrid Transfer).

1. During launch phase the SIC stage of flight was nominal. During SII flight the center engine shut down early which had the effect of "slowing down" all trajectory "milestones".

2. Insertion was nominal with the IU vector being used to transfer to orbit phase.

3. An IU vector was "saved" at insertion and shipped to MSFC for their analysis; this vector was ICHU01.

4. At $\sim$ T+1:00:00 the RTCC J-2 engine model was updated in accordance with the predicted values as supplied by the BSE. They were as follows:

THRUST (LBS)	FLOW RATE (LBS/SEC)
169,696	394.235 before PU shift
200, 606	469.546 after PU shift

5. After the NO TLI acquisition data had been sent to the Network the second opportunity TLI was generated in the LM ephemeris. Tig was 4:04:14 (based on CYI3).

6. The interrupt vector that was established with all States data prior to 1:37:00 was GYMS9. This vector was uplinked to the spacecraft prior to TLI.

7. TLI was frozen on ICHU06 which was the last IU vector available prior to TLI.

8. Following TLI cutoff, HAW was requested to provide high speed data such that another source of trajectory information would be available for "best TLI cutoff" vector determination. The choice of the best post-TLI

vector was augmented by use of residual data from the Select. Of the three dynamic vectors available (IU, CMC, high speed) the residuals were truncated on HSRC (high speed cutoff) and the IU (ICHU08) vector. The residuals on the CMC (CCHU08) were 77. CCHU08 was used to update the ephemeris as our "best" definition of TLI cutoff.

9. Shortly after TLI cutoff, we received MSFC's best estimate of the post-TLI conditions ("IFT TLI BEST").

10. At $\approx$ 4:20:00, the Selects had collected enough data to build another vector (BDA 36) which could be used for further trajectory source evaluation. This vector compared somewhat favorably with the current ephemeris (CCHU08) in that the MCC-2 ΔV on CCHU08 was 23 while that of BDA 36 was 17 fps. In addition, this vector and impact data was sent to MSFC. BDA 36 showed good component agreement with the MSFC "IFT TLI best" vector which was stored in the RTCC as LLHU01. The BDAX36 vector was transmitted to MSFC along with the information pertaining to its verification of the exactness of LLHU01.

11. The spacecraft ejection, SIVB LOX dump and SIVB evasive maneuvers were all input to the RTCC.

12. The tracking data following the first SIVB MCC was sent to MSFC as GWMX53. This vector indicated no need for a second SIVB MCC as the impact point was within acceptable limits.

13. At $\approx$ 10:30:00 the G&C's informed us that the ΔV_c bias was -0.34 fps.

14. At $\approx$ 11:00:00 the SIVB vector (NBEX74) showed the impact point to be 8.149°S x 29.53°W. This vector and impact information was sent to MSFC.

15. At $\approx$ 14:30:00 the SPS single bore engine values were loaded into the RTCC as the MCC-2 maneuver would not be long enough (burn time) to have two banks of ball valves.

16. At $\approx$ 14:35:00 NBEX78 indicated SIVB impact to be at 10°:34'S x 28°:26'W.

17. At $\approx$ 20:33:00 the SIVB impact point was updated to 8°:35'S x 33°:54'W with impact at 77:51:32 based on RIDX91.

18. At $\approx$ 24:38:00 MILX99 showed the SIVB impact point to be 0.21°N x 31.79°W with impact now at 77:58:37. (See Problems and Resolutions, Section I.B.).

19. At 29:30:00 MILX108 indicated SIVB impact at 0.932°N x 29.53°W with impact at 77:57:37. This information and vector was passed to MSFC.

20. MCC-2 (hybrid transfer) was executed on time and was nominal.

C. MCC-2 through PC+2.

1. The final update to the SIVB ephemeris was on HAWX199 and predicted the following information:

a. GETIP = 77+56+45.62.

b. ϕ IP = 2.156°(S).

c. λ IP = 28.217°(W).

2. As a result of the contingency, a free-return lunar flyby maneuver was executed using the DPS at 61:29:42.84. The flyby was targeted for an Indian Ocean splashpoint at approximately 152 hrs GET. The maneuver was executed nominally. (See the maneuver summary for details.)

D. Transearth Coast.

1. A DPS maneuver was executed approximately 2 hrs after pericynthian arrival time. The maneuver was targeted to achieve an MPL landing point. Final PAD and NAV were generated on GWMX289. Execution was nominal.

2. The MCC-5 execution technique presented two significant problems. These concerned alignment of the AGS and the burn monitoring technique. AGS alignment was accomplished using COAS sightings on the earth. Essentially, the spacecraft +Z axis was aligned along the local vertical and the +X axis was placed retrograde along the local horizontal. This technique was modeled in the MPT using an OST REFSMMAT that duplicated the alignment and manually iterated on ΔV_M to achieve the desired γ_{EI}. The RTE computed maneuver gave the first guess ΔV and only small changes were required to compensate for the 8° difference between the RTE desired thrust direction and the true thrust directly obtained from the spacecraft alignment. The Manual guidance mode in the MPT was utilized to most correctly model the maneuver.

The monitoring technique was developed using two basic assumptions. First, though the AGS should perform nominally, it might not due to the low temperatures to which its accelerometers had been subjected. Secondly, the RTCC burn time prediction was considered to be accurate after analysis of the PC+2 maneuver data. Considering these two points, it was decided to manually terminate the burn at PAD ΔT_B minus 1 second and let MCC advise on the trim procedures. If the AGS appeared off-nominal, only 2 seconds of +X RCS would be required to achieve the proper burnout conditions and in no case should the undesirable use of -X RCS be required. At the end of the maneuver, however, a "GO" to trim the AGS was given as it appeared to be functioning nominally.

3. The crew had enough difficulty in establishing PTC that it was deemed desirable to minimize the time delta between MCC-5 and the SHe vent since both events would probably effect the PTC. Thus MCC-5 was set at 105:30:00 which was ½ hr prior to the predicted SHe vent.

4. MCC-5 was scheduled at 105:30:00 with the final maneuver data being computed on GDSX252. Execution was nominal with the exception of Tig, which was so insensitive that the crew was told to execute the maneuver whenever they felt ready within PAD Tig ± 30 mintues.

E. MCC-7 through Entry.

1. At 135:10:00 the PNGS was being "brought up" with consideration then being given to doing a PNGS P-41 midcourse maneuver.

2. MCC-7 was executed under AGS control. The burn was completed satisfactorily and no trimming was required.

3. SM separation was executed as planned with the exception of the ΔV imparted to the CM. (See Section I.E., Problems and Resolutions.)

4. The tracking data following MCC-7 again reflected a "shallowing trend" in the γ_{EI}. This was noted and work continued based on the pre-MCC-7 vector and the confirmed MCC-7 and separation maneuvers. (See Section I.E.)

5. The crew photographed the SM and continued with the CMC powered up and IMU alignment.

6. CM/LM SEP occurred a little early and with the ΔV's as follows:

a. LM (body) $X \approx -0.75$, $Y = -0.25$

b. CM $X \approx -1.0$

7. Tracking data was interrupted just prior to LM SEP with the final entry PAD based on this data (GWMX307) and the confirmed CM/LM SEP maneuver.

8. The following is a summary of the vectors/entry flightpath angles that were observed prior to entry:

VECTOR	FLIGHTPATH ANGLE
CROS 312	-6.22
GWMS 315	-6.23
CROS 320	-6.27
NBES 321	-6.28
NBES 323	-6.295
CROS 325	-6.295
HSKS 331	-6.292
HSKS 333	-6.289

VECTOR	FLIGHTPATH ANGLE
HSKS 335	-6.288
HSKS 338	-6.289
HSKS 340	-6.29
HSKS 342	-6.289

9. Following splashdown the LM cask aerodynamics were input to the RTCC, and the post-LM/CM SEP data was processed to determine the "cask" IP's. These IP's will be published in a separate memorandum.

Jay H. Greene

Jay H. Greene

H. David Reed

William M. Stoval Jr.

William M. Stoval, Jr.

William J Boone III

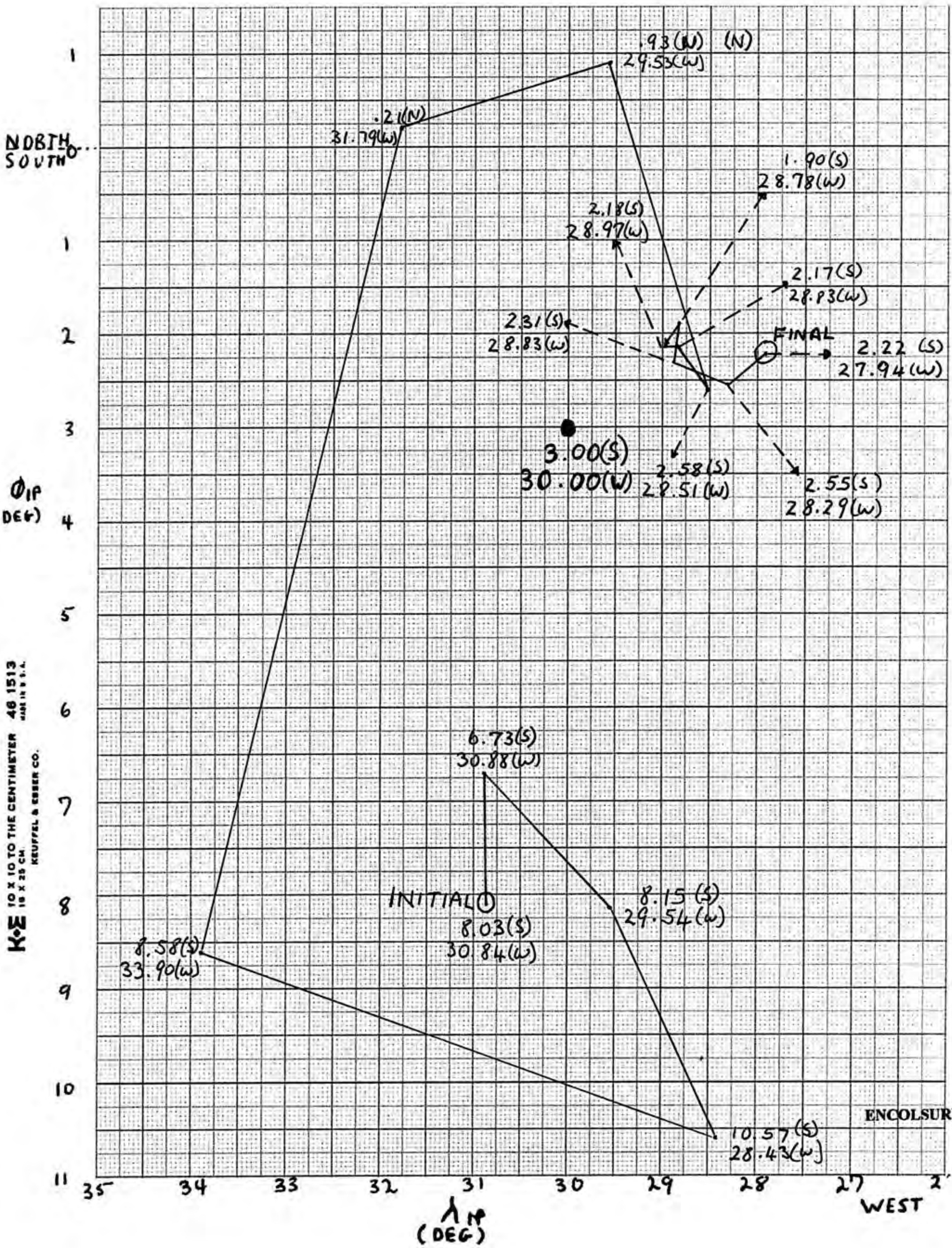
William J. Boone, III

Enclosures 2

cc:
FC/E. F. Kranz
J. W. Roach
M. F. Brooks
Branch Chiefs
FC5/J. C. Bostick (26)
FS5/J. R. Garman
FC/Flight Directors

MANEUVER	VEH/PROP/GUIDANCE	PREDICTED	CONFIRMED	CONFIRMATION
1. TLI	STACK/SIVB/IU	GETI = 2:35:43.8 ΔV = 10,416.1 fps hpc = 335.39	 hpc = 255.79	UPDATE ON CCHU08
2. MCC-2	CSM-LM/SPS/G&N	GETI = 30+40+49 ΔV = 23.2 fps hpc = 60.22	GETI = 30+40+49 ΔV = 23.1 fps hpc = 64.87 n.m.	IMU Vg's V_{gx} = -18.30 fps V_{gy} = -13.00 fps V_{gz} = -5.30 fps
3. FLYBY	CSM-LM/DPS/G&N	GETI = 61+29+42.8 ΔV = 38.0 fps hpc = 136.5 n.m. γ_{EI} = -6.53	GETI = 61+29+42.8 ΔV = 37.8 hpc = 137.57 γ_{EI} = ?	IMU Vg's V_{gx} = -37.70 V_{gy} = +3.02 V_{gz} = -0.93
4. PC+2	CSM-LM/DPS/G&N	GETI = 79+27+38.3 ΔV = 861.5 γ_{EI} = 6.51	GETI = 79+27+38.3 ΔV = 860.5 γ_{EI} = ? hvp = 82.6	IMU Vg's V_{gx} = +747.04 V_{gy} = -420.72 V_{gz} = +73.80
5. MCC-5	CSM-LM/DPS/AGS	GETI = 105+30+00 ΔV = 7.8 fps γ_{EI} = -6.52	GETI = 105+18+31.6 ΔV = 7.8 γ_{EI} = -6.05	Tig and ΔV
6. MCC-7	CSM-LM/LM RCS/AGS	GETI = 137+39+48.4 ΔV = 3.1 fps γ_{EI} = -6.50	GETI = 137+39+48.4 ΔV = 2.9 fps γ_{EI} = -6.3	IMU Vg's V_{gx} = +2.91 V_{gy} = +0.44 V_{gz} = -0.05

ENCLOSURE 1



.93(N) (N)
29.53(W)
.21(N)
31.79(W)
NORTH
SOUTH
1.90(S)
28.78(W)
2.18(S)
28.97(W)
2.17(S)
28.83(W)
2.31(S)
28.83(W)
FINAL
2.22 (S)
27.94(W)
3.00(S)
30.00(W)
2.58(S)
28.51(W)
2.55(S)
28.29(W)
ϕ_{IP} (DEG)
6.73(S)
30.88(W)
INITIAL
8.15(S)
29.54(W)
8.03(S)
30.84(W)
8.58(S)
33.90(W)
10.57(S)
28.43(W)
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. 46 1513 KEUFFEL & ESSER CO. MADE IN U.S.A.
WEST
λ_{IP} (DEG)

ENCOLSURE 2

APPENDIX D

Guidance Officer (GUIDO)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

IN REPLY REFER TO: FC5

APR 24 1970

MEMORANDUM TO: Apollo 13 Flight Director

FROM : FC5/Guidance Officers

SUBJECT : Apollo 13 Postflight Report

I. Problems/Resolutions.

A. Prelaunch - There were no anomalies experienced during the prelaunch period.

B. Launch through MCC-2 (hybrid transfer).

1. During powered flight to earth orbit insertion, a slight crossrange and downrange error developed between the IU and CMC.

Post earth orbit insertion analysis verified a definite but acceptable error in the IU navigation state.

2. During the P23 operation, the OCDU fail inhibit bits were not reset during the optics mode switching.

The crew performed the appropriate reset procedure provided by the ground.

C. MCC-2 through PC+2.

1. At 55:55:40 GET, a restart occurred in the CMC caused by a power glitch. The CMC vectors, clock, and REFSMMAT were checked and found to be good.

2. In advance of the PC+2 hr maneuver, it was decided to verify the accuracy of the current LM platform alignment. Such a verification of the alignment would allow waivering a P52 and conserving LM RCS.

To adequately check the alignment, it was decided to instruct the LGC to point the LM AOT at a celestial body and have the crew indicate how well it was able to achieve this.

D. Transearth Coast.

1. Since the LM had been powered down after the PC+2 maneuver, a method of executing the midcourse had to be determined.

A procedure using earth terminator aligned on the horizontal line of the COAS was developed.

E. MCC-7/Entry.

Problem - Powering down both LM and CSM G and N's necessitated alternate methods for executing MCC-7 and subsequently aligning the CSM platform for entry.

The approach proposed for MCC-7 execution and CSM platform alignment followed two constraining guidelines. First, minimum reliance on the LM was desirable due to possible consumable problems, and secondly, the technique shouldn't require stars since they might not be adequately visible without use of auto optics. With this in mind, a plan was formulated requiring only AGS body axis align and attitude control capability, and the use of moon and sun as celestial targets for the CSM alignment. The plan also allowed a good deal of flexibility if extra capability became available, such as the LM PGNCS.

II. Mission Narrative.

A. Prelaunch - No problems.

B. Launch through MCC-2 (hybrid transfer).

1. During powered flight to earth orbit insertion, a slight navigation error developed between the IU and CMC. This gave the following differences between the two navigation sources at insertion.

$\Delta\dot{X}$ (downrange) = 6.18 fps

$\Delta\dot{Y}$ (crossrange) = -7.67 fps

$\Delta\dot{Z}$ (radial) = 1.56 fps

The crossrange error buildup started as a step function in IU crossrange velocity at lift-off of approximately 2.6 fps. Thus indicating the IU out-of-plane accelerometer had sensed a false acceleration right at lift-off. Post-insertion orbital parameter comparison between MSFN and IU confirmed both the out-of-plane and downrange error. The downrange error accumulated during powered flight was attributed to an IU scale factor or pipa bias. The latter would seem likely since the error is more linear than non-linear with time. Comparison between MSFN and IU at the pre-selected time was as follows:

GET 00:56:00 ΔRV (downrange position) = +8059.6 ft

Δa (semi-major axis) = -.679 n.m.

$\Delta\dot{W}_{max}$ (crossrange velocity) = 12 fps

GET 01:45:00 ΔRV (downrange position) = +63509 ft

Δa (semi-major axis) = 1.257 n.m.

$\Delta\dot{W}_{max}$ (crossrange velocity) = 15 fps

2. During the P23 operation, the OCDU fail inhibit bits were not reset during the optics mode switching. The possibility is a known program anomaly and was described in Colossus 2D program and operational note 1.2.1 (b.). Briefly stated, if a restart occurs (due to POODOO, bailout V37, or hardware cause) during certain portions of IMU or optics mode switching, certain failure inhibit bits may remain set, preventing the program from sending appropriate alarms if a genuine failure occurs. During optics mode switching after the optics have been in zero for 33 cycles of T4Rupt (15.84 - 16.32 seconds), the OCDU fail inhibit is left on for an additional .4 seconds. A V37 was executed during the .4 second interval which prevented the OCDU fail inhibit bits from being reset. The crew performed the appropriate reset procedure (V25 N07E, 1331E, 7E, E) provided by the ground.

3. MCC-2 - State vectors and a target load were uplinked at 28:50. The maneuver was executed as follows:

Planned	Executed
Vg IMU X = -18.22	Vg IMU X = -18.3
Y = -13.20	Y = -13.0
Z = -5.51	Z = -5.3
T_{IGN} = 30:40:49.00	

C. MCC-2 through PC+2.

1. At 55:55:40 GET, a restart occurred in the CMC caused by a power glitch. The CMC vectors, clock, and REFSMMAT were checked and found to be good.

2. At the point that ECCOM estimated that only 20 minutes of power remained in the CSM, it was decided to bring up the LGC and do a docked alignment. This was completed on CM battery power. The LGC is unable to navigate in cislunar space, and how to handle state vectors and target loads became our biggest concern. It was decided to make sure that the RTCC vectors were in the earth sphere of influence, and that the state vectors uplinked to the LGC would be timetagged at T_{IGN} - 30, which is the time the LGC would have to integrate the vectors in any burn program. Also the external ΔV components must be in the same sphere as the vector. A state vector, target load, and REFSMMAT were uplinked. The free return maneuver was executed as follows:

Planned	Executed
Vg IMU X = -37.89	Vg IMU X = -37.71
IMU Y = +2.96	IMU Y = +3.02
IMU Z = -1.21	IMU Z = -3.93
T_{IGN} = 61:29:42.84	

3. PC+2 Planning and Execution - The LM platform was aligned to the CMC using the docked alignment procedure at 58+40+00 GET. The free return maneuver was executed using this alignment. Since no stars could be seen by the crew, it was decided to perform a sun check prior to going behind the moon, to determine if a P52 would be required while on the backside. It was desirable not to have to do the P52 to conserve LM RCS propellant. Real-time evaluation of the PC+2 hr maneuver with attitude variation indicated that an attitude within $\pm 1^{\circ}$ of desired would be adequate. Based on this limit, a test, to see if the LGC knew

its inertial orientation well enough, was developed. A ground derived unit vector for the sun at GET 74:00:00 was provided for input to P52 to allow orientation of the AOT at the sun as if marks were to be taken. A ground sun vector was provided because the current LGC ephemeris knowledge was unknown with no telemetry available. P52 was chosen over V49 because it performs a two-axis versus a three-axis maneuver and achieves attitude more quickly. The sun subtends an arc of 0.5° which indicates that if the center of the AOT, at the completion of the maneuver, was off by more than two sun diameters an equivalent platform misalignment of 1° exists. The sun check revealed that the LGC was able to place the AOT reticle center within .66 sun diameters of the desired deviation. This equates to a platform misalignment of $.33^{\circ}$ assuming perfect attitude control within the deadband. Also a gross star check was made on the backside of the moon. It also confirmed that the LM platform was within acceptable limits to execute the maneuver without a P52.

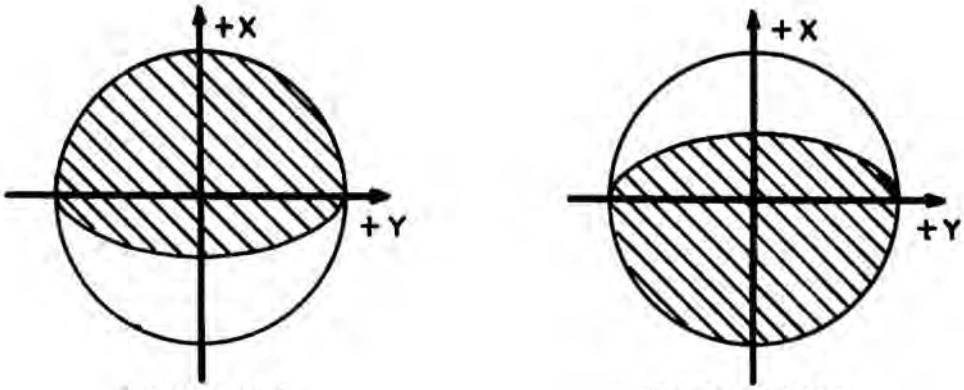
4. MPAD ran some window and AOT VIEWSAT T_{IGN}, and this data was passed to the crew. However, this data could not be verified in the RTCC and Flight was advised that it was probably wrong. MPAD reran the data and discovered that they had made an error in inputing the REFSMMAT to their processor. This time they came up with the center of the moon on the 14° mark on the LPD at burn attitude. This was verified in the RTCC, and the data was read up to the crew for a burn attitude check. It was estimated from the sun check that the platform was misaligned approximately $1/2^{\circ}$. Based on the best vector prior to MCC5, the burn was probably executed with a pitch attitude error of approximately $1/4^{\circ}$.

The PC+2 maneuver was executed as follows:

Planned	Executed	
Vg IMU X = +743.08	Vg IMU X = +742.21	AGS X = 858.7
IMU Y = -426.42	Y = -425.88	Y = 19.5
IMU Z = +90.84	Z = +91.04	ΔVT = 858.9

T_{IGN} = 79:27:38.30

D. Since the crew could not find stars in the AOT before going behind the moon prior to PC+2, a method of executing the midcourse maneuvers was recommended using the earth terminator aligned on the horizontal line of the COAS with the COAS mounted in the FWD window looking down the LM +Z body axis. The sunlit part of the earth could be placed in the COAS as shown below for either a posigrade or retrograde burn.



POSIGRADE RETROGRADE

MCC-5 was executed with the AGS body axis aligned using the retrograde alignment. A REFSMMAT OST 009 was computed that was equivalent to the above alignment, for use by other MOCR positions and by MPAD in their processors. AGS addresses 404, 405, 406 were loaded with zeros. The burn was monitored by 470R. The AGS accelerometer drift at T_{IGN} was determined to be -.2 fps. The burn was cutoff by the crew at 7.4 fps and trimmed to 7.6 in 470.

E. MCC-7/Entry.

1. To provide an attitude and burn monitor reference for MCC-7, the AGS was to be body axis aligned when in a known inertial orientation This was done by making celestial fix on the earth, using the terminator cusp to set up an inplane posigrade or retrograde attitude dependent on the actual MCC-7 maneuver. From this point on through CSM entry preparations, the AGS MCC-7 alignment was to be maintained.

2. Alignment of the CSM would then be performed as a LM to CSM course alignment using the AGS MCC-7 alignment as the LM alignment. The AGS MCC-7 alignment can be and was equated to a REFSMMAT by the ground. The CSM coarse alignment to a MCC-7 REFSMMAT would then be followed by an alignment to the desired entry REFSMMAT through a CSM P52, optic 1 using the moon/sun as fine align celestial targets.

3. Implementation of the above process applied use of ground computed data based on a knowledge of the AGS MCC-7 alignment. Using the AGS driven FDAI as an attitude reference, two sets of FDAI angles to point the CSM optics, with shaft = 0°/trunnion = 0°, at the moon and sun respectively, were computed. For the moon attitude equivalent, CSM coarse align angles were computed. Once at moon attitude, coarse aligned, and with that equivalent alignment loaded in memory as the "actual" REFSMMAT, a P52, optic 1 is executed switching to the entry REFSMMAT which has been placed in the "preferred" memory location. Marks made after coarse aligning to the entry REFSMMAT in option 1 are performed on the moon and sun respectively with a LM attitude maneuver to the sun between successive marks.

4. Several hours prior to MCC-7, it was decided that sufficient LM consumables existed to power up the LM PGNCS as well as AGS. As pointed out previously, the addition of the LM PGNCS was compatible with earlier preparations.

5. Just prior to the LM PGNCS alignment, an AGS body axis align at a known inertial orientation, with respect to the earth, was performed. The LM was then coarse aligned to this AGS orientation with the equivalent REFSMMAT being stored as "actual" in LGC memory. Since this initial orientation was not that originally planned for MCC-7 and subsequent activity, a P52, option 1 was set up in the LGC to realign to the desired MCC-7 alignment. Celestial marks made after coarse aligning in P52 were executed on the moon and sun since star visibility via the AOT wasn't acceptable.

6. With a fully operational LM PGNCS available, it was initially decided to perform a normal LGC burn for MCC-7 with AGS as backup, but not targeted via external delta V. However, just prior to the burn, with the PGNCS <u>fully</u> configured for a guided burn and near burn attitude, it was decided to use AGS instead of PGNCS control. This decision was based on current LM RCS usage. Attitude control modes were changed during this time period causing two confusion factors. The actual LM attitude drifted away from burn attitude in yaw and roll, and the crew reported that the yaw and roll error needles weren't nulled. Instructions were given to maneuver to burn attitude via the FDAI, leave the PGNCS in P41 as if it were to do the burn, go to AGS control, and complete the burn by body axis aligning at burn attitude and selecting attitude hold. The burn was performed substituting an AGS to PGNCS align for body axis align.

Planned	Executed	AGS
Vg IMU X = +3.02	Vg IMU X = +2.91	470 = +2.8
IMU Y = +0.44	Y = +0.44	
IMU Z = +0.07	Z = -0.05	

T_{IGN} = 137:39:48.40

7. After completion of MCC-7, the vehicle was maneuvered to SM separation attitude using LM FDAI attitudes. It was decided to vary the original CSM coarse align procedure and use the SM separation attitude rather than the moon sighting attitude. This was done in anticipation that stars might be available for the CSM P52, and the two LM attitude maneuvers for moon and sun sightings could be eliminated. CSM coarse align angles equivalent to the SM separation attitude were thus substituted by the ground for the original angles at moon sighting attitude. The moon and sun FDAI attitudes were held in reserve until it was certain that the crew would be able to see stars near the SM separation attitude.

8. The CMC was powered up with the LM at SM separation attitude and appropriate erasable loads put in prior to the alignment sequence. These were a state vector, time increment, "actual" REFSMMAT, and "preferred" REFSMMAT. The alignment sequence was started and completed substituting stars for the moon and sun marks.

9. During the CSM alignment sequence, an unexpected program alarm 220, IMU not aligned, occurred. It can be explained by the fact that the REFSMMAT flag wasn't set prior to entering P52 as described via the modified checklist. The error was corrected and no further anomalies were experienced.

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APPENDIX E

CSM Electrical and Environmental Officer(EECOM)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

IN REPLY REFER TO:

MAY 11 1970

MEMORANDUM TO: Distribution

FROM : Apollo 13 EECOM's

SUBJECT : Apollo 13 Post Mission Report

Attached is an addendum to the Apollo 13 EECOM Post Mission Report. Also, correct typographical error on Page E-2, second paragraph from page bottom: 224.5 psia vice 224.5°F.

S. A. Liebergot
Seymour A. Liebergot

FC 33:SALiebergot:elr

7. <u>Suit Pressure Sensor Erratic (CF0012)</u>

The suit pressure and cabin pressure diverged during the launch phase when the cabin was relieving. The maximum divergence was 0.7 psid, i.e., cabin pressure = 6.1 psia and the suit pressure = 5.4 psia. During earth orbit, the ΔP remained constant at 0.5 psi. At 3+30 hours GET when the CM cabin pressure was increased to 5.7 psia for LM pressurization, the suit pressure sensor gave a maximum reading of 5.0 psia. After LM press was complete, the ΔP = 0.5 psi for 4 hours, then increased to 0.8 psid where it remained. Similar behavior was seen when the LM was again pressurized for the first ingress (LM Fam) at 53 + 34 hours GET. The ΔP remained constant at 0.7 to 0.8 psid until after the O2 Tank 2 anomaly when the suit pressure reading dropped 0.2 psia resulting in cabin pressure = 5.1 psia and suit pressure = 4.1 psia. This condition then stayed constant through CSM powerdown.

The cabin and suit pressures both = 5.1 psia during both brief CSM activations. The pressure readings were also normal when the CM was powered up for entry.

During the mission, SPAN reported that suit pressure variations were observed during the altitude chamber test. In addition, suit pressure transducer erratic behavior occurred on Apollo 12.

APPENDIX E

APOLLO 13

EECOM POST MISSION REPORT

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J. W. Aaron

W. C. Burton

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April 28, 1970

APPENDIX E

TABLE OF CONTENTS

I. SYSTEMS

A. GENERAL COMMENTS

1. An improvement of 0.15 volts was noted in fuel cell performance as the result of the scheduled O2 and H2 purges. This improvement can be accounted for based on the prelaunch cryogenic purities and was considered normal.

2. Battery charging was successful. The cryo O2 tank anomaly resulted in additional usage of battery A energy, but the total energy was restored to 118 a-h with LM support before entry.

3. Battery energy margins during entry were maintained approximately 20 a-h above the established redline. There were 28 a-h remaining at splash (based on 40 a-h batteries) which would have provided one uprighting and approximately 20 hours on the water.

4. For entry, Battery C was tied to both main busses while batteries A and B were on Main Bus A and B, respectively. Battery C was assumed depleted at 10k feet leaving batteries A and B to support sequential system and RCS dump events.

5. Fuel cell load sharing in the "split" main bus configuration was as predicted prelaunch; i.e., FC 1 and 2 each at 32 percent, and FC 3 at 36 percent.

6. Waste water dumps were performed per flight plan with no problems.

7. The primary coolant loop performed nominally when in operation. The loop was powered up with evaporator for entry and provided more than adequate cooling since the CM was already chilled down.

8. The CO_2 partial pressure transducer appeared to give reliable readings. LIOH cannister changes were reflected by the sensor.

B. ANOMALIES

1. Fuel Cell 3 Tce (SC 2083)

Fuel cell 3 Tce was seen to "glitch" $\pm$ 4 bits (2° F) every 70 seconds. This phenomenon has been observed on at least one fuel cell on every mission and has not affected nominal fuel cell operation. It is attributed to slugs of cold water leaving the condensor and is a function of current load.

However, after MCC-2 the fuel cell 3 "glitch" pattern chaged to a sinusoidal ripple with a frequency of one cycle every 30 seconds and a peak-to-peak amplitude of 6.2° F. The ripple continued for approximately 9 hours before it damped out. Although this is not a normal condition, a similar condition occurred on Apollo 10 and was attributed to thermal oscillations in the fuel cell glycol loop.

2. Potable Water Quantity Erratic (CF0009)

Quantity fluctuations occurred after each of the first two crew sleep periods ended, presumably when water was used for food preparations. The greatest fluctuation occurred when the quantity dropped from a reading of 104 percent down to 79 percent and recovered in approximately 1 minute.

During the entry phase, after CSM power up, the potable water tank quantity read approximately 61 percent and the waste water tank indicated a 24 percent increase. Both tank quantities were considered unreliable at this time because:

(a) It was calculated that the potable water tank should have been exhausted by 107 hours GET at nominal usage rates. The crew reported they could get no water out of the tank at 125 hours GET.

(b) The waste tank indicated a 24 percent increase which is not possible because the CSM had been completely powered down.

3. Primary Coolant Glycol Flow Rate (CF0157)

The glycol flow rate was lower on this mission than on previous missions. The lower flow rate reading was present during both prelaunch while on GSE and inflight; i.e., 210 lb/hr. Other flight data:

Apollo 11	230-240 lb/hr
Apollo 12	220-230 lb/hr

Since all loop temps were normal, it is possible that the flow rate transducer was biased.

4. Hydrogen Low Pressure MC and W

At 32 hours GET, a quantity imbalance of 2.38 percent existed between the H_2 tanks and a quantity balancing procedure was commenced. Since Tank 2 had the greater quantity, the Tank 1 heaters were turned OFF and Tank 2 left in AUTO taking more flow from Tank 2. In this configuration, low cryo pressure master alarms occurred on the start of every Tank 2 pressure cycle.

Both tank's heaters were placed to AUTO for sleep and on the first "down" cycle, a master alarm occurred due to H_2 Tank 1 low pressure point shifting lower than 224.5° F. The crew reset the alarm which did not occur again through the sleep period.

After the crew sleep period ended, the Tank 1 heaters were placed to AUTO and Tank 2 OFF to determine the Tank 1 pressure switch activation point in anticipation of using this configuration for sleep. This was accomplished, and the tank heater configuration was reversed to Tank 1 OFF, Tank 2 AUTO to drive the quantity balance in favor of Tank 1 for sleep. This procedure was in progress at the time of the O2 Tank 2 anomaly.

5. O2 Tank 2 Quantity Sensor Fail (SC0034)

The O2 Tank 2 quantity reading was observed to fail off scale high (101.17 percent) at 46 + 40 + 10 GET after fluctuating for 10 seconds. This time was just after crew wake up and probably occurred during the routine cryo fan operation scheduled after each sleep period. The O2 Tank 2 fans were turned on again at 47:55 GET as an attempt to restore the quantity gaging with no success.

6. O2 Tank 2 Anomaly Chronology

CTE Hrs:Min	
46:40	O2 Tank 2 Qty fluctuating - Cryo quantities reflect crew stirring cryos.
46:40:10	O2 Tank 2 Qty transducer failed off scale high (101.17 percent)
47:55	O2 Tank 2 fans - ON to attempt to restore quantity gaging.
51:07	Cryo Stir
51:08	MC and W on H2 Tank 1 low pressure
52:02	MC and W on H2 Tank 1 low pressure
55:52	MC and W on H2 Tank 1 low pressure
55:53	Cryo Stir. At this time, Cryo O2 pressures were decreasing normally and approximately halfway through their downswing.
55:53:18	Fuel cell 1, 2, and 3 O2 flow transducers started slow fluctuations (≈ one cycle per 40 sec) between 0.4 lb/hr and 0.8 lb/hr. Small fluctuations were not an out-of-tolerance condition, but when coupled with no similar H2 flow fluctuations, and no change in fuel cell O2 pressures, can be indicative of cryo O2 pressure changes or instrumentation problems. Total SC current staying between 70 to 75 amps.
55:53:35	O2 Tank 2 pressure starts to increase rapidly while O2 Tank 1 remains normal. Tank 2 pressure at this time was 891 psi. (See Fig. 3)

55:54:28 O2 Tank 2 pressure passed through 973 psi with no Hi Cryo Press MC and W. H2 Tank 2 was below its low pressure limit. O2 Tank 2 Qty dropped from 101.17 percent down to 6.5 percent for 3 seconds and the temperature started increasing from -190° F. (See Fig. 3.)

55:54:31 O2 Tank 2 Qty rose to 75 percent and appeared to give correct readings for approximately 5 seconds before fluctuating again. (See Fig. 2.)

55:54:48 O2 Tank 2 press had rapidly increased to a max of 1008 psi at this time, then started to decrease slightly.

55:54:52 O2 Tank 2 press dropped to 998 psi, indicating possible pressure relieving. Temp had increased to max of -153° F, then dropped off scale low (-329° F.). (See Fig. 3.)

55:54:53 Three second loss of data starts. Crew report of Main Bus B undervolt may have occurred at this time, since no MC and W was present in downlink.

55:54:56 Reacquired data -

O2 Tank 2 pressure read 19 psi (OSL) and the temperature was +84° F (OSH). O2 Tank 1 and surge tank pressures started decreasing. Crew had reported a "bang" and gas venting from the SM. At this point, circumstantial evidence pointed to loss of O2 Tank 2 and impending loss of O2 Tank 1.

FC 1 N2 press had dropped from 55.8 psia to 0 psia. This was an instrumentation problem as FC 1 H2 and O2 pressure were normal and O2 pressure regulators are referenced to N2 pressure. Total SC current jumped 10 amps. Cryo O2 auto heaters could have accounted for this. MC and W due to cryo tank pressures.

55:55:10 FC 1 and FC 3 O2 flow rates had decayed to zero from 55:54:56. FC 2 O2 flow rate dropped approx. 0.1 #/hr and returned to normal. FC 1, FC 2 and FC 3 O2 pressures, H2 pressures, H2 flow rates, and load sharing were normal. Total SC current had fluctuated to 90 amps and back to a 75 to 80 amps range.

55:57:10 FC 3 O2 pressure starts to drop from 63.2 psia.

55:57:25 FC 1 O2 pressure starts to drop from 64.3 psia. FC 3 O2 pressure is 58.2 psia with O2 to N2 delta pressure of 4.4 psi. FC 3 load sharing is 34.8 percent but starts to drop.

55:57:39 MC and W - Main Bus B falls below 26.25 VDC (FC 3 failing). FC 3 O2 pressure 55.5 psia, with O2 to N2 delta pressure of 1.44 psi. FC 3 load sharing 28.2 percent with total current 74.4 amps. FC 1 O2 pressure is 60.1 psia and falling.

55:57:44 Previous MC and W still on - AC inverter 2 automatic input disconnect. AC Bus 2 voltage is 0 volts. Main Bus B voltage is 17.6 VDC. FC 3 has flooded with O2 to N2 delta pressure of 0.84 psi and is lost for the mission. FC 1 and FC 2 are carrying 54.2 amps load.

55:57:50 FC 1 O2 pressure has dropped to 58.5 psia. FC 1 load sharing starts to drop. Main Bus A voltage is 28.3 VDC.

55:58:08 MC and W - Main Bus A falls below 26.25 VDC. FC 2 carrying 45.4 amps of total Main Bus A load of 54.1 amps.

55:58:30 FC 1 carrying less than 2.0 amps at Main Bus A voltage of 25.6 VDC. FC 2 is carrying 50.2 amps at skin temperature of 413° F. FC 2 current started fluctuating between 50 and 55 amps with Main Bus A voltage between 25.2 and 25.8 VDC.

56:00 Assumed FC 1 and 3 off main busses. Requested crew reconnect FC 1 to Main A and FC 3 to Main B. Crew confirmed gray talkbacks. No change was detected in O2 flow readings.

56:00:05 MC and W unexplained - possible cycle of Main Bus A voltage above 26.25 VDC.

56:00:37 MC and W unexplained - Possibly Main Bus A voltage.

56:02:55 MC and W unexplained - Possibly Main Bus A voltage.

56:02:59 Sudden increase in FC 2 current from 54 amps to at least 67 amps. Automatic signal conditioning equipment (SCE) shutdown for approximately 0.4 seconds due to drop in Main Bus A voltage falling below required SCE operating level of approx. 23 VDC.

56:03:07 Battery A on line, Main Bus A voltage rises to 27.4 VDC. FC 2 current drops to approximately 35 amps and Battery A draws approximately 19 amps.

56:09 Requested crew open circuit FC 1 - confirmed.

56:19 Crew performed requested emergency power down per checklist E 1-5 and reduced current level to 41 amps total. First 14 steps were accomplished.

56:25 Inverter 1 connected to AC Bus 2 (on both AC busses, now) per request. This was to allow us to look at O2 Tank 2 readings.

56:26 FC 2 pumps back on per ground request (placed on AC 1).

56:32 Requested further powerdown -BMAG's off and lights to a minimum. E 1-5, steps 15 and 16)

56:33 Requested FC 3 open circuited.

56:35 Requested and got Surge tank isolated to preserve entry O2. Pressure read 858 psia at this time.

56:36:19 SC total current was decreased to cycling 40-46 amps. Battery A requested to be isolated from Main A and accomplished with 27.9 a-h remaining. FC 2 skin temp has risen to 436° F. and was stable.

56:37 Requested O2 Tank 1 heater ON to pump up decaying pressure which was 310 psi. No success.

56:38 Requested and got Repress pkg. isolated for same reason as Surge tank.

56:39 Requested O2 Tank 1 fans ON to try to get pressure up, but no success.

56:57 Verified FC 1 inline heater and DSE both OFF.

57:00 Crew performed FC 3 shutdown procedure per request. Purpose was to isolate possible O2 leak in fuel cell manifold by shutting reactant valves.

57:18 Crew performed FC 1 shutdown procedure per request. Purpose was same as for FC 3 at 57:00.

57:19 HGA power and overboard dump line heaters OFF.

57:27:11 Started charging battery A to get as much energy back in before loss of all O2; i. e., FC 2.

57:39 O2 Tank 2 fans ON as last ditch effort to see if any pressurization could be accomplished.

57:40 ECS 100 psi O2 manifold decreasing with O2 Tank 1 pressure of 130 psi.

57:48:54 Terminated Battery A charging with 0.74 a-h restored.

57:53 Primary coolant loop radiators bypassed and glycol pump turned OFF.

57:56 O2 Tank 2 fans off. There was no change in pressure or temp. FC 2 pumps turned OFF. All RCS heaters OFF.

58:04:05 Battery A tied to Main Bus A to support SC loads in anticipation of FC 2 loss. O2 Tank 1 pressure was 65 psi.

58:07 Primary USBPA - OFF

58:15 (approx.) FC 2 flooding occurred with loss of all O2 pressure.

58:18 O2 Tank 1 heaters and fans turned off. Panel 276, CB3 and CB 4 - opened (SM Instrumentation)

IMU powered down
CMC powered down
IMU heaters - OFF
SCS electronics - OFF
FDAI/GPI - OFF
Auto Jet Select (16) - OFF
Rotational Control power and Auto Coils - OFF

58:27 Direct RCS powered up to hold attitude.

58:36 FC 2 open circuited and reactant valves closed.
All inverters powered down.

58:40 Total CSM power down accomplished when Battery A taken off Main Bus A (20.5 a-h remained in battery). Batteries A, B, and C were isolated from all loads; i.e., off battery busses and main busses. Battery relay bus had been powered down and Main Bus Ties - OFF.

C. DORMANT CSM OPERATIONS PHASE (59+00 GET thru 136+00 (EI-6+30)

Shortly after the O2 Tank 2 anomaly, and after the CSM was completely powered down, it became apparent that knowledge of the complete CSM switch configuration was uncertain. This situation was expected to worsen as we developed new CSM procedures for crew operations. Work began on a "Baseline Configuration Checklist", then referred to as the "Square One List". The list was constructed by making changes to the prelaunch switch configuration section of the CSM Launch Checklist. This was accomplished and performed by the crew at 92 hours GET. The intent of this list was to remove all loads from busses and to provide a baseline for further procedural changes which would be required. This baseline would be reestablished whenever a particular procedure was completed.

Even before implementation of this list, a procedure to provide potable water with the drinking gun was developed since the 100 psi manifold did not have pressure. The procedure involved pressurizing the manifold, i.e., the water tank bladders, using the Surge tank whenever water was required. It was read to the crew at 64 hours GET.

The condition of Main DC Bus B was initially unknown due to the way FC 3 "died on the vine" and a Main Bus B checkout procedure was developed as a "delta" to the square one list. The procedure called for powering Main Bus B with Battery B to establish that there were no shorts and was performed at 95 hours GET. The baseline checklist had already isolated all loads from all busses.

It became apparent that the powered down CSM would become very cold by entry interface. Concern arose about the entry batteries ability at that time to provide sufficient potential to drive the battery bus-to-main bus tie motor switches to the Closed position. Hence, a Main Bus Ties Close procedure was read up and the crew closed the motor switches at 95 hours GET. The circuits were then left open using appropriate circuit breakers.

CO2 removal became cause for concern based on the lifetime of LM/PLSS LIOH canisters. The total manhour ratings added up to approximately 136 hours (not to exceed 7.6 mmHg). Based upon the quick return time home, the CO2 scrubbing would be required for approximately 261 manhours.

A negative margin existed (approximately 125 manhours) that required utilization of the CM LIOH canisters in which over 288 manhours of CO2 removal remained.

A simplified procedure was developed by Crew Systems Division personnel to use two CM LIOH canisters attached to the two LM ECS suit return hoses by placing a flight data file card bridged over the canister outlet side and sealing around the inlet hose ends inside the bridge with tape and plastic bag material to prevent collapsing due to suction. This procedure was later modified to create additional pressure drop within the LM ECS to prevent overspeed of the centrifugal water separator by partially taping over the outlet hose ends and over the complete CM LIOH canister inlet side bypass ports. This technique provided very low CO2 PP readings (approximately 0.1 mmHg) after installation when indicated cabin CO2 was approaching 8 mmHg on the LM secondary LIOH canister.

After approximately 20 hours (GET 93 to 113 hours) the CO_2 PP approached 1.8 mmHg on the two CM LIOH canisters. Another procedure was implemented at 113 hours to install two additional CM LIOH canisters in series with the initial two canisters by simply stacking and taping together. This technique provided very low CO2 PP readings for the remainder of the LM life support scrubbings requirements.

The CM reentry phase CO2 scrubbing was accomplished for 30 minutes with two newly installed canisters. Initially, the CO2 PP read 1.6 mmHg and 30 minutes later, when the suit compressor was deactivated, the CO2 PP had been lowered to 0.2 mmHg.

At 102 hours GET, a procedure for the First CSM Activation was initiated. It involved using battery B power for a partial power up to provide telemetry to MSFN for the purpose of systems and thermal evaluation of the spacecraft. The power up lasted less than 10 minutes showing the powered systems to be nominal and a 52° F cabin. It was decided to charge entry battery A as early as 112 hours GET (followed by battery B) to make sure this could be successfully accomplished. The entry sequence being developed was contingent upon full CM batteries. A series of procedures was necessary to effect CSM battery charging using LM power. The first, CSM to LM Power Transfer involved feeding the LM by Main Bus B power provided by CM Battery B just long enough to set the LM control relays which would then allow LM power to be fed to CSM Main Bus B. This accomplished, a Power Main B From LM procedure was performed and Main Bus B was successfully powered solely from the LM. The Battery A Charge procedure was initiated with battery A voltage and charger current readouts provided by the crew on request so that the flight control team could integrate the battery charge.

At 123 hours GET, battery A charging was interrupted to allow LM power to be provided for a Second CSM Activation. This was another partial power up to provide MSFN with telemetry for 7 minute look at systems and thermal data. The powered systems were again nominal and the cabin temperatures were at 46° F.

Battery A charge was resumed immediately and terminated at 126 hours GET and battery B charging was commenced using an appropriate procedure. When all charging was complete at 128 hours GET, the battery energy status was calculated to be:

Batt A	40.0 a-h
Batt B	40.0 a-h
Batt C	38.8 a-h (not charged
	118.8 a-h total

This total energy available was used to build the entry and post-landing phase power profile.

One procedure had been prepared but not read up to the crew. A procedure for Transfer of CM Waste Water to LM was ready in the event the LM ran short of water for cooling. It involved using the PLSS as a transfer tank and proved to not be necessary.

E . CONCLUSIONS AND RECOMMENDATIONS

1. Cryogenic Caution and Warning

A master caution and warning of the cryogenic O2 tank pressure problem was not available at the time of the O2 tank 2 failure because of a previous out-of-tolerance cryogenic H2 pressure condition. A low H2 tank 2 pressure warning precluded the warning of a high O2 tank 2 pressure. This demonstrates the undesirable feature of using a single caution and warning lamp driver circuit to provide both master alarm trigger signal and lamp activation for several parameters.

2. Fuel Cell Reactant Valves

It is probable that fuel cell 1 and fuel cell 3 would have continued to function properly until loss of Tank 2 oxygen pressure, as fuel cell 2 did, if the oxygen reactant valves had been reopened after the "bang". Unfortunately, positive warning cues were insufficient to allow the crew to perform the necessary corrective action. A circuit revision is required that would preclude a similar occurrence. For example, a circuit that would automatically reopen the valves, and give the crew a visual indication of the occurrence.

3. CM LIOH Canister Usage

Several alternate procedures were in work to control PP CO2. These are listed below in their order of priorities:

(a) The LM ECS and CM ECS be connected with the IVT suit hose for CO2 scrubbing within CM canister assembly. This procedure was thought to cause a high flow restriction for the LM compressor. It was learned later that this technique would have worked if the LM canisters were removed.

(b) Venting the combined cabins and replenishing with oxygen (100 percent) to nominal pressures. This procedure would be used as a last ditch effort because oxygen margins were not sufficient for many ventings and subsequent purgings plus efficiencies are very low for this mode of controlling high CO2 levels.

RECOMMENDATION:

CO2 scrubbing could have been accomplished by operating the CM suit compressor with two canisters installed in the canister assembly in their normal configuration.

This technique would have eliminated the makeshift LM setup plus creating some much needed heat in the CM cabin environment. However, the power requirement for this and the initial unknown condition of the CSM Main Bus B eliminated this setup.

D. ENTRY OPERATIONS PHASE

Immediately after the O2 Tank 2 anomaly occurrence and activities settled down, it became obvious that a modified, power conserving, entry sequence would be required. The initial cut of the entry phase power profile was completed at approximately 70 hours GET. This power profile was based on total battery energy capability of 98 amp-hours (no LM power), an EI -2 hour power up, and worst case recovery requirements (one uprighting and 12 hours on the water). Using this power profile as a guideline there was a margin of 23 amp-hours (based on a 40 amp-hour battery) remaining after uprighting.

After receiving additional entry requirements and expanding the timeline to provide the crew additional time, it was evident that the CSM batteries would have to be charged to a minimum of 115 amp-hours. This was performed as described in the dormant operations phase.

The entry sequence timeline was then eventually moved back to EI - 6+30. The primary plan of operation was to have the crew ingress the CM at EI -6 1/2 hours and use LM power to support Main bus B loads and battery C to support Main bus A loads, during CM RCS preheat and up to EI -2 1/2 hours where the CM went full internal. All possible loads during this time period were placed on Main B only (LM power). A contingency plan of operation using less power was also available, but not uplinked, in the event that the LM was unable to supply the CM with power during the entry phase (see figure 4 for redlines).

As can be noted from Figure 4, the actual battery energy margin was approximately 20 amp-hours above the redline at all times. Battery C was depleted, as predicted, prior to splash, thus leaving two good batteries (A and B) to support ELS sequential functions and Main Bus A and B loads. Figure 5 shows the load profile as predicted with real time loads superimposed on the predicted graph. It had been predicted that the Battery VI characteristic would be degraded due to low temperatures. This concern turned out to be invalid, as the Battery VI characteristic was comparable to previous flights with Main A = 29.2 VDC and Main B = 29.2 VDC for a total spacecraft load of 38 amps on two batteries. In the event that the loads had been higher than predicted, and the battery energy redline violated, the following equipment was planned to have been turned off in the order shown:

		Amps
(1)	BMAG No 2 (if G and N was GO)	2.5
(2)	S-Band Power Amp	4.1
(3)	PCM, SCE, PMP, and Xponder	2.7
(4)	Suit Compressor	4.0
(5)	Primary Coolant Loop (Pump and Evap)	3.7
(6)	EMS	1.0

General Comments on Entry Sequence Timeline

Hrs and Min

EI -6+30 The CM Main Buses were configured with the LM supplying power to Main Bus B and entry Battery C supplying power to Main Bus A.

This configuration was used until EI -2.5 hours with Main Bus B supplying power for CM RCS Ring 2 preheat, C and W equipment and lighting and with Main A supplying power for CM RCS Ring 1 preheat. Battery C was used because it was predicted that whichever battery was placed on line at this time would be depleted prior to splash, thus if Battery A or B had been used there would only have been one Battery Bus to support ELS functions which uses battery busses for redundancy.

EI -4+40 CM RCS activation was performed without a Go No/Go from MSFN on the arming of the SECS Pyro system. This was primarily because of: (1) The limitation of both the LM and CM to furnish power above the existing power requirements and, (2) the impact that it would have been on the timeline to power up the COMM equipment at this time.

EI -4+30 CM RCS checks and CM/SM separation was performed with no problems.

EI - 2+30 A complete transfer to CM entry batteries was performed which was followed by the power up of the Telcomm, G and N, and EPS systems. Maximum inverter efficiency was achieved by going to single inverter operation.

EI -1+30 The ECS coolant loop pump was turned on at this time to provide glycol circulation for the G and N system. A modified CM cabin pressure integrity check was performed by decreasing the CM tunnel/LM pressure to a ΔP of 3.0 to 3.5 and verifying the ΔP did not decrease. This is different than the normal integrity check, such that, the normal checklist has the tunnel pressure zero psia at LM/CM jettison.

EI -1+10 When the suit compressor was turned on, it was noted that the CO2 partial pressure decreased from 1.6 to 0.1 mmHg. This indicated the CO2 partial pressure was normal and the suit compressour could have been turned off then to conserve entry battery energy.

EI -30 When the primary evaporator was activated, the evaporator outlet temperature was 60° F. Temperature trends indicated that without an evaporator, i.e., the primary coolant loop, the evap out temp would not have exceeded the limit of 80° F prior to splash. Hence, the primary coolant loop evaporator could have been turned off to conserve power.

II. OPERATIONS

A. GENERAL COMMENTS AND RECOMMENDATIONS

1. Staff Support Room (SSR)

The EECOM SSR personnel performance during the mission was excellent. The EPS personnel in particular, are due special praise for their efforts since the O2 Tank 2 anomaly rapidly became a power managment problem both at the time of the anomaly and for entry planning.

2. HSD Format 30

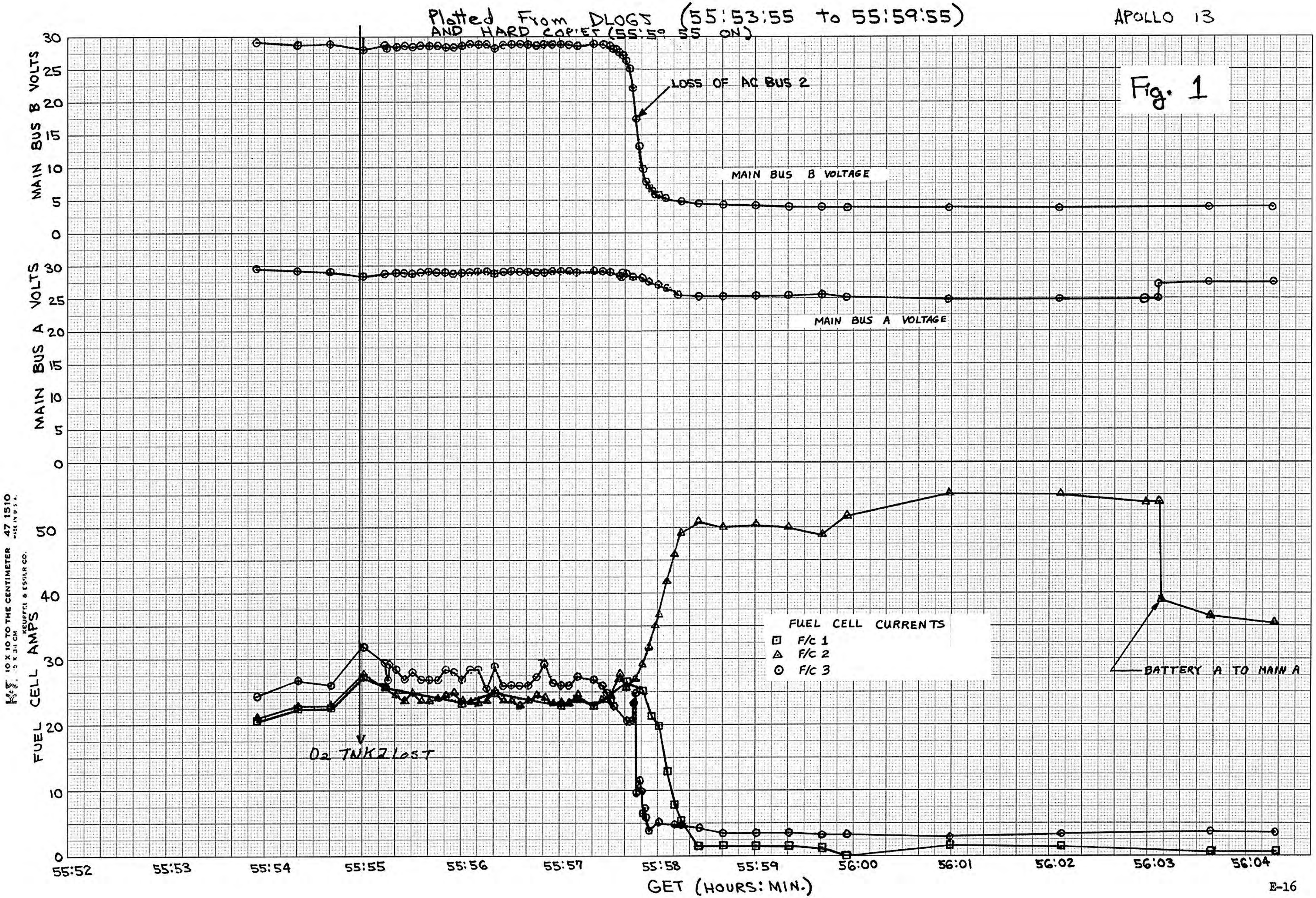
Format 30 was available for the first time on this mission and proved to be valuable. It was used extensively for data playbacks associated with the O2 Tank 2 anomaly.

3. Site Data Tapes

Early in the mission it was discovered that the NOD required the sites to only hold the data tapes for 24 hours (and without cutting a dupe) before shipment to GSFC. This was changed to 72 hours which should be made standard for all missions.

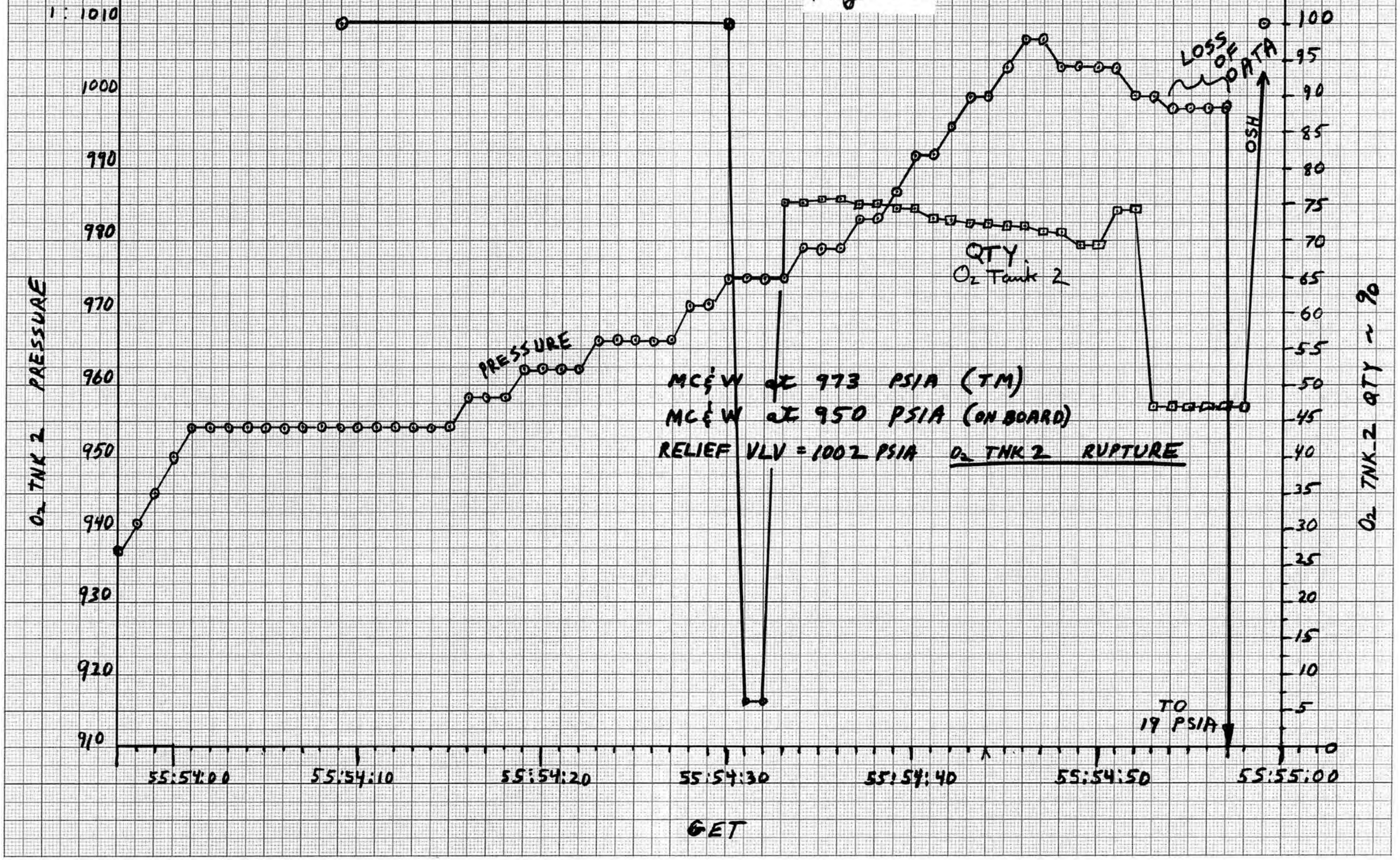
III. SUPPORTING INFORMATION

A. Graphs



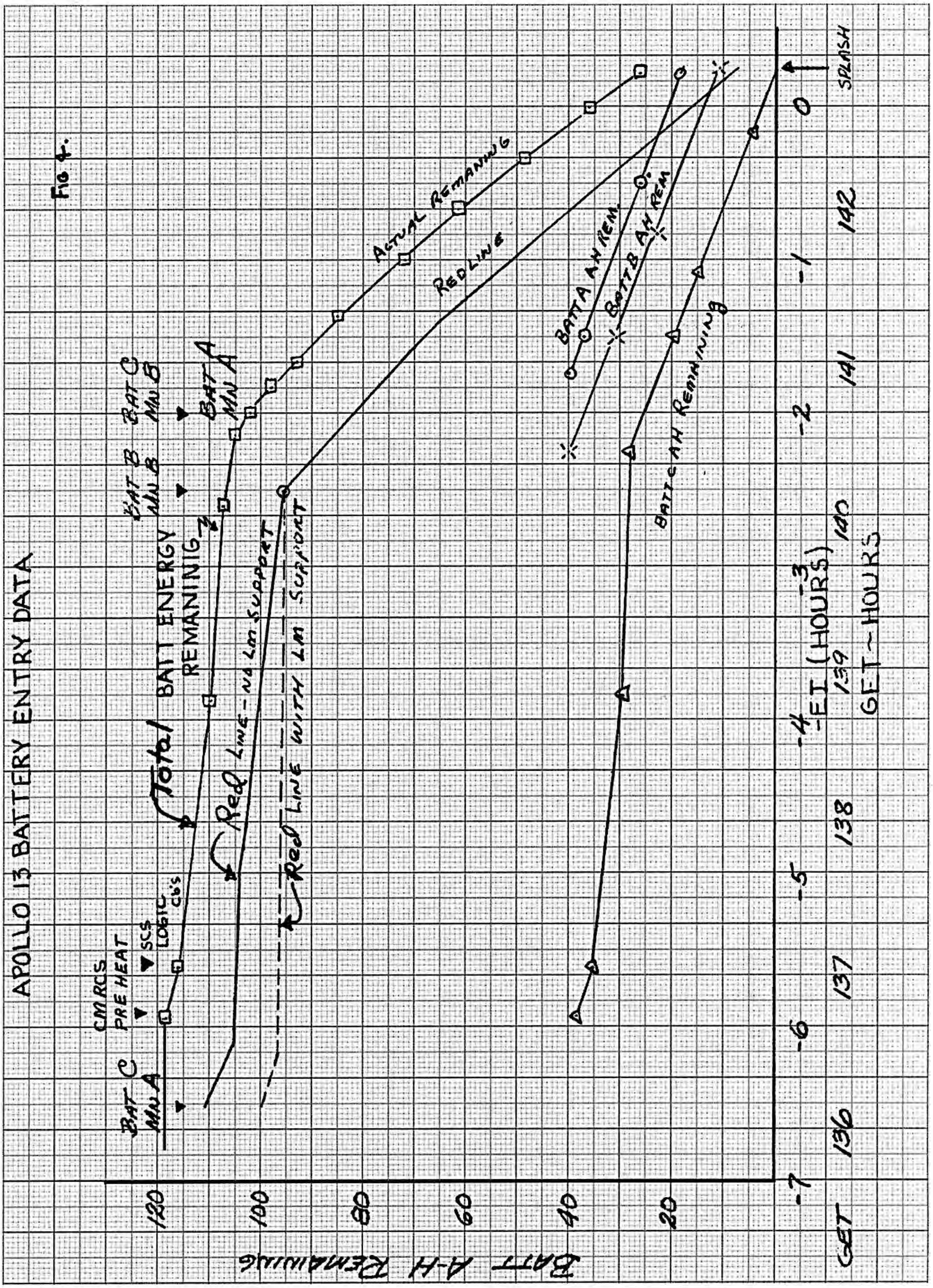
Plotted From DLOGS (55:53:55 to 55:59:55)
AND HARD COPIES (55:59 55 ON)
APOLLO 13
Fig. 1
MAIN BUS B VOLTS
LOSS OF AC BUS 2
MAIN BUS B VOLTAGE
MAIN BUS A VOLTS
MAIN BUS A VOLTAGE
FUEL CELL AMPS
FUEL CELL CURRENTS
F/C 1
F/C 2
F/C 3
BATTERY A TO MAIN A
O2 TNK 2 lost
55:52
55:53
55:54
55:55
55:56
55:57
55:58
55:59
56:00
56:01
56:02
56:03
56:04
GET (HOURS: MIN.)

Fig. 2



1:1010
1000
990
980
970
960
950
940
930
920
910
O2 TNK 2 PRESSURE
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
O2 TNK 2 QTY ~ %
PRESSURE
QTY
O2 Tank 2
LOSS OF DATA
OSH
MC&W at 973 PSIA (TM)
MC&W at 950 PSIA (ON BOARD)
RELIEF VLV = 1002 PSIA
O2 TNK 2 RUPTURE
TO 19 PSIA
55:54:00
55:54:10
55:54:20
55:54:30
55:54:40
55:54:50
55:55:00
GET


Fig. 3
○ = TANK 1
X = TANK 2
⊡ = SURGE TANK
◇ = MANF PRESS
△ = TANK 1 TEMP
• = TANK 2 TEMP
⌂ = TANK 2 QUANTITY
▽ = TANK 1 QUANTITY
55:53:37 GET
1ST RISE
TANK 2
+6372 PSI/hr
"NOTE"
O2 TANK 2 QUANTITY FAILED OFF SCALE HI AT 46:40:10 GET
'NOTE'
NO O2 C&W IS DUE TO H2 TANK 1 PRESS < 224
NO MC&W TANK 2 PRESS 970 - 975 PSI
TANK 2
10,160 PSI/hr
TANK 1
-37,600 PSI/hr
NO DATA
OFF SCALE HI
TANK 2 T.
OFF SCALE LOW -329°
@ ≈ 55:53:00 CREW WAS ASKED TO STIR O2 & CREW SAID OK
@ ≈ 55:54:55 CREW REPORTED NOISE ASSOCIATED W/ MC&W, WHEN DATA CAME BACK NO O2 TK 2 & O2 TK 1 WAS ON THE WAY.
TANK 1
-100.8 PSI/hr
TANK 1
-205.8 PSI/hr
891
858
DIFFERENT TIME SCALE
1 SEC
1 MIN
@ ≈ 56:39:00 O2 TK 1 HTRS TO MANUAL
@ ≈ 56:39:00 SURGE TANK ISOLATED
@ ≈ 56:12:00 MNB GONE, NO O2 TK 2 HTRS
@ ≈ 56:27:00 MNB ON FOR INSTR CK
@ ≈ 57:56:00 O2 TK 2 FANS OFF
@ ≈ 57:40:00 MANF PRESS DOWN
@ ≈ 58:18:00 O2 TANK 1 FANS & HTRS OFF
TANK QUANTITY %
TANK TEMP °F
TANK PRESS.
100%
50%
0%
GET - HRS: MIN: SEC
← GET HRS: MIN: SEC.
GET - HRS: MIN →
55:53:00
55:54:00
55:55:00
55:56:00
55:57:00
56:00:00
57:00:00
58:00:00


APOLLO 13 BATTERY ENTRY DATA
FIG 4.
Total BATT ENERGY REMANINIG
ACTUAL REMANING
REDLINE
Red LINE - NO LM SUPPORT
Red LINE WITH LM SUPPORT
BATT A AH REM.
BATT B AH REM
BATT C AH REMAINING
BAT C MN A
CM RCS PRE HEAT
SCS LOGIC CB'S
BAT B MN B
BAT C MN B
BAT A MN A
SPLASH
BATT A-H REMAINING
-EI (HOURS)
GET ~ HOURS
GET

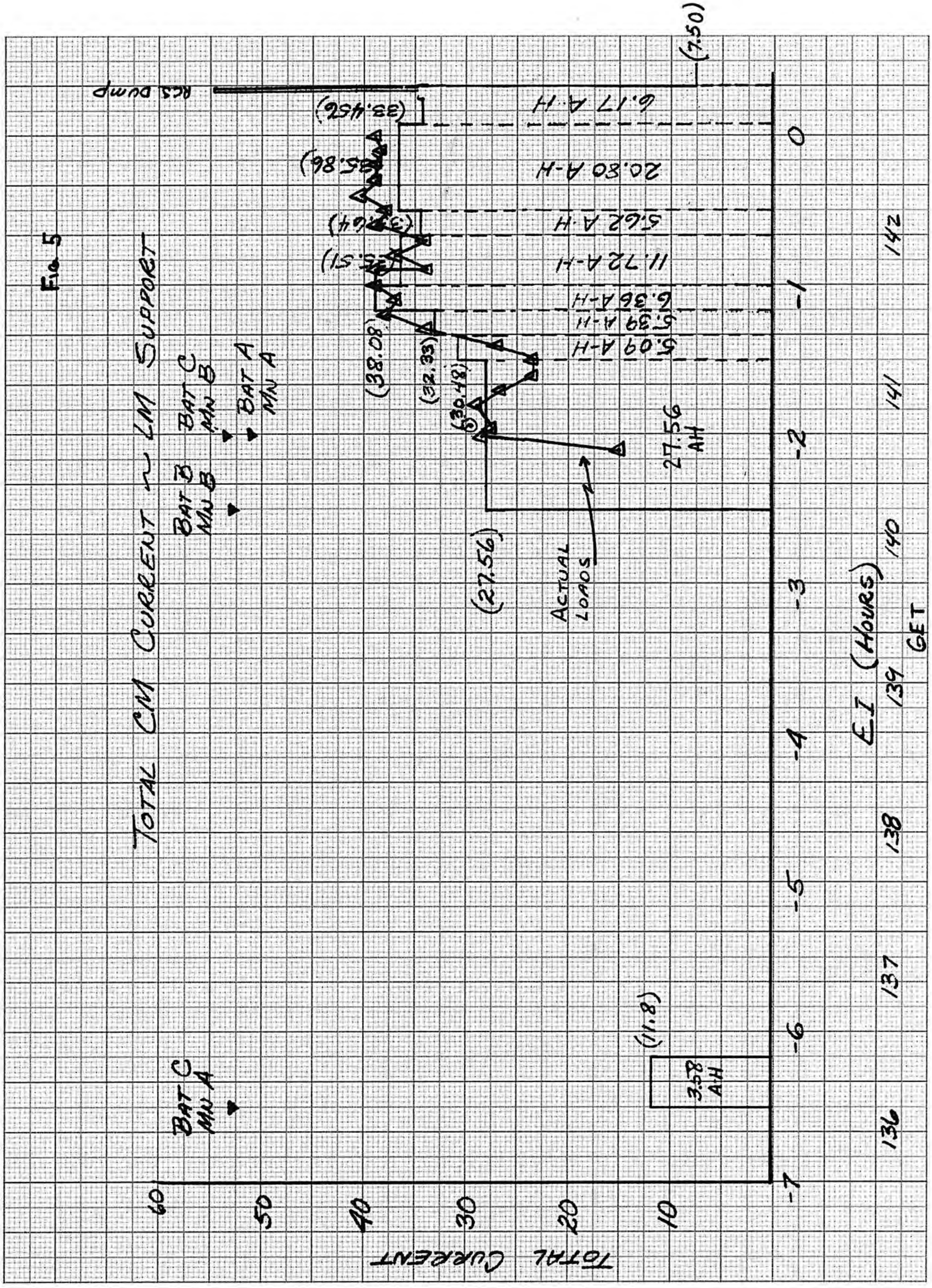


FIG 5
TOTAL CM CURRENT ~ LM SUPPORT
TOTAL CURRENT
EI (HOURS)
GET
BAT C MN A
BAT B MN B
BAT C MN B
BAT A MN A
ACTUAL LOADS
RCS DUMP
(7.50)
(11.8)
3.58 AH
(27.56)
27.56 AH
(30.48)
(32.33)
(38.08)
5.09 A-H
5.39 A-H
6.36 A-H
11.72 A-H
5.62 A-H
20.80 A-H
6.17 A-H
(35.86)
(33.456)
60
50
40
30
20
10
-7
-6
-5
-4
-3
-2
-1
0
136
137
138
139
140
141
142

Front Color ________

III. B. Emergency Checklist

EMER 1-5

EMERGENCY POWER DOWN	AMPS
HYCON CAMERA - OFF	5.1
O2 HTRS (2) - OFF (CTR)	11.1
O2 FANS (2) - OFF (CTR)	5.4
H2 HTRS (2) - OFF (CTR)	1.4
H2 FANS (2) - OFF (CTR)	0.7
G&N OPT PWR - OFF	3.1
POT H2O HTR - OFF	1.6 MAX
ECS RAD HTRS (2) - OFF	17.2 EA
SPS LINE HTR - OFF (CTR)	6.2 (A/B)
SPS GAUGING - OFF	3.0
GMBL MTRS P2 & Y2 - OFF (NOT LAUNCH)	10.0
cb SPS P1 & Y1 (Pnl 3) - OPEN	
TVC GMBL DR (P&Y) - 1	
IF UNSUITED, SUIT COMP - OFF	4.0
FC PUMPS (3) - OFF (UNTIL TSKIN >460°F)	3.7 TOTAL
SM RCS HTRS (4) - OFF	2.9 EA MAX
(ELECTRICALLY ISOLATE IF QUAD <55°F)	
BMAG #2 - OFF	2.6 from ON 1.9 from WARMUP
LIGHTS - MIN REQD	1.6
S BD PWR AMP - OFF (CTR)	4.0
TAPE RCDR - OFF (CTR)	1.6
ECS PRI GLY PUMP - OFF (G&N LIMIT 2.5 HRS)	2.6
SEC COOL EVAP - RESET (58 SEC), THEN OFF	4.3
SEC COOL PUMP - OFF (CTR)	
cb ECS RAD CONT/HTRS (2) (Pnl 5) - OPEN	
CMC POWERDOWN	6.3
CMC MODE - FREE	
G&N IMU PWR - OFF	
V48E	
F V04 N46 LOAD 0 (NO DAP) IN LEFT DIGIT OF R1	
PRO,PRO,PRO	
V46E	
V37E06E	
F V50 N25, 00062 CMC PWR DN	
PRO REPEATEDLY UNTIL STBY LT - ON	
G&N PWR - OFF	1.5
SCE PWR - OFF (CTR)	0.7
C/W NORMAL - ACK	
VHF AM (2) - OFF (CTR)	0.2 EA
HGA PWR - OFF	1.9
TELECOM GRP 1&2 - OFF	1.8
cb INSTR ESS MN A&B (Pnl 5) - OPEN	4.9

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Changed

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EPS

IIIC. Baseline Configuration Checklist

(Square one List)

TOFF CONFIG

PANEL 1

- ✗ EMS FUNC - ~~ΔV~~ OFF
- EMS MODE - STBY
- GTA - off (down)
- EMS GTA COVER - Secure
- CMC ATT - IMU ✓
- FDAI SCALE - 5/5
- ✗ FDAI SEL - ~~1/2~~ 1
- ✗ FDAI SOURCE - ~~CMC~~ GDC ✓
- ATT SET - GDC
- MAN ATT ROLL - RATE CMD
- ✗ MAN ATT PITCH - ~~ACCEL CMD~~ RATE CMD
- MAN ATT YAW - RATE CMD
- LIM CYCLE - OFF
- ATT DBD - MIN
- RATE - HIGH
- ✗ TRANS CONTR PWR - ~~on (up)~~ OFF
- ✗ RHC PWR NORM (2) - ~~AC/DC~~ OFF
- ✗ RHC PWR DIR (2) - ~~MNA/MNB~~ OFF
- SC CONT - SCS
- CMC MODE - FREE
- ✗ BMAG MODE ROLL - RATE ~~1~~ 2
- ✗ BMAG MODE PITCH - RATE ~~2~~ 2
- ✗ BMAG MODE YAW - RATE ~~1~~ 2
- SPS THRUST - NORMAL (lock)
- ΔV THRUST (2) - OFF (guarded)
- SCS TVC PITCH - AUTO
- SCS TVC YAW - AUTO
- SPS GMBL MOT PITCH (2) - OFF
- SPS GMBL MOT YAW (2) - OFF
- ΔV CG - LM/CSM
- ELS LOGIC - OFF (guarded)
- ✗ ELS AUTO - ~~AUTO~~ MAN
- ✗ CM RCS LOGIC - ~~on (up)~~ OFF (DOWN) ✓
- CM PRPLNT DUMP - OFF (guarded)
- CM PRPLNT PURG - off (down) (guarded)
- IMU CAGE - off (down) (guarded)
- EMS ROLL - OFF
- .05G sw - OFF

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Back Color__________

LIFTOFF CONFIG

✗ α/Pc IND sw - α Pc ✓
✗ LV/SPS IND SII/SIVB - ~~SII/SIVB~~ GPI ✓
TVC GMBL DR PITCH - AUTO
TVC GMBL DR YAW - AUTO
EVNT TMR RSET - up (center)
✗ EVNT TMR STRT - ~~center~~ STOP ✓
EVNT TMR MIN - center
EVNT TMR SEC - center

PANEL 2

PL VENT vlv - push (lock)
PROBE EXTD/REL - OFF (guarded)
PROBE EXTD/RETR (2) tb - gray
DOCK PROBE RETR PRIM - OFF
DOCK PROBE RETR SEC - OFF
EXT RUN/EVA LT - OFF
EXT RNDZ LT - off (center)
TUNL LT - OFF
LM PWR - OFF
SM RCS He 1 (4) - center (on,up*)
SM RCS He 1 tb(4) - gray
UP TLM CM - BLOCK
UP TLM IU - BLOCK
CM RCS PRESS - off (down) (guarded)
SM RCS IND sw - PRPLNT QTY
SM RCS He 2 (4) - center (on,up*)
SM RCS He 2 (4) tb - gray
SM RCS HTRS (4) - OFF
SM RCS PRPLNT (4) - center (on, up*)
✗ SM RCS PRPLNT tb (3) - ~~gray~~ SM RCS PRPLNT tb (4) - bp -
RCS CMD - center (OFF*)
RCS TRNFR - center (SM*)
CM RCS PRPLNT (2) - center (on,up*)
CM RCS PRPLNT tb(2) - gray
SM RCS SEC FUEL PRESS (4) - Center (CLOSE*)
✗ EDS AUTO - on ~~(up)~~ OFF
CSM/LM FINAL SEP (2) - off (down) (guarded)
CM/SM SEP (2) - off (down) (guarded)
SIVB/LM SEP - off(down)(guarded)
✗ PRPLNT DUMP - ~~AUTO~~ RCS CMD
✗ 2 ENG OUT - ~~AUTO~~ OFF ✓
✗ LV RATES - ~~AUTO~~ OFF

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OFF
*TWR JETT (2) - ~~AUTO~~ (down) (guarded)
LV GUID - IU
LV STAGE - off(down)(guarded)
XLUNAR - INJECT
MN REL - off(down)(guarded)
MSN TMR HR - off (center)
MSN TMR MIN - off (center)
MSN TMR SEC - off (center)
* C/W NORM - ~~BOOST~~ ACK
* C/W CSM - ~~CSM~~ CM
* C/W PWR - ~~1~~ OFF
C/W LAMP TEST - off (center)
MSN TMR - START
RCS IND sel - SM D
CAB FAN (2) - OFF
* H2 HTRS (2) - ~~AUTO~~ OFF
* O2 HTRS (2) - ~~AUTO~~ OFF
O2 PRES IND sw - SURGE TK
H2 FANS (2) - OFF
O2 FANS (2) - OFF
ECS IND sel - PRIM
ECS RAD FLOW AUTO CONT - AUTO
ECS RAD tb - gray
ECS RAD FLOW PWR CONT - off (center)
ECS RAD MAN SEL - RAD 1
ECS RAD PRIM HTR - off (center)
ECS RAD SEC HTR - OFF
POT H2O HTR - OFF
SUIT CKT H2O ACCUM AUTO - 1
SUIT CKT H2O ACCUM - off (center)
SUIT CKT HT EXCH - off (center)
SEC COOL LOOP EVAP - off (center)
SEC COOL LOOP PUMP - off (center)
H2O QTY IND sw - POT
GLY EVAP IN TEMP - MAN
GLY EVAP STM PRESS AUTO - MAN
GLY EVAP STM PRESS INCR - center
GLY EVAP H2O FLOW - off (center)
CAB TEMP - MAN
CAB AUTO TEMP tw - max decr
HI GAIN ANT TRACK - AUTO
HI GAIN ANT BEAM - WIDE
HI GAIN ANT PITCH POS - 0°

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HI GAIN ANT YAW POS - 180°
HI GAIN ANT PWR - OFF
HI GAIN ANT SERVO ELECT - PRIM

PANEL 3

VHF ANT - SM LEFT
SPS ENG INJ VLV ind (4) - CLOSE
FC RAD (3) - center (NORMAL*)
FC RAD (3) tb - N/A
* FC HTRS (3) - ~~on (up)~~ OFF ✓
FC IND sel - 2
SPS QTY TEST - off (center)
OXID FLOW VLV INCR - ~~[illegible]~~ INCR
OXID FLOW VLV PRIM - PRIM
PUG MODE - NORM
FC PURG (3) - OFF
FC REAC (3) - center (o[illegible]*)
FC REAC tb (3) - gray
* FC 1 MN BUS A - ~~center (on, up*)~~ OFF ✓
FC 1 MN BUS A tb - gray
* FC 2 MN BUS A - ~~center (on, up*)~~ OFF ✓
FC 2 MN BUS A tb - gray
FC 3 MN BUS A - OFF
* FC 3 MN BUS A tb - ~~bp~~ gray ✓
* MN BUS A RSET - ~~center (RESET*)~~ OFF ✓
FC 1 MN BUS B - OFF
* FC 1 MN BUS B tb - ~~bp~~ gray ✓
FC 2 MN BUS B - OFF
* FC 2 MN BUS B tb - ~~bp~~ GRAY ✓
* FC 3 MN BUS B - ~~center (on, up*)~~ OFF ✓
FC 3 MN BUS B tb - gray
* MN BUS B RSET - ~~center (RESET*)~~ OFF ✓
DC IND sel - MNA
BAT CHARGE - OFF
SPS He vlv (2) - AUTO
SPS He vlv tb (2) - bp
SPS LINE HTRS - off (center)
SPS PRESS IND sw - He
* S BD XPNDR - ~~PRIM~~ CENTER (OFF) ✓
S BD PWR AMPL PRIM - PRIM
* S BD PWR AMPL HI - ~~HIGH~~ CENTER (OFF) ✓
* PWR AMPL tb - ~~gray~~ bp ✓

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L
1-5

S BD MODE VOICE - VOICE
S BD MODE PCM - PCM
S BD MODE RNG - RNG
S BD AUX TAPE - off (center)
S BD AUX TV - off (center)
UP TLM DATA - DATA
* UP TLM CMD - ~~NORM~~ OFF ✓
S BD ANT OMNI - B
S BD ANT - OMNI
VHF AM A - (center)
* VHF AM B - ~~DUPLEX~~ CENTER ✓
VHF AM RCV - off (center)
VHF AM SQLCH tw (2) - noise threshold + 1 div
VHF BCN - OFF
VHF RNG - OFF
* S BD SQUELCH - ~~ENABLE~~ OFF ✓
* FC REACS vlv - ~~LATCH~~ NORMAL ✓
H2 PURG LINE HTR - OFF
TAPE RCDR PCM - PCM/ANLG
TAPE RCDR RCD - RCD
* TAPE RCDR FWD - ~~FWD~~ CENTER ✓
* TAPE MOTION tb - ~~gray~~ bp ✓
* SCE PWR - ~~NORM~~ CENTER ✓
* PMP PWR - ~~NORM~~ CENTER ✓
PCM BIT RATE - HI
* AC INV 1 - ~~MNA~~ OFF ✓
* AC INV 2 - ~~MNB~~ OFF ✓
AC INV 3 - OFF
* INV 1 AC 1 - ~~on (up)~~ OFF ✓
INV 2 AC 1 - OFF
INV 3 AC 1 - OFF
* AC 1 RSET - ~~center (RSET*)~~ OFF ✓
INV 1 AC 2 - OFF
* INV 2 AC 2 - ~~on (up)~~ OFF ✓
INV 3 AC 2 - OFF
* AC BUS 2 RSET - ~~center (RSET*)~~ OFF ✓
AC IND sel - BUS 2ØC

PANEL 4

* SPS GAUGING - ~~AC1~~ OFF ✓
* TELCOM GRP 1 - ~~AC1~~ OFF ✓
* TELCOM GRP 2 - ~~AC2~~ OFF
* GLY PUMPS ~~- 1 -~~ AC1 - OFF ✓

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* SUIT COMPR ~~1 - AC1~~ (BOTH) - OFF ✓
SUIT COMPR 2 - OFF
CB Panel 4 - all closed

PANEL 5

* FC1 PUMPS - ~~AC1~~ OFF ✓
* FC2 PUMPS - ~~AC2~~ OFF –
* FC3 PUMPS - ~~AC2~~ OFF –
* G/N PWR - ~~AC1~~ OFF –
* MN BUS TIE BAT A/C - ~~on (up)~~ OFF –
* MN BUS TIE BAT B/C - ~~on (up)~~ OFF –
BAT CHGR - AC1
NONESS BUS - OFF
* INT INTGL LT - ~~as desired~~ OFF –
* INT FLOOD LT - OFF, ~~full dim or full bright~~
INT FLOOD LT DIM - 1
INT FLOOD LT FIXED - OFF
* cb Panel 5 all ~~closed except:~~ OPEN ✓
~~cb INST NONESS - open~~
~~cb INST SCI EQUIP SEP 1 - open~~
~~cb INST SCI EQUIP SEP 2 - open~~
~~cb INST SCI EQUIP HATCH - open~~
~~cb WASTE H2O/UR DUMP HTRS (2) - open~~

PANEL 6

MODE - INTERCOM/PTT
* PWR - ~~AUDIO/TONE~~ OFF ✓
INTERCOM - T/R
PAD COMM - OFF
S BD - T/R
VHF AM - T/R
AUDIO CONT - NORM
* SUIT PWR - ~~on (up)~~ OFF ✓
tw settings - as desired

PANEL 7

* EDS PWR - ~~on (up)~~ OFF ✓
* SCS TVC SERVO PWR #1 - ~~AC1/MNA~~ OFF ✓
* SCS TVC SERVO PWR #2 - ~~AC2/MNB~~ OFF ✓
* FDAI/GPI PWR - ~~BOTH~~ OFF ✓
* LOGIC 2/3 PWR - ~~on (up)~~ OFF –

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SCS ELEC PWR - ~~GDC/ECA~~ OFF
SCS SIG CONDR/DR BIAS 1 - ~~AC1~~ OFF
SCS SIG CONDR/DR BIAS 2 - ~~AC2~~ OFF
BMAG PWR ~~(2) - ON~~ (BOTH) - OFF
DIRECT O2 vlv - ~~open (CCW) - (0.2 - .4 - 120 on SUIT/CAB ΔP ind)~~ CLOSE

PANEL 8

cb Panel 8 - all closed except:
cb CM RCS HTRS (2) - open
cb FLOAT BAG (3) - open
cb SCS LOGIC BUS (4) - OPEN
cb SPS PITCH, YAW (4) - OPEN
cb SPS GAUGING (4) - OPEN
cb SECS ARM (2) - OPEN
cb EDS (3) - OPEN
cb ELS BAT A BAT B (2) - OPEN
cb PL VENT FLT/PL - OPEN
cb SCS DIRECT ULL (2) - OPEN
cb SM RCS HTR A MN B - open
cb SM RCS HTR C MN B - open
" " " B MN A - open
" " " D MN A - open

AUTO RCS SEL A/C ROLL A1 - OFF
AUTO RCS SEL A/C ROLL C1 - OFF
AUTO RCS SEL A/C ROLL A2 - OFF
AUTO RCS SEL A/C ROLL C2 - OFF
AUTO RCS SEL B/D ROLL B1 - ~~MNA~~ OFF
AUTO RCS SEL B/D ROLL D1 - ~~MNB~~ OFF
AUTO RCS SEL B/D ROLL B2 - ~~MNA~~ OFF
AUTO RCS SEL B/D ROLL D2 - ~~MNB~~ OFF
AUTO RCS SEL PITCH A3 - ~~MNB~~ OFF
AUTO RCS SEL PITCH C3 - ~~MNA~~ OFF
AUTO RCS SEL PITCH A4 - ~~MNA~~ OFF
AUTO RCS SEL PITCH C4 - ~~MNB~~ OFF
AUTO RCS SEL YAW B3 - ~~MNA~~ OFF
AUTO RCS SEL YAW D3 - ~~MNB~~ OFF
AUTO RCS SEL YAW B4 - ~~MNB~~ OFF
AUTO RCS SEL YAW D4 - ~~MNA~~ OFF
INT NUM LT - ~~as desired~~ OFF
INT INTGL LT - ~~as desired~~ OFF
INT FLOOD LT - OFF, ~~full dim, or full~~ brt
FLOOD LTS DIM - 1
FLOOD LTS FIXED - OFF
FLOAT BAG (3) - VENT (locked)
SECS LOGIC (2) - ~~on (up) (locked)~~ OFF (DOWN)
SECS PYRO ARM (2) - ~~on (up) (locked)~~ OFF (DOWN)

PANEL 9

MODE - INTERCOM/PTT
PWR - ~~AUDIO/TONE~~ OFF
INTERCOM - T/R
PAD COMM - OFF
S BD - T/R
VHF AM - T/R

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AUDIO CONT - NORM
* SUIT PWR - ~~on (up)~~ OFF
VHF RNG - NORM
tw settings - as desired

PANEL 10

MODE - INTERCOM/PTT
* PWR - ~~AUDIO/TONE~~ OFF
PAD COMM - OFF
INTERCOM - T/R
S BD - T/R
VHF AM - T/R
AUDIO CONT - NORM
* SUIT PWR - ~~on (up)~~ OFF
tw settings - as desired

PANEL 12

LM TUNL VENT vlv - LM/CM ΔP

PANEL 13

FDAI sw (2) - INRTL
EARTH/LUNAR - PWR OFF
ALT SET - 100
LTG - OFF
MODE - HOLD/FAST
SLEW - off (center)

PANEL 15

COAS PWR - OFF
UTIL PWR - OFF
PL BCN LT - off (center)
PL DYE MARKER - off (down)(guarded)
PL VENT - OFF

PANEL 16

DOCK TRGT - OFF
UTIL PWR - OFF
COAS PWR - OFF

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PANEL 100

UTIL PWR - OFF
FLOOD LTS DIM - 1
FLOOD LTS FIXED - OFF
OPT PWR - OFF
* IMU PWR - ~~on (up) (guarded)~~ OFF ✓
RNDZ XPNDR - OFF
* NUMERICS LT - ~~as desired~~ OFF ✓
* FLOOD LTS - off, ~~full dim, or full bright~~ ✓
* INTGL LT - ~~as desired~~ OFF ✓

PANEL 101

SYS TEST (LH) - 4
SYS TEST (RH) - B
CM RCS HTRS - OFF
* UR DUMP - ~~HTR A~~ OFF ✓
* WASTE H2O DUMP - ~~HTR A~~ OFF ✓
RNDZ XPNDR - OPR

PANEL 122

OPT ZERO - ZERO
OPT TELTRUN - SLAVE TO SXT
OPT COUPLING - DIRECT
OPT MODE - MAN
OPT SPEED - LO
* COND LAMPS - ~~ON~~ OFF ✓
UP TLM - ACCEPT

PANEL 162

SCI PWR - OFF (verified at panel closeout)

PANEL 163

SCI/UTIL PWR - OFF (verified at panel closeout)

PANEL 201

FOOD WARMER - OFF

PANEL 225

cb Panel 225 - all closed except:
cb HI GAIN ANT FLT BUS - open
cb HI GAIN ANT GRP 2 - open
* cb S-BAND FM XMITTER DATA STOWAGE EQUIP GROUP 1 - OPEN ✓
* cb FLT BUS "MN A" & "MN B" (BOTH) - OPEN ✓ FLT BUS - OPEN
* cb CTE (BOTH) - OPEN ✓
cb RNDZ XPNDR FLT BUS - OPEN

Basic Date 3/9/70 Changed

CSM 109

PANEL 226

* cb Panel 226 - all ~~closed~~ OPEN except:
~~cb FC REACS (3) - open~~
~~cb FC RAD (3) - open~~
~~cb COAS/TUNL LTG MNB - open~~
cb LIGHTING FLOOD MNA, MNB, & FLT/PL - CLOSED (3)
cb LIGHTING NUMERICS/INTEGRAL LEB AC 2, LMDC-AC1, & RMDC-AC1 - CLOSED (3)

PANEL 227

SCI PWR - OFF

PANEL 229

cb Panel 229 all closed except:
cb MAIN REL PYRO (2)- open
cb 02 VAC ION PUMPS (2) - open
* cb TIMERS MNA & MNB (2) - OPEN

PANEL 250

* cb Panel 250 - all ~~closed~~ OPEN except:
~~cb PYRO A TIE TO BAT BUS A - open~~
~~cb PYRO B TIE TO BAT BUS B - open~~
~~cb BAT C TO BAT BUS A - open~~
~~cb BAT C TO BAT BUS B - open.~~
cb SEQ A - CLOSED
cb SEQ B - CLOSED

PANEL 251

WASTE MGMT OVBD DRAIN vlv - OFF

PANEL 252

BAT VENT vlv - CLOSED
* WASTE STOWAGE VENT vlv - ~~VENT~~ CLOSED

PANEL 275

* cb Panel 275 - all ~~closed~~ OPEN ~~except~~:
~~cb MNA BAT C - open~~
~~cb MNB BAT C - open~~
~~cb FLT/PL BAT BUS A - open~~
~~cb FLT/PL BAT BUS B - open~~
~~cb FLT/PL BAT C - open~~

Basic Date ____ Changed ____

Basic Date 3/9/70 Changed ____

CSM 109

PANEL 276

cb Panel 276 - all closed

PANEL 278

OPEN
cb Panel 278 - all ~~closed~~ ~~except:~~
~~cb UPRT SYS COMPR (2) - open~~

PANEL 300

LH SUIT FLOW vlv - FULL FLOW

PANEL 301

RH SUIT FLOW vlv - FULL FLOW

PANEL 302

CTR SUIT FLOW vlv - FULL FLOW

PANEL 303

PRIM CAB TEMP vlv - COLD (CW)
SEC CAB TEMP vlv - COOL-MAX (CW)

PANEL 304

DRNK H2O SUPPLY vlv - OFF (CW)

PANEL 305

FOOD PREP COLD H2O vlv - rel
FOOD PREP HOT H2O vlv - rel

PANEL 306

MSN TMR - ~~START~~ STOP ✓
EVNT TMR RSET - UP (center)
EVNT TMR STRT - ~~center~~ STOP ✓
EVNT TMR MIN - center
EVNT TMR SEC - center
MSN TMR HR - center
MSN TMR MIN - center
MSN TMR SEC - center

(Trim front page on solid crop marks; back page on dash crop marks.)

PANEL 325

* CAB PRESS RELF vlv (RH) - ~~BOOST/ENTRY~~ NORMAL
* CAB PRESS RELF vlv (LH) - ~~BOOST/ENTRY~~ NORMAL
PRIM GLY TO RAD vlv - BYPASS (pull)

PANEL 326

* REPRESS PKG vlv - ~~ON~~ OFF
* SM O2 SUPPLY vlv - ~~ON~~ OFF
* SURGE TK O2 vlv - ~~ON~~ OFF
* GLY RSVR IN vlv - ~~OPEN~~ CLOSED
* GLY RSVR BYPASS vlv - ~~CLOSE~~ OPEN
* GLY RSVR OUT vlv - ~~OPEN~~ CLOSED

PANEL 350

CO2 CSTR DIVERT vlv - both (center)

PANEL 351

* MAIN REG vlv (2) - ~~open~~ CLOSED
* H2O/GLY TK PRESS REG vlv - ~~BOTH~~ OFF
* H2O/GLY TK PRESS RELF vlv - ~~BOTH~~ OFF
EMER CAB PRESS vlv - OFF
CAB REPRESS vlv - OFF (CCW)

PANEL 352

WASTE TK SERVICING vlv - CLOSE
PRESS RELF vlv - 2
POT TK IN vlv - OPEN
WASTE TK IN vlv - AUTO

PANEL 375

SURGE TK PRESS RELF vlv - open (CW)

PANEL 376

PLVC - NORMAL (up)

Basic Date
Changed

Basic Date 3/9/70
Changed

CSM 109

PANEL 377

GLY TO RAD SEC vlv - BYPASS (CCW)

PANEL 378

PRIM GLY ACCUM vlv - open (CCW)

PANEL 379

PRIM ACCUM FILL vlv - OFF (CW)

PANEL 380

* O2 DEMAND REG vlv - ~~BOTH~~ OFF ✓
SUIT TEST vlv - OFF
* SUIT CKT RET vlv - ~~close (push)~~ OPEN ✓ (PULL)

PANEL 382

SUIT HT EXCH PRIM GLY vlv - FLOW (CCW)
SUIT FLOW RELF vlv - OFF
PRIM GLY EVAP IN TEMP vlv - MIN (CCW)
SUIT HT EXCH SEC GLY vlv - FLOW (CCW)
* SEC EVAP H2O CONT vlv - ~~AUTO (CW)~~ OFF (CCW)
* PRIM EVAP H2O CONT vlv - ~~AUTO (CW)~~ OFF (CCW)
H2O ACCUM vlv (2) - RMTE (CCW) ← CREW Reported WENT TO OFF

PANEL 600

EMER O2 vlv - close

PANEL 601

REPRESS O2 vlv - close

PANEL 602

REPRESS O2 RELF vlv - OPEN (CW)

FWD HATCH

PRESS EQUAL vlv - CLOSE
ACTR HNDL sel - stow/check locked

(Trim front page on solid crop marks; back page on dash crop marks.)

SIDE HATCH

CAB PRESS DUMP vlv - close (CW)
GEAR BOX sel - LATCH
ACTR HANDLE sel - UNLATCH
LOCK PIN REL KNOB - LOCK
LOCK PIN ind - flush
GN2 VLV HANDLE - outboard
BPC JETT KNOB - toward BPC JETT

* - last momentary position before liftoff.

Basic Date ____
Changed ____

Basic Date 3/9/70
Changed ____

CSM 109

MSC FORM 2206 (JUN 67)

III. D. Dormant Operations Phase Procedures

A. Transfer Pot H_2O from CM drinking gun

B. Main Bus B Checkout

C. Closing Bus Tie Procedure

D. Additional Utilization of CM Lioh Canisters

E. First CSM Activation (TM Only)

F. LM to CSM Power Transfer

G. Transfer of LM Power to Main B

H. Batt A Charge Procedure

I. Second CSM Activation for TLM (Using LM Pwr)

J. Charge of Batt B Following Batt A Charge

K. CM H_2O Transfer to LM Procedure

A. TRANSFER POT. H_2O FROM CM

A. Turn off the following valves:

Repress Pkg

Emergency Cabin Press

Direct O_2

Demand Reg.

Water Accumulator

SM Supply

B. Turn on the following valves:

Main Regulators

Water & Glycol tanks pressure inlet & outlet both

C. Turn surge tank on & cycle H_2O as necessary

B. MAIN BUS B CHECKOUT

MDC 3	DC Indicators SW - Bat Bus B
MDC 5	Battery Charger Bat B Chg - Closed
	EPS Sensor Signal MNB - Closed
RHEB 250	Bat B Pwr Entry/Postlanding CB - Closed
	(Verify Battery Bus B voltage okay with zero current)
RHEB 275	Main Bus B Bat Bus B CB - Close
MDC 5	Main Bus Tie Bat B/C - Bat B/C
	(Verify no change in battery voltage or current)
MDC 3	DC Indicators SW - Main Bus B
	(Verify good bus voltage)
MDC 5	Main Bus Tie Bat B/C - Off
RHEB 275	Main Bus B Bat Bus B CB - Open
RHEB 250	Bat B Pwr Entry/Postlanding CB - Open
MDC 5	Battery Charger Bat B Chg - Open
	EPS Sensor Signal MNB - Open

MDC 5	cb Batt Chg Batt A Charge - Closed
	cb Batt Chg Bat B Charge - Closed
	cb EPS Sensor Signal MNA - Closed
	cb EPS Sensor Signal MNB - Closed
Pnl 250	cb Batt A Pwr Entry/Post Ldg - Closed
250	cb Batt B Pwr Entry/Post Ldg - Closed
275	cb Main A Bat Bus A - Closed
275	cb Main B Batt Bus B - Closed
	Read Bat Bus Voltage
MDC 5	Main Bus Tie A/C - Bat A/C
	Read Main A Volts & Batt A Cur.
	Main Bus Tie B/C - Bat B/C
	Read Main B Volts & Batt B Cur.
	To reconfigure reverse procedure except:
	Main Bus Tie A/C - Batt A/C
	Main Bus Tie B/C - Batt B/C

D. Additional UTILIZATION OF CM LiOH Canisters

A procedure has been developed to permit easier crew rigging for the fresh CM LiOH cartridges when it is time to change (estimated time GET 121:00 hrs). Uptaping and rebagging can be avoided by using the following:

1. Cut a piece of tape approximately 3 feet long.

2. Make a belt around the sides at the top of the new CM cartridge with sticky side out.

3. Cut 4 pieces approximately 2" square from an EVA cue card. Bend each square in half to form a 90° angle. These squares will be used as corner supports when attaching the cartridges in series.

4. Remove plug from old cartridge bypass and insert same plug in bottom bypass of new cartridge.

5. Arrange in series with top of new cartridge on bottom of old cartridge.

6. Put corner supports on sticky tape so that they overlap both cartridges.

7. Make sufficient wraps of tape around cartridges to seal and hold th together.

8. Repeat 1-7 to rig the other unit.

For Orignal utilization procedure Reference TEXT Section I.C. (Dormat operation phase)

E. FIRST CSM ACTIVATION (TM ONLY)

Panel 4	Telcom Gp 1 - AC1	(OFF)
Panel 5	The following cb's closed:	
	ECS Press Group 1 MN B	(OPEN)
	ECS Press Group 2 MN B	(OPEN)
	ECS Temp MN B	(OPEN)
	ECS Sec Loop Xducer MN b	(OPEN)
	ECS Rad Contl/Htrs MN B	(OPEN)
	Bat Rly Bus Bat B	(OPEN)
	BAT CHGR BAT B CHG	(OPEN)
	Inverter Control 1	(OPEN)
	Inverter Control 2	(OPEN)
	EPS Sensor Signal AC 1	(OPEN)
	EPS Sensor Signal MN B	(OPEN)
	EPS Sensor Unit AC Bus 1	(OPEN)
	Waste and Pot H_2O MN B	(OPEN)
	Instruments Ess. MN B	(OPEN)
Panel 3	Transponder - Prim	
	Pwr Amp - Prim (verify)	
	Pwr Amp - High	
	Mode Voice - Off	(Voice)
	Power Sce - Norm	(Off)
	PMP - Norm	(Off)
	S-Band Ant - Omni D	Omni B

Panel 225	cb Flt Bus Mn B - Close	(Open)
	CTE MN B - Close	(Open)
Panel 250	cb BATC Bat Chg/EDS 2 - Close	(Open)
	cb BATC Pwr Entry/Post Lndg - Close	(Open)
Panel 275	cb Main B Bat Bus B - Close	(Open)
	cb Inverter Pwr 2 MN B - Close	(open)
Panel 250	cb Bat B Pwr Entry/Post Lndg - Close	
MDC 3	AC Inverter 2 - MN B	
	AC Inverter 2 Bus 1 - ON (up)	(Off)
MDC 3	AC Inverter AC Bus 1 - Reset (Then CTR)	
MDC 3	Up TLM - (CMD Reset (then Off)	
	Select Best OMNI	
	The following onboard readouts are required:	
MDC 3	Batt C Voltage	
	Pyro Bat A Voltage	
	Pyro Bat B Voltage	
	Sps He Press	
Panel 101	CM RCS Injector Temps	
	Positions 5C, 5D, 6A, 6B, 6C & 6D	
	Bat Manifold Press	
	Position 4 A	
	Backout	

Panel 3	Pwr Amp - Off
	Transponder - Off
	AC Inverter 2 - Off
Panel 250	cb Bat B Pwr Entry/Post Lndg - Open
	Reconfigure all other switches and breakers as configured prior to this procedure as noted in red.

F. LM TO CSM POWER TRANSFER

ASSUMES ALL DES BATTERIES ON-LINE AND NO ASCENT BATTERIES ON-LINE

LM CB (11 and 16) - ASC ECA - CLOSE (2)
BATT 6 NORM FEED - ON
BATT 1, 2, 3, and 4 - OFF/RESET

CSM CONNECT LM/CSM UMBILICAL
CB - LM PWR-1 MN B - CLOSE
CB - LM PWR-2 MN B - CLOSE
CB BATT B PWR ENTRY/POST LANDING - CLOSE
CB EPS SENSOR SIGNAL MAIN B - CLOSE
CB MAIN B BATT BUS B - CLOSE
VERIFY MAIN BUS VOLTAGE
LM PWR SW - CSM
CB MAIN B BATT BUS B - OPEN
CB BATT B PWR ENTRY/POST LANDING - OPEN
VERIFY MAIN BUS B VOLTAGE

LM BATT 1, 2, 3, and 4 - HI VOLT - ON

NOTES:

1. CIRCUIT BREAKER PROTECTION LIMITS CURRENT TO 15 AMPS
2. LM/CSM UMBILICAL IS "HOT" AND MAIN BUS VOLTAGE MAY BE MONITORED BY SELECTING MAIN B

POWER REMOVAL FROM CM/LM UMBILICAL

ASSUMES ALL DESCENT BATTERIES ON-LINE AND ASCENT BATTERY 6 ON NORMAL FEED

CSM CB66 LM PWR 2 - OPEN
CB74 LM PWR 1 - OPEN
EPS SENSOR SIGNAL cb MAIN B - OPEN

LM CB(16) EPS : BAT FEED TIE (2) - OPEN
BAT 1 HV - OFF/RESET
BAT 2 LV - OFF /RESET THEN ON
BAT 2 HV - OFF/RESET THEN ON
BAT 1 HV - ON
CB(16) EPS: BAT FEED TIE (2) - CLOSE

G. TRANSFER OF LM POWER TO MAIN B

LM CB (11 & 16) ASC ECA - Close

ASC ECA Cntl - Close

Batt 5 & 6 Norm Feed - On

Batts 1 & 3 - Off/Reset

Wait 30 Min.

Batt 2 & 4 - Off/Reset

CSM Open all CB's on Main B listed on Fig. 3.1, Flight Data File (Bus Dist. Matrix)

Connect LM/CSM Umbilicals

LM Pwr - 1 MNB CB - Close (MDC 5)

LM Pwr - 2 MNB CB - Close (MDC 5)

Batt B Pwr Entry/Post Landing CB - Close

Batt Chg Batt B Chg CB - Close (MDC-5)

Main B - Batt Bus B CB - Close

Main Bus Tie - Batt B/C

Verify Main B Voltage by:

(A) EPS Sensor Signal Main B CB - Close (MDC 5)

(B) DC Indicator - Main B

LM Pwr SW - CSM (MDC 2)

Main Bus Tie Batt B/C - Off

Batt B Pwr Entry/Post Landing CB - Open (Pnl 250)

IMU Htr Main B CB - Close (MDC 5)

EPS Sensor Signal Main B CB - Open (MDC 5)

LM Batt 1, 2, 3, 4 - HI Volt - On

BATT A CHARGE

PANEL 250	CHARGE START	CHARGE TERMINATION
CB BATT A PWR ENTRY/POSTLANDING	- CLOSE	
PANEL 275		
CB INVERTER PWR 2 MAIN B	- CLOSE	OPEN
PANEL 5		
CB BAT RELAY BUS BAT A	- CLOSE	OPEN
CB EPS SENSOR UNIT AC BUS 2	- CLOSE	OPEN
CB EPS SENSOR SIGNAL AC-2	- CLOSE	OPEN
CB BATTERY CHARGER MN B	- CLOSE	OPEN
CB BATTERY CHARGER AC PWR	- CLOSE	OPEN
CB BATTERY CHARGER BAT A CHG	- CLOSE	OPEN
CB INVERTER CONTROL 2	- CLOSE	OPEN
CB INVERTER CONTROL 3	- CLOSE	OPEN
SW MAIN BUS TIE BAT A/C	- OFF	--
CW BAT CHARGE	- AC-2	AC-1
PANEL 3		
SW AC INVERTER 2	- MNB	
SW (65) INVERTER 2 AC BUS 2	- ON (UP)	OFF
SW (67) AC BUS 2 RESET	- RESET (CENTER)	OFF
SW BATTERY CHARGE	- A	
SW DC INDICATOR SEL	- BAT CHARGER	MN-B

REPORT CHARGER CURRENT AND VOLTAGE TO MSFN EVERY 10 MINUTES FOR FIRST 1/2 HOUR: THEN ONCE EVERY 30 MINUTES. (MSFN WILL CALL)

FOR CHARGE TERMINATION - DO BELOW FIRST THEN GO TO PREVIOUS BACKOUT PROCEDURE.

PANEL 3	CHARGE START	CHARGE TERMINATION
SW BATTERY CHARGE		- OFF
SW INVERTER INVERTER 2		- OFF
PANEL 5		
SW MAIN BUS TIE BAT B/C		- ON (UP)
PANEL 250		
CB BAT A PWR ENTRY/POSTLANDING		- OPEN
CB BAT B PWR ENTRY/POSTLANDING		- OPEN
PANEL 5		
CB BATTERY CHARGER BAT B CHG		- OPEN

DATA PASS USING LM POWER

I. (2nd CSM Activation for TLM)

1. Same procedure as passed up for last CSM data pass

   except:

   Page 1

   Pwr Amp - Low

   Page 2

   Pnl 275

   Delete cb Main B Bat B - Close

Attached is the proposed procedure to obtain a second hack of CSM data utilizing.

1. LM Pwr to Main Bus B
2. AC Bus 1
3. Inverter 2
4. Goldstone 210' site
5. Low Power

J. CHARGE OF BAT B FOLLOWING BAT A CHARGE

PNL 3

SW	BATTERY CHARGE	— OFF	

PNL 5

SW	MAIN BUS TIE BAT A/C	— BAT A/C	(UP)
cb	BATTERY CHARGER BAT A CHG	— OPEN	
cb	BATTERY CHARGER BAT B CHG	— CLOSE	

PNL 250

cb	BAT B PWR ENTRY/POSTLANDING	— CLOSE	

PNL 5

SW	MAIN BUS TIE BAT B/C	— OFF	(DOWN)

PNL 3

SW	BATTERY CHARGE	— B	

FOR CHARGE TERMINATION - DO BELOW FIRST
THEN GO TO LIST

PNL 3

SW	BATTERY CHARGE	— OFF
SW	AC INVERTER INVERTER 2	— OFF

PNL 5

SW	MAIN BUS TIE BAT B/C	— BAT B/C (UP)

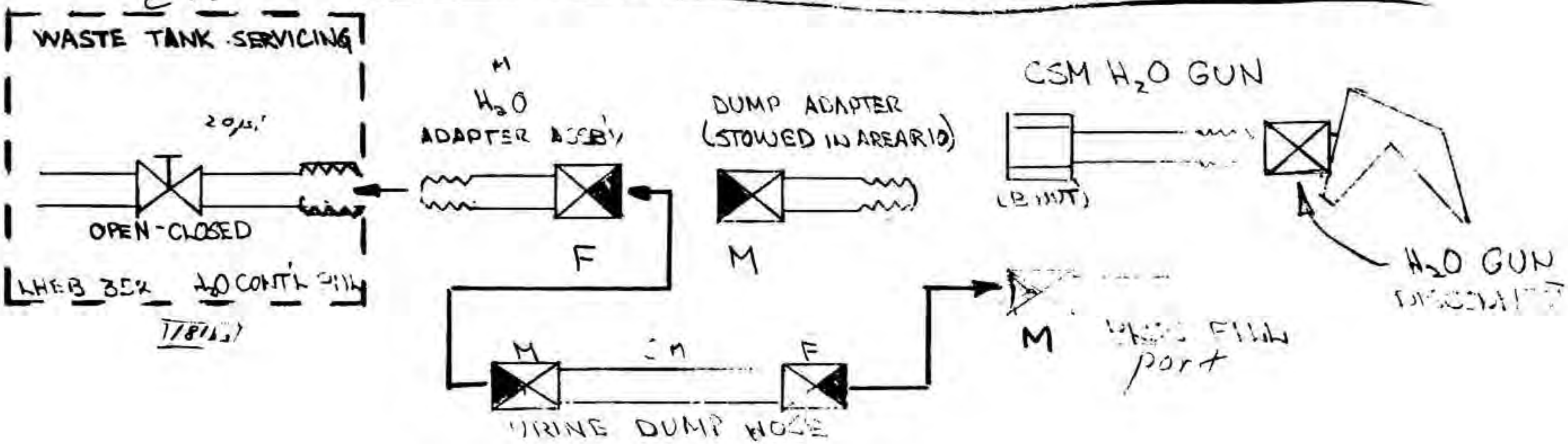
PNL 250

cb	BAT A PWR ENTRY/POSTLANDING	— OPEN
cb	BAT B PWR ENTRY/POSTLANDING	— OPEN

K. CM H_2O TRANSFER TO LM PROCEDURE (& Sketch)

1. Pressurize H_2O tanks per procedure used for drinking gun H_2O.
2. Remove plug from port on waste tank servicing panel.
3. Install H_2O adapter assembly in port.
4. Connect urine dump hose to H_2O adapter assembly.
5. Connect PLSS to urine dump hose.
6. Open waste tank servicing vlv until PLSS is full (per sight glass) then close waste tank servicing vlv and disconnect PLSS.
7. Transfer H_2O from PLSS to LM H_2O tanks per procedure used to empty PLSS tanks originally.

XFR of CM Waste Water to LM



ENTRY SEQUENCE
REV 6
4/17/70

CHECKLIST

EI-6+30

COPY LM & CM PADS

INSTALL LIOH CANISTERS, STOW ORDEAL

EMS MNA & MNB	- OPEN
PNL 8 FLOOD	- FIXED
PNL 5 INTERIOR LTS REHOSTAT TO FLOOD	
LEB100 FLOOD	- FIXED
BATT A ENTRY & PL CB	- CLOSED
BATT B ENTRY & PL CB	- CLOSED
BATT C ENTRY & PL CB	- CLOSED
CB BATT CHRG BATT A CHRG	- CLOSE
CB BATT CHRG BATT B CHRG	- CLOSE
BATT RELAY BUS BATT A & B	- CLOSED
MAIN BUS TIES (2)	- ON (UP)
EPS SENSOR SIG MNA MNB	- CLOSE
MNA BATT C CB	- CLOSED
INST PWR CNTL CB 3 & 4	- OPEN
ESS INST PWR MNB CB	- CLOSED
PRIM EVAP H_2O CNTL VLV	- AUTO (CW)
SEC EVAP H_2O CNTL VLV	- AUTO (CW)
CM RCS PREHEAT	TO TO E 1-5 STEP 35
C&W MNB CB	- CLOSED
C&W PWR	- 1
EPS SENSOR UNIT DC BUS A&B	- CLOSE
MAIN BUS A&B	- RESET/CENTER

EI-5+05

EARTH TERMINATOR AGS ALIGN

EI-5+00

MCC 7

MANEUVER TO SEP ATTITUDE

EI-4+40

PERFORM PYRO BATT CHECK STEP 39 E 1-6

PNL 8

ALL CLOSED EXCEPT

DIR ULLAGE MNA & MNB	- OPEN
CM RCS HTR MNA & MNB	- OPEN
SMRCS HTRS C MB	- OPEN
SM RCS HTRS D MNA	- OPEN
EMS (2)	- OPEN
SPS GAUGING (4)	- OPEN
SPS P & Y (4)	- OPEN
FLOAT BAG (3)	- OPEN
EDS (3)	- OPEN
PL VENT/FLT/PL	- OPEN

CM RCS ACTIVATION STEP 41 E 1-6

EI-4+30

LM CONFIGURED FOR CMRCS HOT FIRE

G/N IMU HTR MNB	- CLOSED
ROT CNTL PWR NORMAL (2)	- AC/DC
SCS LOGIC PWR 2/3	- ON
RCS COMMAND	- ON

CM RCS CHECK STEP 4 E 2-1 WITH EXCEPTION OF FOLLOWING:

MAN ATT SW TO ACCEL CMD VICE MIN IMP

DELETE STEPS: RCS TRANS - SM
MAN ATT (3) - RATE CMD
S/C CONT - CMC AUTO

LOCK RHC'S

SECS PYRO (2)	- ARM
LM +X 0.5 FT/SEC	
CM/SM SEP (2)	- ON (UP)
LM -X 0.5 FT/SEC	
SECS PYRO (2)	- SAFE
SECS LOGIC (2)	- OFF (DOWN)

LM PITCH UP TO ACQUIRE SM AND PHOTOGRAPH

(LM USE ACA FOR ALL ROTATIONS)

EI-3+00

LM START MANEUVER TO "MOON VIEW" ATTITUDE

G/N COMPUTER MNB - CLOSED

V37E 06E PRO (HOLD UNTIL DSKY BLANKS)

EI-2+30

CB ESS INST MNA - CLOSED

CB IUM HTR MNA - CLOSED

CB G/N COMPUTER MNA - CLOSED

CB LM PWR 1 - OPEN

CB LM PWR 2 - OPEN

CB MNB BATT BUS B - CLOSED

INVERTER PWR 1, 2, 3 - CLOSED

BATT RELAY BUS BATT A&B CB - CLOSED

INV CONTROL 1-2 & 3 CB'S - CLOSED

AC INVERTER 1 - MNA

AC INV AC BUS 1 - ON (UP)

AC INV AC BUS 2 - ON (UP)

EPS SENSOR SIG AC 1 & 2 - CLOSED

EPS SENSOR UNIT AC 1 & 2 - CLOSED

C&W MNA - CLOSED

AC INV AC BUS 1 & 2 - RESET (CNTR)

PNL 225

FLT BUS MNA & MNB - CLOSED

CTE MNA & B - CLOSED

PNL 4

TELECOM GROUP 1 - AC 1

TELECOM GROUP 2 - AC 2

S-BAND NORM XPONDER - PRIM

PWR SCE - NORM

PWR PMP - NORM

UPTEL CMD RESET - RESET THEN NORM

UP TM - ACCEPT

PNL 275

FLT AND P.L. MNA & MNB - CLOSED

CONFIGURE FOR COMM ON PNL 6, 9 & 10

IMU MNA & B - CLOSED

OPTICS MNA & B - CLOSED

G&N PWR AC 1 - CLOSED

G&N PWR AC 2 - CLOSED

G&N PWR SW - AC-2

PERFORM CMC POWER UP - G 2-2

THEN EMOD, CLOCK INCREMENT UPDATE (COMPLETE BY EI-2+15)

STATE VEC, 2 REFSMATS: ENTRY TARGET, V66

PERFORM IMU POWER UP - G 2-1

PERFORM OPTICS POWER UP - G 2-3

PNL 229

CB TIMERS MNA - CLOSED

SET MISSION TIMER

CSM

V41 N20

R_____ P_____ Y_____ (FROM LM ATTITUDE)

V40 N20 WHEN AT LM FDAI MOON VIEW ANGLES,

SET REFSMMAT AND DRIFT FLAGS

V37E 52E OPTION 1

COARSE ALIGN

MARK ON MOON

LM MANEUVER TO SUN ATTITUDE: MARK ON SUN

TORQUE (NOUN 93)

LM MANEUVER TO JETTISON ATTITUDE (WATCH GIMBAL LOCK)

LM MAX DB, ATT HOLD

CB MAIN A BATT BUS A - CLOSED

CB MAIN B BATT C - CLOSED

EI-1+30

PROCEED WITH CLOSEOUT AND HATCH INSTALLATION; CLOSE LM HATCH
CLOSE DUMP VLV

PERFORM HATCH DECAL

LM TUNNEL VENT VLV - CM/LM DELTA P

SURGE TANK - ON

MAIN REGS (2) - OPEN

EMERG CABIN REGS - BOTH

SUIT DEMAND REGS - BOTH

WATER AND GLYCOL TANK REGS INLET AND OUTLET - BOTH

ECS TRANSDUCERS PERSS GROUP 1 & 2 MNA & MNB (4) - CLOSED

ECS GLYCOL PUMPS 1 - AC-1

INCREASE CABIN PRESS TO 5.5 PSIA USING DIRECT O_2

VENT TUNNEL TO 3.0 to 3.5 ΔP

VERIFY LM-CM DELTA P - POSITIVE AND NOT DECREASING FOR 10 MINS

ECS TRANSDUCERS TEMP MNA & MNB - CLOSED

EI-1+20

BMAG NO. 1 PWR - WARMUP

EI-1+10

SCS PWR UP G 2-4

WITH CHANGES

1. DELETE STEP 1

2. SIG COND DRI BIAS PWR - ON

BMAG PWR 1 - ON

FDAI PWR - 1

BMAG MODE (3) - RATE 1

SUIT COMPRESSOR 2 - A/C 1

S/C CONTROL - SCS

MAN ATT SWITCHES (AS DESIRED)

PERFORM GDC ALIGN

ROT CNTL PWR DIRECT 1 & 2 - MNA/MNB

EI-1+00

V37E - 47E

SECS PYRO ARM (2) - UP/ON

CSM/LM FINAL SEP (2) - UP/ON

SECS PYRO ARM (2) - SAFE

PRO 00E

CONFIGURE FOR SINGLE RING
MANEUVER TO ENTRY ATTITUDE

EI-55 MINS

SEXTANT STAR CHECK

PARK OPTICS 90° SHAFT

OPTICS POWER OFF

STOW OPTICS

PERFORM EMS CHECK STEP 32 E1-4

INITIALIZE EMS STEP 2 E2-1

EI-45 MINS

ENTRY PAD & STATE VECTOR

MANEUVER TO MOON "CHECK" ATTITUDE (36° WINDOW MARK)

EI-40

BMAG NO.2 PWR - WARMUP

VERIFY SURGE TANK & REPRESS PKG ON

CB ECS CONT SYS WASTE WATER/URINE DUCT HTRS (2) - CLOSED

SUIT COMPRESSOR 2 - OFF

EI-30

BMAG NO. 2 PWR - ON

FDAI PWR - BOTH

SECS LOGIC (2) - ON (UP)

ACTIVATE PRIMARY EVAPORATOR

GO TO ENTRY CHECKLIST E 2-2 (P61)

EI-19 P61

EI-3 (MOON SET)

CHECK IMU AND GDC ATT - INTO CHECKLIST E 2-5 HORIZON CHECK

BEGIN BLACKOUT

APPENDIX F

CSM Guidance and Navigation Officer (GNC)

GNC APOLLO 13

POST MISSION REPORT

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William J. Strahle

John A. Kamman

1. SMRCS - Prior to 55+54 GET, the only SMRCS anomaly was the Quad D P/T ratio instrumentation. This readout had, for some period of time after TD&E, remained at full scale high. It subsequently indicated correctly and the problem was attributed to inability of the transducer to follow the changes during the high usage period around TD&E.

Concurrent with the loss of the MNB and AC-2 busses the auto coils selected to MNB lost their enable power. The rates caused by the venting resulted in a great many thruster commands but with reduced thruster authority. During this period, the crew used direct RCS from RHC 2 to assist in vehicle control.

Shortly after the power loss, single jet control was available using Quad B jets for Yaw control and Quad C for Roll and Pitch. The Quad D fuel and oxidizer manifold pressures had decreased several PSI. The crew was requested to activate the HE valves on Quad D. The manifold pressures returned to normal values confirming that the HE isolation valves had been closed by the shock of the O2 tank rupture.

Subsequently, the crew reported continued trouble damping the vehicle rates. This was because the DAP had A/C roll selected and the crew had turned off thruster A1. With this configuration ± Yaw, -Pitch and -Roll was the only control available. There was at this time no indication of Quad C propellant usage forcing the conclusion that either the fuel and oxidizer primary propellant isolation valves were closed or that Quad C was inoperable because of damage. Since both the propellant valves and their talkback indicators required MNB power, the anomaly was left open. The crew subsequently selected B/D roll in the DAP and selected MNA on the RCS jet selects to regain auto control. Figures 1 through 4 show the SMRCS propellant usage on this flight.

2. CMRCS - The CMRCS performed normally during this mission with no anomalies noted.

Because of the thermal conditions existing up to the time of SM jettison, the instrumented RCS injectors were below the minimum temperature for operation and required 20 minutes pre-heat. After heating was completed, the jets were hot fired in accel command with the crew reporting that all jets fired.

With the long time lapse between the hot fire and LM jettison, the injector temps were again checked at approximately EI-2hrs. At this readout, 2 temps were found to be below the 28° limit and it was requested that the appropriate jets be fired prior to LM jettison. The spacecraft was in an attitude with a high middle gimbal angle and the LM hatch was closed. Since the control direction of the Yaw jets could possibly aggravate the platform middle gimbal angle, it was decided to forego the firing and accept the slight possibility of a jet problem.

3. SPS - There were no SPS anomalies during this flight. Figure 5 is a plot of the propellant tank surface temperatures and shows an interesting but unexplained rise in the temperature sensor located in SM BAY 3. There is no data indicating damage to the SPS as a result of the O2 tank fracture.

4. G&N System - The G&N System exhibited adequate performance throughout the mission. The entire G&N System, including the IMU heaters was powered down at 58+17 and powered up again $2\frac{1}{2}$ hours prior to EI. The IMU heaters and CMC were brought on at EI-$3\frac{1}{2}$ hours. The CMC was powered for 2 hours and the IMU for 1 hour prior to entry without coolant flow. At the time the coolant pumps were brought on the stable member was 129.6°F and subsequently cooled by $.3^{\circ}$F. The highest coolant temperature encountered was 60°F, therefore, the IMU heaters never approached the temperature (75°F) where they would be off 100% of the time. The entry time line was more than adequate in terms of G&N cooling.

Inertial Parameters - The IMU PIPA bias in the Z-axis was observed to be slightly high prior to TLI. (.005 ft/sec^2). We chose not to update the bias PRE-TLI, because it was reflecting some components of acceleration due to booster venting and its effects would not be significant in monitoring TLI. Measurements of all three PIPA biases post TLI showed much better consistency. The Z-pipa, after TLI, exhibited the null bias phenomenon, that is, it did not show any drift. When the platform was powered up for entry, the Z PIPA bias shifted from its previous measured value. The bias of -.0547 ft/sec^2 was updated in the CMC at EI-45 minutes. Table 1 is a history of the PIPA bias measurements taken throughout the mission.

Four measurements of gyro drift were obtained. At 32+03, on the basis of three measurements, the values for all three gyrc drifts were updated in the CMC. One data point was available after the updɛte. It shows that we essentially nulled the drift rates in the Y and Z axes by updating, but accomplished no improvement in the X axis. This bias represented -1.1 MERU error in the X axis, so no further updates were required. (The mission rule criteria is 3 MERU after an update has been attempted.) Table 2 is a compilation of the gyro data obtained.

Optics-Shaft Oscillations - The optics CDU shaft telemetry at 40 hours GET showed oscillations from 0 to .6 degrees. We asked the crew to compare Noun 91 (shaft and trunnion angles) to the mechanical counters on the optics. The oscillation was evident from both sources and occurred in the OPTICS ZERO mode only. The problem was no constraint to the optics function. However, we recommended that the optics be powered down when not in use to preclude physical wear. This same problem occurred on Apollo 12. Post flight analysis on Apollo 12 showed a transformer in the OPTICS ZERO feedback loop to be the most likely cause of the failure.

5. SCS - The SCS performed nominally. However, we did observe that when the BMAG #1 package was powered up at EI-1+20, it took longer (90 sec) for the yaw gyro to output nulled rates than the other two axes. This particular gyro apparently took longer to spin up than the other two axes. During the entry power up sequence, the crew readouts showed that Main Bus A was loaded by 2 amperes. Our plan was to keep that bus isolated until LM power was to be disconnected. It was found that our checklist had not included isolating SCS power from Main A, so we requested that the crew turn off the SCS 2/3 Logic Power switch, which cut the power drain on Main A in half.

6. EMS - Several EMS bias tests were conducted. As a result, we biased the EMS VC used for MCC-2 by .34 ft/sec^2. Comparing the EMS and G&N subsequent to MCC-2 showed an EMS % error of 3.9. The test results and comparisons are given in Tables 3 and 4.

7. PTC - Two attempts at PTC initiation were aborted. The PTC attempt at 8 hours was aborted because it was begun under single jet roll control and accomplished at an incorrect roll rate. After discussing both points with

the crew, PTC was reinitiated successfully. At 32+22, another attempt at initiating PTC was unsuccessful. For some unexplained reason, the minus roll jets fired in opposition to the desired roll rotation 13 seconds after initiation. Our investigation through playbacks and delogs reaffirmed that the procedure had been correctly executed and that the G&N should not have fired the minus roll jets. The G&N rates in roll prior to the firing showed a slight increase (.02°/sec) that was not reflected in the SCS rates. However, this should not have caused a jet firing. No anomalous operation of the RCS dap, control systems, or G&N, was exhibited prior or subsequent to this occurrence. PTC was restarted with no problem.

8. Control Systems Operations-O2 Tank Rupture - In order to determine if the control systems might have contributed to the O2 tank rupture we constructed a sequence of events from playback data, delogs, and chart recorder information. Generally the control systems performed as would be expected under the conditions prevailing on the vehicle buses. (No Main Bus B, no AC-2, no Quad C.) Table 5 is the event sequence.

9. Entry Timeline - The entry timeline was developed by the White Team and reviewed by all teams. From the GNC standpoint, it was an exercise in off nominal operation in terms of G&N warm-up time and BMAG warmup and operation in an attempt to help conserve battery energy. Systems problems encountered and mission action taken have been included in this report. Section II will provide a more detailed evaluation and conclusions that can be derived from pre-entry operations data.

TABLE 1

PIPA BIASES

APOLLO 13

	X	Y	Z
Loaded Values	-.0056	-.0075	-.0013
Time (GET)	ft/sec^2	ft/sec^2	ft/sec^2
00+22+42	-.0032	-.0072	-.0000
00+55+39	-.0092	-.0068	.0033
01+32+56	-.0062	-.0066	.0020
01+41+40	-.0037	-.0064	.0041
02+27+10	-.0066	-.0068	.0042
3+52+56	-.0061	-.0067	.0005
5+19+20	-.0063	-.0064	.0003
6+18+10	-.0059	-.0065	.0001
6+51+50	-.0059	-.0066	.0000
8+46+12	-.0063	-.0067	.0001
9+34+05	-.0062	-.0069	.0000
11+09+52	-.0064	-.0067	.0000
13+09+01	-.0062	-.0068	.0000
16+22	-.0065	-.0065	.0000
17+57	-.0067	-.0066	.0000
19+36	-.0068	-.0065	.0000
20+06	-.0071	-.0065	.0000
21+17	-.0069	-.0065	.0000
23+53	-.0068	-.0064	.0000
25+35	-.0068	-.0065	.0001
28+04	-.0068	-.0065	.0000
30+26	-.0071	-.0066	.0000
33+45	-.0064	-.0067	.0001
36+48	-.0066	-.0067	.0000
38+57	-.0067	-.0067	.0000
40+38+29	-.0067	-.0067	.0--0
42+38+01	-.0069	-.0067	.0--0
43+28+12	-.0068	-.0066	.0--0
45+21+53	-.0069	-.0066	.0--0
48+08+16	-.0069	-.0067	.0--0
53+00+	-.0069	-.0064	.0--0
55+12	-.0071	-.0062	.0--0
56+48	-.0074	-.0051	.0012
57+11	-.0096	-.0044	.0006
57+43	-.0101	-.0045	.0--0
140+43+59	-.0008	.0000	-.0024
140+49+29	-.0054	-.0048	-.0546
140+59+47	-.0052	-.0055	-.0547 (UPDATED)
141+09+00	-.0007	-.0063	-.0532
141+19+00	-.0041	-.0056	-.0541

TABLE 2

TORQUE CMD - MERU (GYRO DRIFT)

GET	X	Y	Z	Δt (HRS)
10+40+15	-1.6	-1.5	+1.2	5.18
23+47+30	-1.4	-0.8	+2.0	13.12
29+00+30	-1.1	-1.0	+1.9	5.22
32+03+--	Updated All Three Axes			
49+08+35	-1.1	-0.2	+0.1	20.13

TABLE 3 - EMS ΔVC BIAS TEST RESULTS

PRE TLI	+0.008 FT/SEC^2
POST TLI	+0.010 FT/SEC^2
10+05	+0.018 FT/SEC^2
29+40	+0.015 FT/SEC^2

TABLE 4 - G/N - EMS COMPARISON

BURN	PROP SYS	ΔVT (PAD)	$\Delta V_{TAILOFF}$ (PAD)	EC-NULL DRIFT	ΔVC (PAD)	ΔVCR (RESIDUAL)	ΔVCM (ΔVC-ΔVCR)	ΔVA	%EMS ERR
TLI	SIVB	-	-	-	10416.9	-3.0	10419.9	10416.9	0.03
MCC2	SPS	23.2	4.32	0.34	18.5	-3.8	22.3	23.2	3.9

TABLE 5

SEQUENCE OF EVENTS - O2 TANK RUPTURE

CTE 55+51+21	Auto Roll maneuver to acquire the comet.
55+53+19 55+53+23 55+53+37 55+53+41	Four occurances of noise on the pitch and yaw Auto TVC Cmd parameters CH3582 and CH3583. The O-graph trace indicated both parameters to be in phase and of nearly equal magnitude. Maximum deflection was equal to 1.9 + vdc, peak to peak and occurred at 55+53+37, max voltage for the other three instances was 1.2 vdc, peak to peak.
55+54+54	Event (Rupture) occurred which resulted in a -pitch, -yaw rotational rate of $0.8^{\circ}/S$ and $0.5^{\circ}/S$ respectively. Telemetry sync was intermittent for two seconds and then locked in with apparent loss of CTE time. Approximately four seconds of continuous firing from C3 & A3 thruster and three seconds of continuous firing from D3 & B3 thruster. These apparent firings of pitch & yaw thrusters were overlaping but not simultaneous. All other thrusters appeared normal during this period of time. The +roll thrusters A1 & C1 fired for about 1.5 sec.
55+56+20	Another burst of jet firings in all three control axes commanding -pitch, -yaw and -roll, with the expected response from the rate and attitude error sources.
55+57+42	Main B and AC2 dropped off the line and as a result the SCS telemetry data was lost. Thruster C3 began oscillating (Quad C inoperative) and C4, D3, B4, A3, C1 & A2 went to zero indicating the Bus B loss.

The above timeline summarizes the critical events from the standpoint of the control system except for the Pipa 120 vdc supply which oscillated to a low of +109 vdc during the later part of the same two minutes but recovered after AC2 and MNB dropped off the line and the crew had transferred some non-critical loads off of MNA.

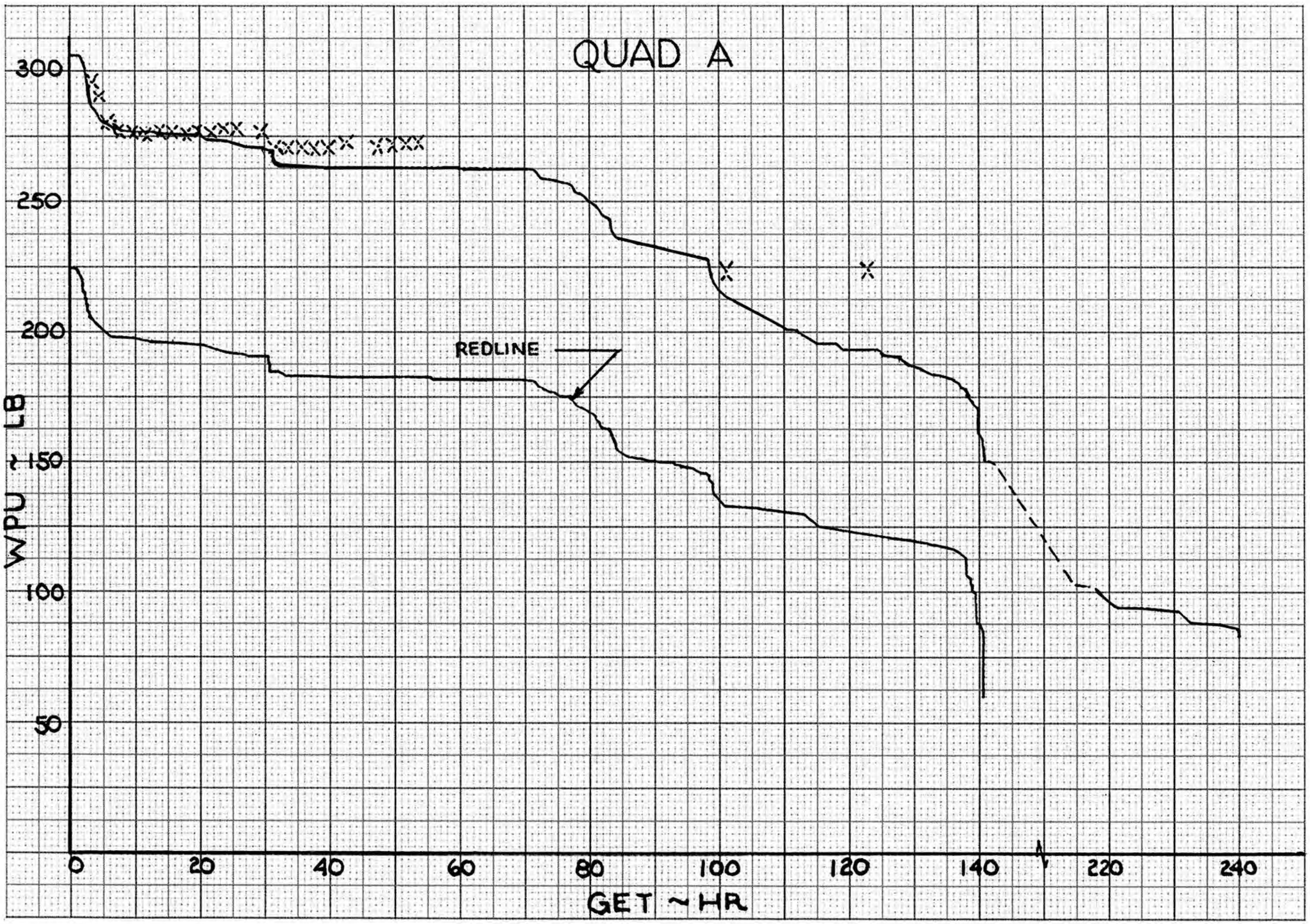
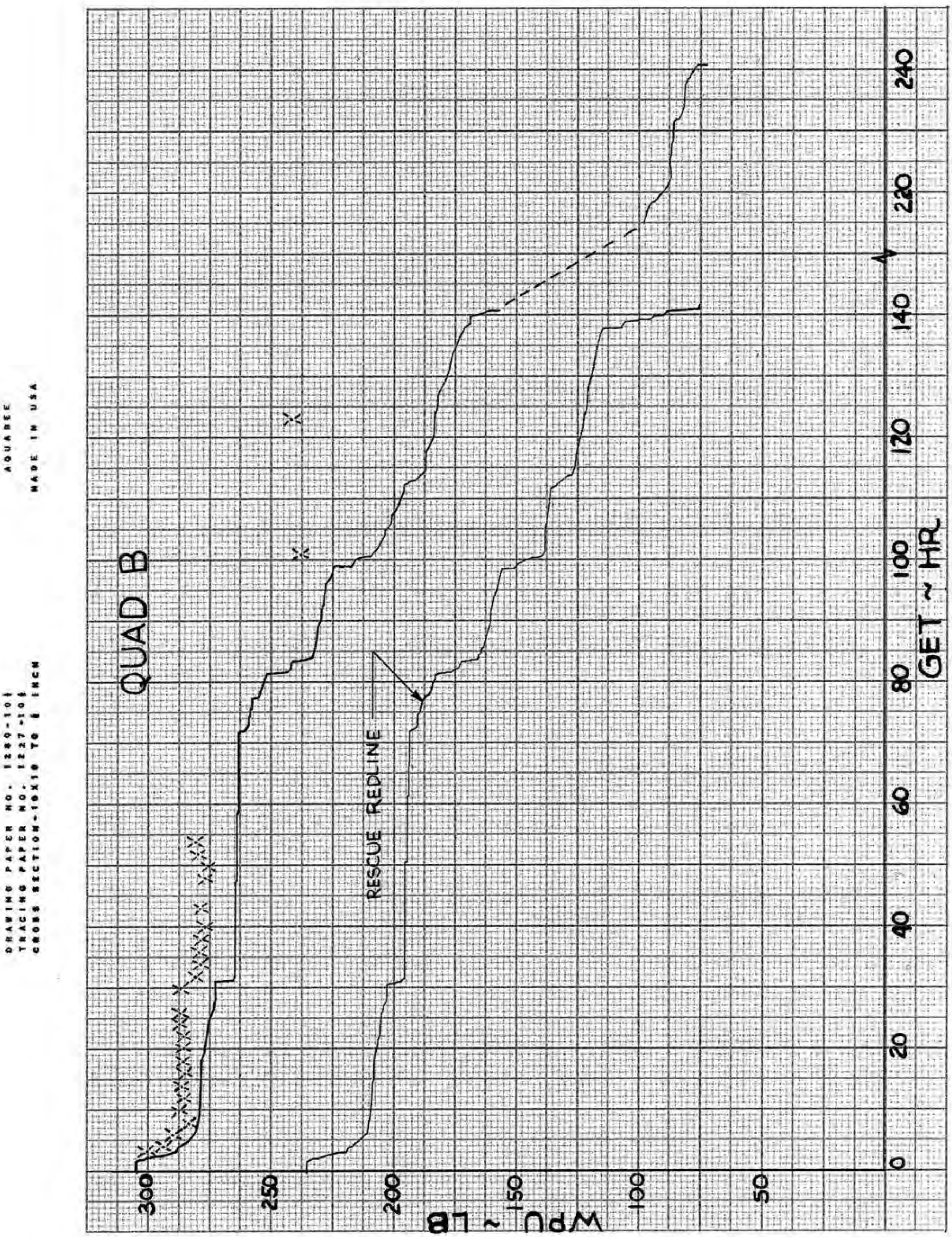

QUAD A
300
250
200
150
100
50
WPU ~ LB
0
20
40
60
80
100
120
140
220
240
GET ~ HR
REDLINE

FIGURE I



QUAD B
RESCUE REDLINE
WPU ~ LB
GET ~ HR
300
250
200
150
100
50
0
20
40
60
80
100
120
140
220
240
DRAWING PAPER NO. 1280-10½
TRACING PAPER NO. 1227-10½
CROSS SECTION-10X10 TO ½ INCH
AQUABEE
MADE IN USA

FIGURE 2

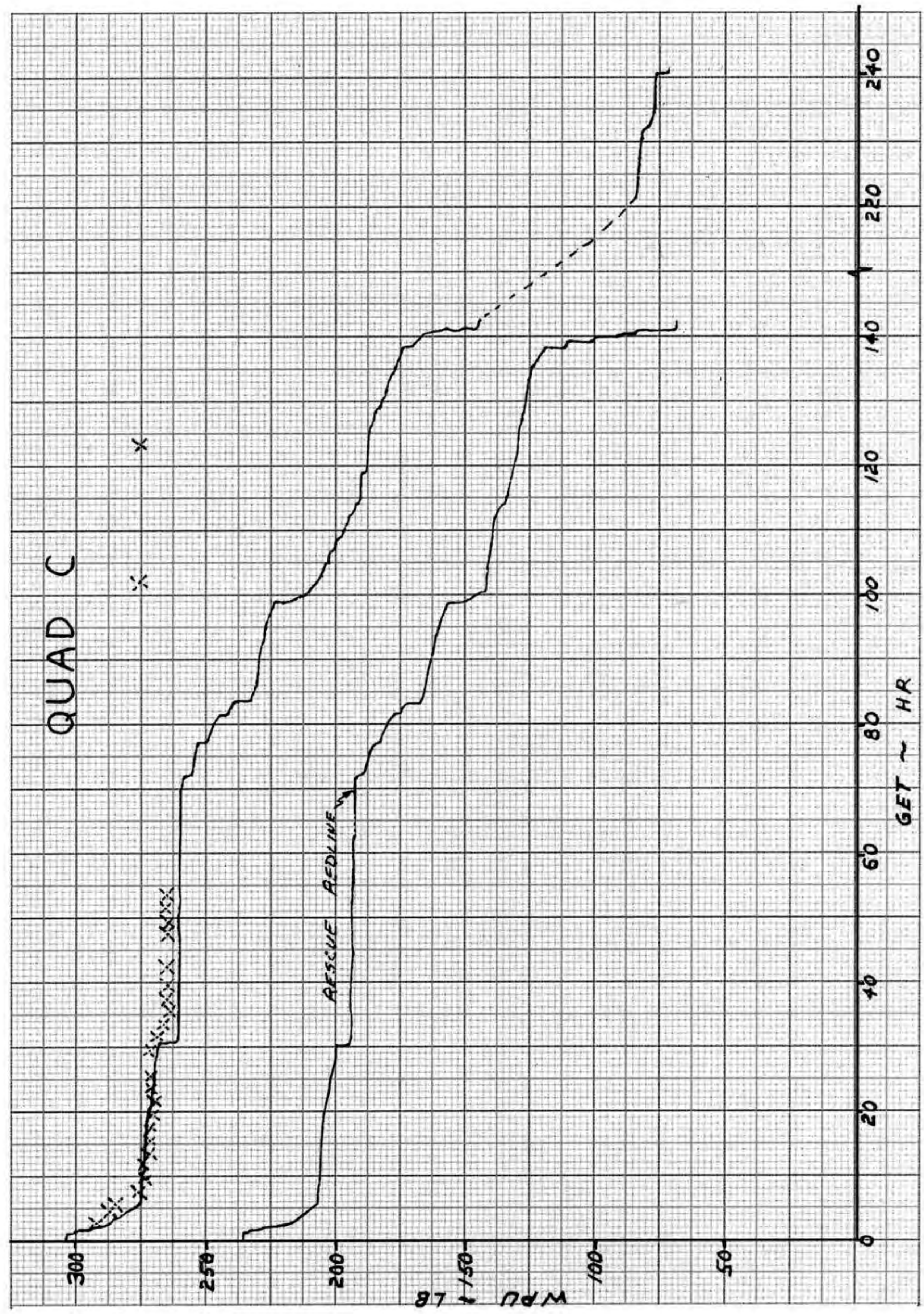

QUAD C
RESCUE REDLINE
WRU ~ LB
GET ~ HR
300
250
200
150
100
50
0
20
40
60
80
100
120
140
220
240

FIGURE 3

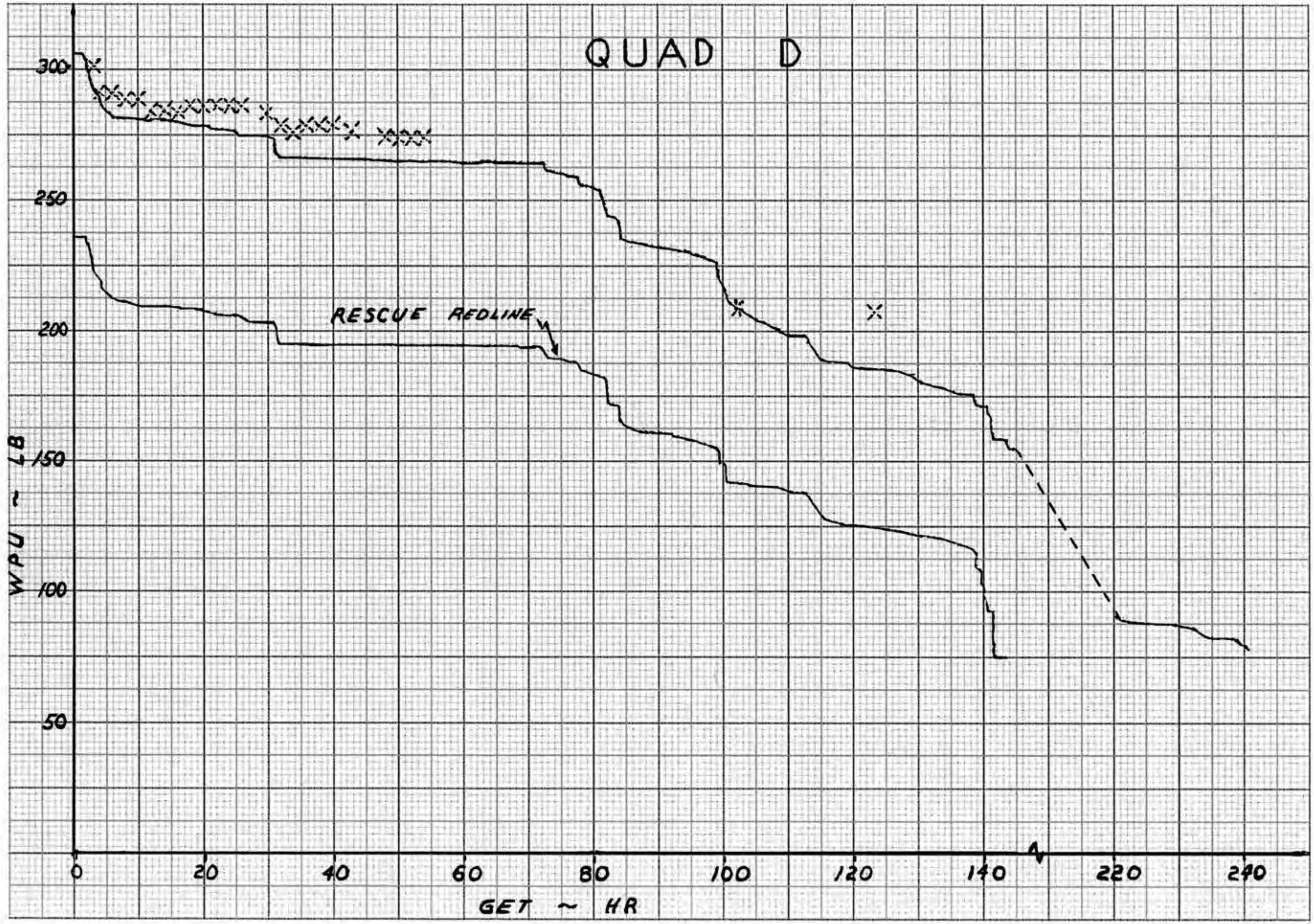

QUAD D
RESCUE REDLINE
WPU ~ LB
300
250
200
150
100
50
0
20
40
60
80
100
120
140
220
240
GET ~ HR

FIGURE 4

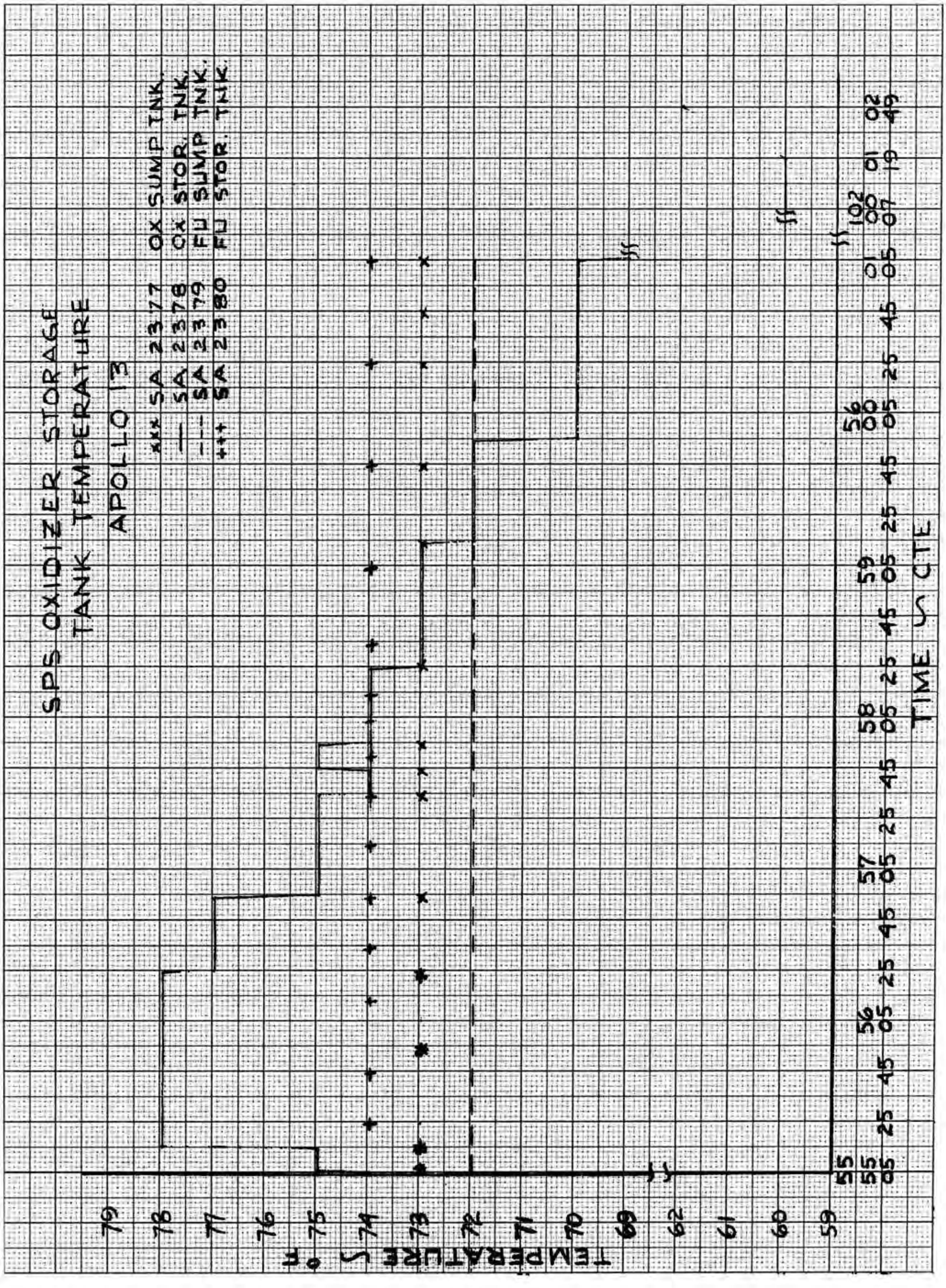

SPS OXIDIZER STORAGE
TANK TEMPERATURE
APOLLO 13
xxx SA 2377 OX SUMP TNK.
— SA 2378 OX STOR. TNK.
--- SA 2379 FU SUMP TNK.
+++ SA 2380 FU STOR. TNK.
TEMPERATURE ~ °F
79
78
77
76
75
74
73
72
71
70
69
62
61
60
59
TIME ~ CTE
55 55 05
25
45
56 05
25
45
57 05
25
45
58 05
25
45
59 05
25
45
56 00 05
25
45
01 05
102 00 07
01 19
02 49

FIGURE 5

APPENDIX G

LM Electrical, Environmental, and EMU Officer(TELMU)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

IN REPLY REFER TO: 70-FC46-67

MEMORANDUM TO: FC/Apollo 13 Flight Director

FROM : FC4/Apollo 13 TELMU Team

SUBJECT : Apollo 13 Post Mission Report

Attached is the Apollo 13, Phase I TELMU Post Mission Report. Any questions concerning this report may be directed to Jack Knight, extension 4576.

Jack Knight

William L. Peters

W. Merlin Merritt

Robert H. Heselmeyer

Enclosure

FC46:JKnight:dh

TELMU

Apollo 13 Post Mission Report

I. MISSION SYSTEMS CHRONOLOGY

A. Prelaunch events were nominal; the LM was on internal power at L/O -30 minutes and PCM was terminated at L/O -10 minutes. The LM was launched with three known anomalies: (1) a leaking ascent #2 O_2 tank valve, (2) a circuit breaker (RCS A/B-2 QUAD 1) mechanically maintained closed, and (3) an apparent heat leak in the Supercritical Helium (SHe) system. The first two anomalies were of a minor nature, expected to cause no problems, but the third would necessitate a procedure/flight plan change to obtain a crew readout during the TLC entry.

B. Launch and TD&E were successfully accomplished with switchover to LM power occurring about 3:46 GET. LM heater current was entirely nominal and remained so throughout the nominal portion of translunar coast. From several readings of LM/CM ΔP, the LM/Tunnel leak rate was determined to be approximately 0.014 lb/hr at 5 psia. The LM was entered at 55:00 GET, 4 hours earlier than originally scheduled, to read the SHe pressure as well as perform the nominal TLC functions. LM power was on for about 12 minutes.

C. Immediately after exiting the LM, the CSM O_2 tank anomaly occurred. The LM HTR current went to a steady reading of 1.3 amps at 56:00 GET. The Main Bus B voltage remained about 3.91v and the LM HTR current went to 1.4-1.5 amps. At 56:36 GET, Main Bus B was 0 volts and the LM HTR current was 0. Relays 4K3 and 4K4 had probably opened. By 57:44 GET, we were on LM internal power. LM data was received at 57:57 GET. The LM was eventually powered up to a current level of 45-50 amps. After an assessment of the possible trajectory plans, one was selected which culminated in landing at approximately 142:45 GET. The immediate concern was the total LM lifetime available, and it became apparent that to stretch the LM lifetime for a 142-hour GET entry, the LM must be powered down. (Even if the H_2O rate decreased to the expected 5.0 lbs/hr, corresponding to the initial power level, this would only allow for a lifetime to approximately 126:00 GET.) This resulted in the following consumable requirements based on the 59:00 GET status:

(1) The current profile must be reduced to an average of 24 amps or less for the remainder of the mission.

(2) The water usage rate must be reduced to an average of 3.5 lbs/hr (corresponding to about 17 amps at the existing external heat load).

(3) The oxygen available was more than adequate since the average usage rate was about 0.23 lbs/hr. Initially, however, a usage rate of 0.6 lbs/hr was noted which was later attributed to pressurization of the ascent #2 O_2 tank through its leaking valve.

(4) The LiOH from the LM alone was inadequate for the remainder of the mission. The LM had a total of 2 primary cartridges and 3 secondary cartridges for an estimated total CO_2 removal capability of approximately 53 hours. This was based on nominal rise rates and allowing the CO_2 level to build to a 15 mmHg level. Some method of using the CSM cartridges was necessary.

Power was gradually reduced to 35-40 amps at 60:40 GET. It was decided to make a DPS burn at 61:29 GET which would place the spacecraft on a free return trajectory and then reduce the power level to approximately 27 amps in order to keep the PGNS up until a second DPS burn at 79:52 GET was completed. We would then power the spacecraft down to a minimum of life support equipment, communication, TM, and ASA, IMU and RCS heaters. The estimated power and H_2O consumption for this configuration was approximately 17 amps and 2.7 lbs/hr, respectively, which would stretch LM lifetime to 165:00 (AMP-HRS) and 155:00 (H_2O) GET. The full power-down resulted in an actual power level of about 12 amps. The water usage rate finally decayed to 2.5 - 2.8 lbs/hr. The full power-down included turn-off of RCS and ASA heaters and all displays except the CWEA. A workable procedure for use of CSM LiOH cartridges with the LM suit loop was developed and implemented, thereby alleviating that potential problem.

D. During the remainder of the return, the LM was powered up for two MCC burns and the final pre-entry maneuvers. Additionally, power was provided for the CSM battery charge, IMU and RCS heater initial activation loads and certain other equipments. Since the low power levels were necessary for consumables management, no attempt was made to maintain a minimum cabin temperature level, resulting in uncomfortably low temperatures (about 45-50°F). A suggestion to place the SUIT TEMP control valve to FULL HOT was implemented but had no effect except to further lower the temp at the low power level. We suggested the crew might don their PGA's for warmth, but this was rejected at the Mission Control Center. The LM was powered up about 2 hours earlier than planned prior to re-entry to provide some warmth. The usable consumable status at LM jettison (141:30 GET) was:

(1) EPS-189.6 A-H (lifetime to 146:00 GET)

(2) H_2O - 28.2 lbs (lifetime to 147:06 GET)

(3) O_2 - 28.5 lbs (lifetime to 265:30 GET)

(4) LiOH - 37 hrs (LM/PLSS cartridges)

II. SYSTEMS PERFORMANCE

A. ECS - The ECS performed nominally throughout the mission. The initial high water usage rates were attributable to the cooling of the entire structural mass in contact with the glycol loop as well as the normally powered equipment. Approximately 6 hours were required for this structural cooling, after which only the online equipment plus metabolic and LiOH-CO_2 reaction heat contributed to water usage. The usage rate decayed from an initial high of 7.7 lbs/hr in a powered up configuration to 2.5 - 2.8 lbs/hr in a powered down configuration (12.5 amps). All drinking water was taken initially from the CSM. The LM ascent tanks were selected at 128:09 GET since the H_2O ΔP measurement was becoming erratic (Descent O_2 quantity was 5.5%), and we wanted to use some remaining descent H_2O for crew consumption.

The primary LiOH cartridge was used until the CO_2 PP level reached 14.9 mmHg (approximately 85:25 GET) at which point the secondary (PLSS-type) cartridge was selected. While on these LM cartridges, the CDR's hoses were configured with the return (red) connector capped and the exhaust (blue) connector taped in the tunnel so as to exhaust into the CM. During this time, a procedure was developed and uplinked to the crew for construction of an adapter to use CSM cartridges with the LM suit fan. The CSM cartridges were selected when the CO_2 PP reached 7.5 mmHg (about 94:53 GET) and the secondary cartridge was removed. See enclosure 1 for adapter construction and subsequent hose location. The location of these cartridges in relation to the total suit loop flow was the same as a LM cartridge. Two other CSM cartridges were added about 20 hours later in series with the original construction and lasted until the end of the mission.

Average oxygen usage rate remained at about 0.23 lbs/hr throughout the mission.

There were a few small irregularities noted during the mission:

(1) 58:30 - 60:04 GET and 64:00 - 65:20 GET - During these periods the ascent #2 O_2 tank was used for the O_2 supply since the shutoff valve allowed significant leakage (0.15 lb/hr with a ΔP of 53 psi and a manifold pressure of 957 psia) into the tank. This was driving the pressure above the official redline value (875 psia) although that was later confirmed by SPAN to be invalid under the existing conditions. After final shutoff of the ascent #2 O_2 valve, the pressure rose to 953 psia (descent regulator pressure) and stabilized.

(2) 94:00 GET - The LM descent O_2 tank quantity decayed for 7.5 minutes at a rate of about 8.5 lbs/hr. Associated with this was the reconfiguration of the LM suit loop after installation of the CSM cartridge adapter. The most likely cause is that the pressure drop across these cartridges caused a decrease in sensed pressure to the demand regulators which caused them to cycle open until the sensed pressure returned to 4.74 psia. The cabin pressure rose to 4.94 and remained there, further substantiating this hypothesis.

(3) 94:52 GET - An abnormal fan noise was reported by the crew. They indicated they first noted it in connection with installation of the CSM LiOH cartridges. This was most likely caused by the increased

loop resistance. No significant degradation in water separator performance was noted although the rpm did decay slightly.

(4) 118:33 GET - The SUIT LOOP RELIEF valve cycled to AUTO position. When queried, the crew reported that one of the ECS hoses had inadvertently dislodged the valve. This occurred several times later and the valve was returned to CLOSE each time.

(5) 118:35 GET - Water Separator speed decayed to 1900 and then rose to its nominal value. A possible explanation is that the WATER SEP SEL valve handle was inadvertently moved from the prelaunch PULL:SEP 2 to the PUSH:SEP 1 position. No other anomalies of this type were observed.

B. EPS - The EPS performed nominally although two descent batteries (3 and 4) tended to take the majority of the load since the crossties were opened between 60:34 and 63:40 GET and between 78:16 and 80:00 GET, and there was a 4:1 CDR/LMP bus power split until 82:30 GET. After 82:30 GET, sharing was nominal until the Ascent battery(s) were online. Initial power levels of 28 - 50 amps were maintained until about 82:30 GET when a 12.5 amp average was reached.

A BATTERY MALFUNCTION indication appeared on descent battery 2 at 99:51 GET. It appeared to be caused by a battery cell overtemperature or a temperature switch instrumentation problem. All voltages and currents were normal but the battery was disconnected to allow cooling even though no changes or effects on the glycol temperature were noted. The battery open circuit voltage returned to 31.9 volts 10 minutes after it was disconnected, which is nominal battery performance. The battery was reconnected after one hour and an overtemperature sensor failure was assumed. This failure could have been caused by either an actual bimetallic switch failure or water vapor condensing in the battery and causing a low resistance path between the wires leading to the switch. This latter is possible due to the very low temperatures at which the batteries were operating. This indication later became erratic causing several master alarms.

At 112:05 GET the LM power was connected to the CSM with battery 6 online and the ASC ECA CONT circuit breakers open. The CSM battery charging began and drew about 8 amps. From this time until full switch-over to CSM internal power (140:00 GET), the LM was connected to the CSM MAIN BUS B although power was not used continually.

Battery 6 was brought online at 111:57 GET and Bat 5 at 133:30 GET.

Battery 3 was disconnected at 139:16 GET with 394 amp-hours expended since it was contributing less than 1.0 amps. Had the mission progressed further and the other batteries reached the same state of charge, Bat 3 would have resumed its share of the load until depletion.

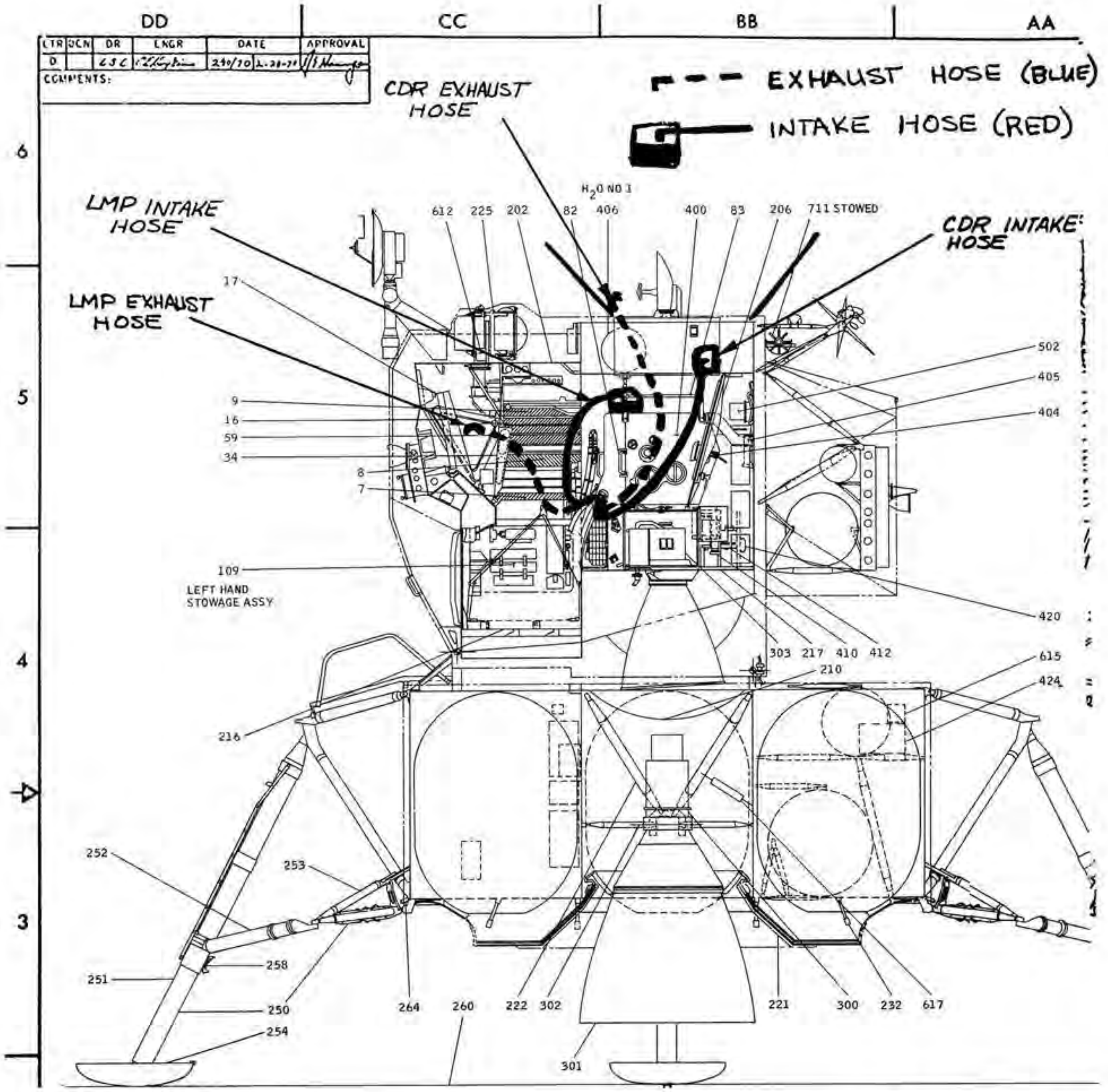
C. INSTRUMENTATION/PYRO - These systems performed nominally except:

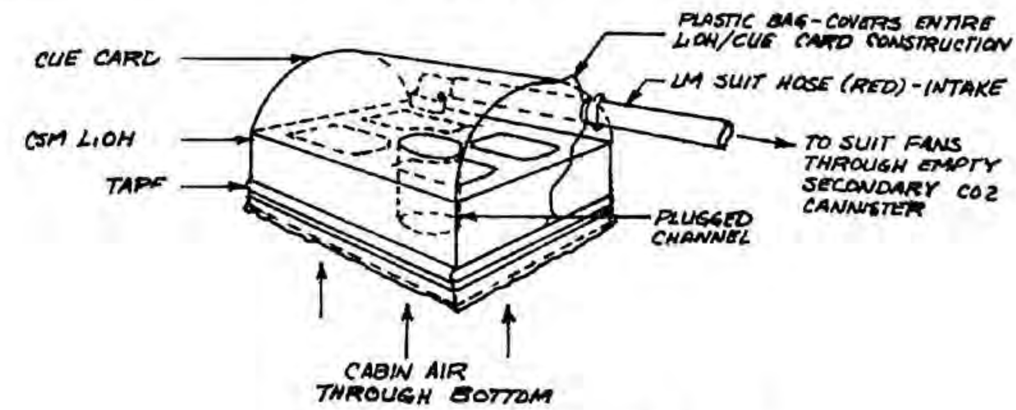
(1) GR5043X, RCS TCP A1U - The pressure switch indicated the thruster was on from the initial RCS fire and remained failed throughout the mission.

(2) GC9962U, BAT 2 MAL - The bi-metallic overtemperature switch failed closed at 99:51. The switch became intermittent causing several master alarms and resulted in the opening of the onboard MASTER ALARM circuit breaker until the latter part of the mission.

(3) GL0401V and GL0402V, CAL 85% and CAL 15%, respectively, were observed to shift up one PCM count prelaunch and throughout the mission. The problem was apparently in the calibration circuit since no other parameters were apparently affected.

Enclosure





CSM LiOH CARTRIDGE ADAPTOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

IN REPLY REFER TO: 70-FC13-47

JUN 9 1970

MEMORANDUM TO: See list below

FROM : FC/Apollo 13 Flight Director

SUBJECT : Apollo 13 Mission Operations Report

The enclosed documents represent Apollo 13 lunar module data tabulated post-mission by the TELMU and CONTROL flight controllers. This data can be inserted into the Apollo 13 Mission Operations Report, Appendixes G and H respectively, in order to complete the operational history of Apollo 13.

Milton L. Windler

Milton L. Windler

Enclosure

Addressees:
CA (10)
CF34 (2)
DD (12)
EA (10)
FA (4)
FC4 (2)
FC5 (2)
FC7 (1)
PM-MO-F (5)
FL (10)
FM (5)
FS (2)
PA/ASPO/Cortright Committee (80)

FC:MLWindler:smm

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

IN REPLY REFER TO: 70-FC41-91

MAY 27 1970

MEMORANDUM TO: Distribution

FROM : FC4/Apollo 13 TELMU Team

SUBJECT : Apollo 13 Data

Attached are additional data from the Apollo 13 mission. This should be attached to the Apollo 13 Phase I Mission Report.

Jack Knight
Jack Knight

Enclosures

FC46:JKnight:dh

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TABLES AND FIGURES

1.0 Mission Events and Consumables Tables

The mission events as applicable to the TELMU team are included in Table 1. These events were extracted from the logs of the team members.

The consumables as calculated from the mission data are included in Table 2. The data prior to 84:30 GET was calculated post-mission; that after 84:30 GET was generated during the mission. Of interest is the period from 79:00 GET to 84:30 GET when the descent Oxygen quantity did not noticeably decrease. A combination of the heat soakback from the 79:27 GET DPS burn and the CO_2 PP build-up is considered to account for this. Since the DPS burn was only four minutes and did not conclude on the lunar surface, it is considered to be of minor influence. The amount of CO_2 added to the cabin atmosphere (assuming the CO_2 cartridge became relatively ineffective) would have equaled the amount of O_2 extracted resulting in no net change in cabin total pressure. Therefore, there would be no demand for additional descent oxygen. This began sometime between 79:00 GET and 80:00 GET when the CO_2 PP was about 5 mmHg.

Please not that the consumable rates shown in Table 2 are averaged values, and do not necessarily agree with instantaneous readings taken in real time.

TABLE 1

Apollo 13 TELMU Mission Events

GET	Event
-00:27:00	LM on internal power
-00:09:00	LM TM off
00:00:00	Liftoff
00:05:59	S-II inboard out
00:09:56	S-II shutdown, S-IVB ignition
00:12:32	S-IVB shutdown
01:05:23	C-4 from SPAN; 1 A/H per descent battery prelaunch
02:41:43	S-IVB shutdown 3-4 secs long
03:02:XX	Reply from SPAN on 4CB22 - don't pull
03:03:XX	SLA panels deploy
03:19:XX	Hard docked
03:26:XX	Start tunnel/LM pressurization
03:38:00	Slight burnt smell in tunnel
03:45:50	Switch to CSM power - looks normal
03:50:XX	CSM hatch sealed - LM pressure 4.8 (?) - probably 4.6
04:01:XX	LM extraction
04:18:XX	S-IVB evasive maneuver
04:33:XX	IMU duty cycle ≈ 17%; LR ≈ 55%; baseline 0.4-0.8
08:15:XX	SPAN estimation of 1.87 amp-hour used from liftoff until TD&E power switchover
12:09:XX	LM/CM ΔP = 0.5 psid; CM pressure = 4.9-5.0
19:18:XX	IMU duty cycle ≈ 20%; LR ≈ 43%
19:35:XX	IMU duty cycle ≈ 14.3%
21:25:XX	IMU duty cycle ≈ 13.8%; LR ≈ 11.6%
24:42:XX	LM/CM ΔP = 0.65 psid; CM pressure = 5.0 psia
31:00:XX	Calculated LM leak rate ≈ 0.0143 lb/hr
31:30:XX	LM entry scheduled for 55:00:00 GET. SPAN says to deploy landing gear if DPS is burned
35:44:XX	LM/CM ΔP = 0.9 psid; CM pressure = 5.1 psia
47:43:XX	LM/CM ΔP = 1.0 psid; CM pressure = 5.0 psia
49:36:XX	IMU duty cycle ≈ 18%; LR ≈ 40%
51:18:XX	IMU duty cycle ≈ 15.2%; LR ≈ 32.1%
51:55:XX	IMU duty cycle ≈ 14.5%; LR ≈ 43.4%

TABLE 1 - CONT'D

GET	Event
53:00:XX	LM/CM ΔP = 1.1 psid
53:16:XX	IMU duty cycle ≈ 14.5%; LR ≈ 24.1%
53:27:XX	LM/tunnel vented to ΔP of 1.7 psid Start ingress procedure
53:34:XX	Start LM/tunnel pressurization
53:50:XX	Pressures equalized
54:06:XX	Start hatch removal
54:21:XX	IMU duty cycle ≈ 14.3%; LR 37.2%
54:24:24	Hatch open, LM htr current baseline 1.4 A (floodlights on); docking tunnel index = -2°
54:43:XX	All floodlights on - baseline 2.8A
54:46:15	Transfer to LM power for SHe readout
54:49:XX	SHe pressure 710 - 720 psi - NUM dimmer had to be turned toward BRIGHT
54:58:50	Transfer to CSM power
55:14:XX	TV show
55:17:XX	LMP reports one loose washer and sequence camera cap loose in LM
55:45:XX	Cabin REPRESS valve "BANG" - floodlights to OVHD/FWD
55:54:XX	Hatch closed (via HTR current)
55:55:XX	CM reports a problem - Main B undervolt
55:57:XX	CMC restart
56:04:XX	LM htr cur steady since 55:58 at 1.3 A
56:09:XX	CM Main Bus B ≈ 4.26 volts with LM htr cur slightly up to 1.4 - 1.5 A; gas venting observed
56:34:XX	LM htr cur is 0 amps; Main Bus B is 0 volts; 4K3 and 4K4 probably open
57:03:XX	First estimate of entry time ≈ 142 Hr GET
57:35:XX	Crewman in LM
57:45:XX	DEMAND REGS - CABIN
57:57:XX	LM data
58:20:XX	LM sublimator startup
58:40:XX	CM powered down
58:52:XX	Select ASC #2 O_2
59:19:XX	H_2O usage rate - 7.7 lbs/hour O_2 usage rate - 0.6 lbs/hour
59:59:XX	Select Descent O_2

TABLE 1 - CONT'D

GET	Event
60:08:XX	H_2O usage rate - 7.2 lbs/hour O_2 usage rate - 0.6 lbs/hour
61:30:XX	DPS burn for free return trajectory
62:33:XX	H_2O usage rate - 4.6 lbs/hour
62:44:XX	Crew beginning power down
63:00:XX	LM powered down to 25 - 26 amps
63:59:XX	Select ASC #2 O_2
64:55:XX	Power amp off; average current ≈ 25 amps
65:19:XX	Switch back to descent O_2
68:58:XX	Average current ≈ 26.4 amps
70:11:XX	Ascent 2 O_2 P = 937 psi
70:46:XX	Average current for 5 hours 26.9 amps
70:58:XX	H_2O usage rate is 4.4 lbs/hour
71:37:XX	H_2O usage rate is 3.89 lbs/hour
71:46:XX	SPAN recommendation to turn off Bats 3 and 4 to even load sharing
72:09:XX	H_2O usage rate is 4.2 lbs/hour
72:15:XX	Average current for 4 hours 26.6 amps
77:08:35	LOS behind moon
77:33:10	AOS
77:59:XX	Power amp on - HBR
78:16:XX	Crossties open
78:43:XX	Onboard EPS/ECS data costs 0.292 amps more than LBR TM without power amp
79:27:XX	DPS burn
79:51:XX	Begin power down after 2nd DPS burn
80:39:XX	ECS caution light due to CO_2 PP ≈ 7 mm Hg
82:20:XX	Current down to 15 amps
82:38:XX	Current down to 12.3 amps
85:00:XX	CO_2 PP 14.2 mm Hg
85:23:XX	Select SEC CO_2 cannister; CO_2 PP down to 6.4 rapidly and decreasing slowly thereafter
85:29:XX	Changed prim LiOH cartridge

TABLE 1 - CONT'D

GET	Event
86:05:XX	Descent O_2 dropped by 0.5 lb when SEC CO_2 selected. Glycol temp increased by about 3F°.
90:09:XX	Crew being read procedure for construction of CM CO_2 cartridge adaptor
90:28:XX	CO_2 PP 4.2 mm Hg (SEC CO_2)
92:29:XX	CO_2 PP 5.9 mm Hg (SEC CO_2)
93:03:XX	Some sort of "funny suit loop pressure"- no explanation
93:23:XX	Master Alarm but no C&W light. Possible CO_2 PP ≈ 6.6 mm Hg
93:40:XX	H_2O separator speed to 3030 rpm due to taping of hose exhausts
93:53:XX	CO_2 PP 7.5 mm Hg on secondary cartridge. Selected CM cartridges amd CO_2 PP dropped to 0.1 mm Hg.
93:55:XX	LMP red hose on ECS package CDR red hose in bottom of tunnel LMP blue hose in LMP window CDR blue hose blowing into CM
94:00:XX	CO_2 PP 0.7 - 0.8 mm Hg
94:10:XX	CO_2 PP 0.5 mm Hg
94:40:XX	Notice high O_2 flow-cycle DMD Reg A
94:52:XX	Crew report suit fan sounds different since CM cartridges installed
95:11:XX	Crew request procedure to power CM from LM
95:15:XX	Suit temp control - MAX HOT
96:38:XX	CO_2 PP stable at 0.1 mm Hg
97:14:XX	Crew report "bang" in descent stage & saw "snow flakes"
99:51:XX	Bat 2 Mal Turned Bat 2 off
100:15:XX	No change in glycol temperature
101:00:XX	Bat 2 back on line with BAT MAL still present
103:53:XX	Suit temp control - FULL COLD Suit temp 42°F to 41°F
104:34:XX	Power up for burn; current ≈ 45 amps
104:40:XX	≈ 6 minutes for RCS quad warmup; current ≈ 35 amps
105:19:28	DPS burn (3rd)
108:55:XX	SHe burst disc ruptured
109:15:XX	BAT MAL again - HBR revealed Battery 2 was erratic

TABLE 1 - CONT'D

GET	Event
110:42:XX	BAT MAL cycling - crew pulled master alarm circuit breaker
111:02:XX	Read up LM/CM power checklist
111:20:XX	Read up turn off procedures in the event of LM/CM power problem
111:57:XX	Bat 6 on; Bats 1 - 4 off
112:05:XX	Bats 1 - 4 and 6
112:12:XX	Begin charging CM entry battery
112:34:XX	CM current ≈ 8.0 amps. Glycol temp increased about 0.5°F since ascent battery online
113:07:XX	Bat 6 OFF procedure to Flight
113:36:XX	At least one new CM LiOH cartridge installed in series per CO_2 PP and H_2O sep rate
113:43:XX	Other cartridge installed; CO_2 PP 0.3 mm Hg, H_2O sep 3145 rpm
113:56:XX	Crew reports both new LiOH cartridges installed
114:51:XX	Battery Mal momentarily - Bat 2 per crew
115:38:XX	BAT MAL
115:39:XX	BAT MAL (twice)
115:40:XX	BAT MAL continuous
116:10:XX	BAT MAL intermittant
117:34:XX	Crew reports H_2O QTY caution light
117:36:XX	DES H_2O QTY 16.2 to 15.8%
118:33:XX	H_2O sep rate <2000 rpm
118:34:XX	H_2O sep rate recovering
118:38:XX	SUIT RLF valve went to AUTO and the back to CLOSE. Crew report inadvertant action by LiOH apparatus
120:17:XX	SUIT RLF AUTO; crew placed to CLOSE on request
120:28:XX	PA on
120:47:XX	PA off
121:03:XX	SUIT RLF AUTO; closed on request
122:48:XX	Remove CM power drain
123:03:XX	CM power up for TM using LM power - additional 12 amps
123:18:XX	CM battery charging resumed ≈ 6 amps
123:38:XX	SUIT RLF AUTO; crew CLOSED on request
125:20:XX	Crew report no more CM potable H_2O
128:09:XX	H_2O ΔP erratic; switch to ascent H_2O; Des H_2O ≈ 5.5%
128:20:XX	Terminate battery charge
132:34:XX	SUIT RLF AUTO; crew closed on request

TABLE 1 - CONT'D

GET	Event
133:30:XX	Battery 5 online for power up
133:38:XX	Current 58 - 61 amps - RCS and ASA heaters
134:01:XX	Crew reports noticeable warmth
134:06:XX	SUIT TEMP control - HOT Crosstie BAL load c/b's are open
134:14:XX	Close BAL load X-tie c/b's Crew reluctant to turn on window heaters Battery 3 current occasionally <1 amp
135:25:XX	Cabin temp - 56°F, W/B H_2O T - 57°F (from 52°F and 54°F respectively)
136:44:XX	CM RCS warmup required about 10 amps from LM
137:52:49	RCS burn - secondary coils only pull 5 amps since in series vice parallel
137:57:XX	All CM RCS rings fired
138:02:09	SM jettison
138:04:XX	Crew drinking from ascent H_2O tanks
138:05:XX	Crew reports whole panel missing from SM
138:24:XX	SUIT RLF AUTO - close on request
139:16:XX	Took Bat 3 offline
139:23:XX	SUIT RLF AUTO - closed on request
139:27:XX	Bat 4 reached 400 A-H out
139:40:XX	Bat 3 OCV = 31.5 volts
140:12:XX	LM/CM power link broken
140:42:XX	Bat 3 OCV = 31.8 volts
140:52:XX	RCS C&W light due to He pressure
141:15:XX	CM/Tunnel ΔP = 2.8 psid LM cabin P = 4.98 psia
141:30:05	LM jettison
142:38:07	LM final LOS

TABLE 2

LM CONSUMABLES STATUS

GET	H_2O			O_2			AMP-HOURS			LiOH					
	USABLE REMAINING	PRESENT RATE	LIFETIME AT PRESENT RATE	USABLE REMAINING	PRESENT RATE	LIFETIME AT PRESENT RATE	TOTAL REMAINING	PRESENT RATE	LIFETIME AT PRESENT RATE	PRIM #1	SEC #1	PRIM #2	SEC #2	SEC #3	CSM
58:00	323.6	5.4	117:54	50.26	0.5	158:30	2181	28.0	135:54	23	7	23	7	7	168
59:00	315.2	6.3	109.00	49.62	0.5	158:12	2144	36.0	118:30	22	7	23	7	7	168
60:00	308.9	6.3	109:00	49.62	0.5	159:12	2113	31.7	126:42	21	7	23	7	7	168
61:00	302.6	5.3	118:00	48.77	0.5	158:30	2080	33.1	123:48	20	7	23	7	7	168
62:00	297.3	5.2	117:00	48.10	0.5	158:12	2045	33.2	123:36	19	7	23	7	7	168
63:00	292.1	5.3	116:24	47.43	0.5	157:48	2016	30.2	129:42	18	7	23	7	7	168
64:00	286.8	4.2	132:06	46.85	0.5	157:42	1986	30.2	129:48	17	7	23	7	7	168
65:00	282.6	4.2	132:18	46.34	0.5	157:42	1956	31.3	127:30	16	7	23	7	7	168
66:00	278.4	4.1	133:24	45.86	0.5	157:42	1929	27.0	137:24	15	7	23	7	7	168
67:00	274.3	4.3	130:18	45.53	0.25	249:06	1900	28.2	134:24	14	7	23	7	7	168
68:00	270.0	4.2	132:12	45.25	0.25	249:00	1873	27.1	137:06	13	7	23	7	7	168
69:00	265.8	4.2	132:18	45.07	0.25	249:12	1846	27.6	135:54	12	7	23	7	7	168
70:00	261.6	4.2	132:18	45.12	0.25	250:24	1821	24.9	143:12	11	7	23	7	7	168
71:00	257.4	4.2	132:18	44.82	0.25	250:18	1794	27.0	137:24	10	7	23	7	7	168
72:00	253.2	3.1	156:12	44.70	0.25	250:48	1768	26.3	139:12	9	7	23	7	7	168
73:00	250.1	4.2	132:30	44.51	0.25	251:00	1741	26.9	137:48	8	7	23	7	7	168
74:00	245.9	4.2	132:30	44.30	0.25	251:12	1714	27.0	137:24	7	7	23	7	7	168
75:00	241.7	4.2	132:30	44.09	0.25	251:18	1687	26.8	137:54	6	7	23	7	7	168
76:00	237.5	3.2	150:12	43.88	0.25	251:30	1660	26.1	139:36	5	7	23	7	7	168
77:00	234.3	4.2	132:42	43.67	0.25	251:42	1635	25.5	141:06	4	7	23	7	7	168
78:00	230.1	4.2	132.42	43.46	0.25	251:48	1607	27.8	135:48	3	7	23	7	7	168
79:00	225.9	4.2	132:42	43.23	0.25	251:54	1571	36.4	122:12	2	7	23	7	7	168
80:00	221.7	4.8	126:06	43.25	0.25	253:00	1533	37.6	120:48	1	7	23	7	7	168
81:00	217.5	4.6	128:12	43.25	0.25	254:00	1509	24.6	142:18	0	7	23	7	7	168
82:00	213.7	4.6	128:24	43.25	0.25	255:00	1483	25.7	139:42	+1	7	23	7	7	168

TABLE 2

LM CONSUMABLES STATUS - CONTINUED

GET	H_2O			O_2			AMP-HOURS			LiOH					
	USABLE REMAINING	PRESENT RATE	LIFETIME AT PRESENT RATE	USABLE REMAINING	PRESENT RATE	LIFETIME AT PRESENT RATE	TOTAL REMAINING	PRESENT RATE	LIFETIME AT PRESENT RATE	PRIM #1	SEC #1	PRIM #2	SEC #2	SEC #3	CSM
83:00	209.1	4.3	131:36	43.25	0.25	256:00	1464	19.0	160:06	+2	7	23	7	7	168
84:00	205.8	3.0	152:36	43.25	0.25	257:00	1454	12.1	204:12	+3	7	23	7	7	168
84:30	203.8	3.1	150:12	43.25	0.36	204:36	1448	12.3	202:30	+3:30	7	23	7	7	168
85:00	201.7	3.1	150:00	43.20	0.36	205:00	1441	12.3	202:30	+4	7	23	7	7	168
87:30	195.4	3.25	147:30	41.90	0.36	204:12	1411	12.0	204:30		5	23	7	7	168
88:30	192.3	3.22	147:30	41.41	0.36	203:30	1398	12.0	204:30		4	23	7	7	168
90:00	188.1	2.7	159:36	41.25	0.31	223:00	1370	12.5	200:00		3:30	23	7	7	168
91:00	186.0	2.5	165:30	41.05	0.25	255:12	1367	11.9	206:09		2:30	23	7	7	168
92:00	183.9	2.5	165:30	40.85	0.25	255:24	1355	11.9	206:09		1:30	23	7	7	168
93:00	180.7	2.5	165:18	40.60	0.25	255:24	1347	11.64	208:42		0:30	23	7	7	168
94:00	178.6	2.5	165:26	40.22	0.25	254:54	1335	11.7	208:06		+0:30	23	7	7	168
95:00	175.5	2.5	165:12	38.88	0.25	250:30	1324	11.7	208:06			23	7	7	167
96:00	173.4	2.5	165:22	38.67	0.25	250:42	1312	11.8	207:11			23	7	7	166
97:00	171.3	2.5	165:31	38.45	0.22	271:48	1300.1	11.9	206:15			23	7	7	165
98:00	168.1	2.5	165:14	38.25	0.22	271:54	1288.5	11.6	209:08			23	7	7	164
99:00	166.0	2.5	165:29	38.04	0.22	271:54	1277.2	11.3	211.03			23	7	7	163
100:00	162.9	2.5	165:00	37.81	0.21	280:00	1265.4	11.8	207:12			23	7	7	162
101:00	160.8	2.5	165:20	37.59	0.22	271:42	1252.3	13.1	196:36			23	7	7	161
102:00	157.6	2.5	165:00	37.38	0.22	271:54	1239.4	12.9	198:00			23	7	7	160
103:00	155.5	2.6	162:30	36.95	0.22	271:00	1227.4	12.0	205:00			23	7	7	159
104:00	149.2	3.1	152:12	36.73	0.22	270:54	1216.6	11.1	213:36			23	7	7	158
105:00	147.1	3.1	152:30	36.52	0.22	271:00	1193.2	23.4	156:00			23	7	7	157
106:00	144.0	3.0	154:00	36.51	0.22	271:54	1168.0	12.5	199:30			23	7	7	156
107:00	141.9	2.8	157:40	36.32	0.22	271:00	1158.4	12.0	203:24			23	7	7	155
108:00	138.7	2.65	160:00	36.11	0.20	288:30	1146.0	12.0	203:24			23	7	7	154

TABLE 2

LM CONSUMABLES STATUS - CONTINUED

GET	H_2O			O_2			AMP-HOURS			LiOH					
	USABLE REMAINING	PRESENT RATE	LIFETIME AT PRESENT RATE	USABLE REMAINING	PRESENT RATE	LIFETIME AT PRESENT RATE	TOTAL REMAINING	PRESENT RATE	LIFETIME AT PRESENT RATE	PRIM #1	SEC #1	PRIM #2	SEC #2	SEC #3	CSM
109:00	136.6	2.55	161:00	35.68	0.21	279:54	1136.0	12.0	203:24			23	7	7	153
110:00	133.5	2.55	161:00	35.46	0.21	278:48	1125.0	12.0	203.24			23	7	7	152
111:00	131.4	2.50	163:00	35.25	0.21	278:48	1114.0	12.0	203.30			23	7	7	151
112:00	129.3	2.50	163:00	35.03	0.21	278:48	1103.5	12.0	203:30			23	7	7	150
113:00	126.1	2.50	163:00	34.59	0.30	228:36	1083.9	20.0	167:00			23	7	7	149
114:00	124.0	2.5	163:00	34.37	0.26	246:06	1064.7	19.2	169:00			23	7	7	148
115:00	121.9	2.5	163:00	33.94	0.3	228:06	1046.2	18.5	172:00			23	7	7	147
116:00	118.7	2.5	163:00	33.72	0.3	228:24	1027.8	18.4	172:00			23	7	7	146
117:00	116.6	2.5	163:00	33.52	0.3	228:42	1009.8	18.0	173:00			23	7	7	145
118:00	114.5	2.5	163:00	33.29	0.3	228:54	991.9	17.9	173.25			23	7	7	144
119:00	111.4	2.5	163:00	33.08	0.26	246:12	974.0	17.9	173:00			23	7	7	143
120:00	109.3	2.55	162:00	32.86	0.22	269:18	956.1	17.9	173:00			23	7	7	142
121:00	106.1	2.55	162:00	32.65	0.22	269:24	937.1	19.0	170:00			23	7	7	141
122:00	104.0	2.55	162:48	32.43	0.22	269:24	919.2	17.9	172:30			23	7	7	140
123:00	101.9	2.55	163:00	32.25	0.22	269:30	902.4	16.8	176:30			23	7	7	139
124:00	98.8	2.55	162:42	31.79	0.22	268:30	885.0	17.1	175:30			23	7	7	138
125:00	94.6	2.55	162:06	31.79	0.22	269:30	867	17.1	175:00			23	7	7	137
126:00	92.5	2.55	162:18	31.57	0.22	269:30	851	17	176:00			23	7	7	136
127:00	90.4	2.55	162:24	31.36	0.22	269:30	832	19.2	170:00			23	7	7	135
128:00	80.4	2.5	155:54	30.93	0.26	247:00	813	19.5	170:00			23	7	7	134
129:00	77.7	2.67	158:06	30.93	0.22	269:36	797	15.5	180:30			23	7	7	133
130:00	75.3	2.47	160:30	30.73	0.22	269.42	784.6	12.0	195:00			23	7	7	132
131:00	72.1	2.55	159:12	30.52	0.22	269:42	773.0	12.0	195:30			23	7	7	131
132:00	69.2	2.80	156:42	30.30	0.22	269:42	759.0	12.0	195:00			23	7	7	130
133:00	66.4	2.80	156:42	30.08	0.22	269:42	EPS OCCUPIED WITH POWER-UP					23	7	7	129

TABLE 2

LM CONSUMABLES STATUS - CONCLUDED

GET	H_2O			O_2			AMP-HOURS			LiOH					
	USABLE REMAINING	PRESENT RATE	LIFETIME AT PRESENT RATE	USABLE REMAINING	PRESENT RATE	LIFETIME AT PRESENT RATE	TOTAL REMAINING	PRESENT RATE	LIFETIME AT PRESENT RATE	PRIM #1	SEC #1	PRIM #2	SEC #2	SEC #3	CSM
134:00	63.7	2.80	156:42	29.65	0.29	236:12	716.0	41.0	151:30			23	7	7	128
135:00	59.2	4.50	148:12	29.43	0.23	262:30	677.2	42.0	151:00			23	7	7	127
135:30	56.8	4.8	147:21	29.43	0.23	262:00	658.0	38.0	152.48			23	7	7	126.5
136:00	54.8	4.0	149:42	29.22	0.23	263:00	641.0	38.0	152:30			23	7	7	126
136:30	52.4	4.8	147:24	29.22	0.23	264:00	621.8	41.8	151:10			23	7	7	125.5
137:00	50.0	4.8	147:30	29.00	0.22	264:42	598.7	46.2	150:00			23	7	7	125
137:30	47.8	4.4	148:18	28.79	0.21	273:06	578.0	41.4	151:30			23	7	7	124.5
138:00	45.4	4.8	147:30	28.79	0.21	274:06	557.4	41.2	151:30			23	7	7	124
138:30	43.0	4.8	147:30	28.79	0.21	275.06	534.5	45.9	150:10			23	7	7	123.5
139:00	40.6	4.8	147:30	28.61	0.21	273.36	512.8	43.4	150:45			23	7	7	123
139:30	38.2	4.8	147:30	28.40	0.21	274:42	490.0	45.6	150:12			23	7	7	122.5
140:00	35.6	5.0	147:10	28.40	0.21	275:12	468.5	43.0	150:50			23	7	7	122
140:30	32.8	5.4	146:35	28.18	0.21	274:12	448.0	41.0	151:20			23	7	7	121.5
141:00	30.6	5.0	147:10	28.18	0.21	274:42	428.6	38.8	152:50						
141:30	28.2			28.18	0.21	275:12	410	38.8	152.50						

2.0 Systems Analog Plots

The analog plots depict the various systems performances throughout the mission.

In addition to the normal compressed time scale plots, seven special expanded time scale plots where unexpected performance occurred and a special comparison plot of battery current and water usage rate versus time are included.

The expanded time scale plots indicate the effects of installation of the CM LiOH cartridge adaptors on the LM ECS hoses (Figure 1-4), an unexplained decay and recovery of the H_2O separator (Figure 1-5), and a possible momentary battery, bus, or feeder short (Figures 9-1 to 9-5).

During post mission analysis of the Apollo 13 data, a voice report by the crew at 97:14:42 GET of a thump and a shower of snowflakes from the descent stage led to the detection of a significant "glitch" in the electrical parameters at 97:13:55 GET. The Electrical Power System was configured with batteries 1-4 on high taps and the crosstie BAL LOAD cb's closed at the time of the transients. The PCM was in the low bit rate mode in which Battery 1-4 voltages and switching bilevels were not available.

A study of a RTCC DELOG during this time frame revealed the following:

1. Battery 2 current was off-scale high for two seconds.

2. Battery 1, 3, and 4 currents reached a maximum of between 30 and 37 amperes during the same period.

3. CDR bus volts dropped to a minimum of 28.9 volts during one sample.

4. LMP bus volts dropped to a minimum of 27.7 volts during one sample.

5. There were no Battery MAL or MASTER ALARM indications.

These data points are graphically depicted in Figures 9-1 through 9-4.

The transients occurred during a period where occasional data dropouts were observed, but close examination reveals supporting data to indicate an Electrical Power System problem. These supporting facts are:

1. The load sharing of the batteries changed for several minutes after these transients before returning to near equal sharing of the load. The approximate load sharing immediately after the transients was BAT 1 = 29%, BAT 2 = 58%, BAT 3 = 6.5% and BAT 4 = 6.5%. The total current

remained the same except during the two-second period. The load sharing may be noted in Figures 9-1 and 9-2.

2. The LMP bus voltage increased from 31.0 volts prior to the transients to 31.1 volts after the transients for 5 seconds, then to 31.3 volts on most samples for the next 1.5 minutes. It remained at 31.1 volts for a few minutes more before dropping to the same 31.0 volts prior to the transients.

3. The CDR bus voltage increased from 31.0 volts prior to the anomaly to 31.3 volts similar to the LMP bus voltage; however, it returned to 31.0 volts after a shorter period of time.

4. The glycol pumps have a history of being very voltage sensitive and the glycol pump ΔP decreased coincident with the bus voltage drop (see Figure 9-3 for the bus voltages and glycol pump ΔP).

5. The four battery currents and the LMP bus voltage have redundant locations in the PCM bitstream and these points tend to corroborate the primary location data points (see Table 3 and Figure 9-4).

6. Battery 2 MAL indications started at 97:51 GET and these MAL indications continued erratically over a several-hours period.

Hence, the evidence is heavily weighted in support of an EPS problem. Attempts have been made to correlate these indications with the thump and snowflakes reported by the crew; however, we are unable to reach any positive conclusions at this time. Some of the factors that hinder the solution of the problem are:

1. The sample rate of the EPS parameters are all one sample per second; however, battery 1-4 currents and LMP BUS voltage do have redundant locations displaced by a few milliseconds that improve data granularity.

2. Battery 1-4 voltages and the battery switching bilevels are not on low bit rate telemetry.

3. The flight crew has been busy and we have been unable to discuss their recollections in more detail.

Special attention is called to battery 2 current readings on Figure 9-4, wherein the redundant location reading of 27.8 amps is bracketed by two off-scale high readings (>60 amperes). At first glance, this reading appears to be inconsistent, and it might be dismissed as a bad data point since the other data points correlate to a single transient on all batteries. However, a closer examination of the LMP BUS voltage readings corroborates the battery 2 current readings and indicates a minimum of two transients.

While the data points are not adequate to confirm positively that the other three batteries did not go off-scale high for a very short period of time, the data points available point toward a reverse current condition in battery 2 with the other 3 batteries feeding a total current in excess of 90 amperes. This condition could occur if there had been a momentary switch to low voltage taps on battery 2, or shorted cells in battery 2. This theory could also be supported by the fact that no Battery MAL or Master Alarm indications were observed. A reverse current of 10 amps for 5 $\pm$ 1 seconds is required to issue a battery MAL. Also, the bus voltages never dropped below 26.5 volts for more than 40 msecs (reaction time of caution and warning) or C&W would have triggered a Master Alarm and a D. C. BUS warning. Probably the greatest single factor that supports the reverse current theory is the battery load sharing after the transients. An interesting correlation can be made between this incident and one that occurred during LTA-8 testing where large reverse currents were drawn by the batteries during switching between low to high voltage taps with the buses cross-tied. The battery currents and bus voltages are plotted versus time in Figure 9-5. As can be seen, the battery that drew the most reverse current for the longest time ended up carrying most of the load after switching was complete. Also battery 1 which drew no reverse current carried the least load when switching was complete. The other two batteries' sharing was related to the amount of reverse current that they carried.

At this time, there is no known possible short on the feeder, bus, equipment line, or load transient that could result in the battery behavior similar to that noted on LM-7; however, a verbal report indicated that during a recent qualification test, when a descent battery had been pulsed with a high load, an increase in the battery voltage was observed when the load returned to normal. Further investigation is being directed in this area to determine if this could be analogous to a short between battery 2 and the ECA and explain the battery load sharing after the transients. It is recognized that shorted cells in battery 2 or a momentary switch to low voltage taps on battery 2 are not readily explainable in view of the subsequent performance of battery 2 and the rest of the EPS system since the anomaly was self-cleared. The capabilities to the SEENA program are being investigated to simulate and attempt to duplicate the Apollo 13 anomaly.

All plots except for Figure 9-4 were made using RTCC processed data with LM display times, which are time tagged at the remoted site. This reference time is called LEMEGMT. Figure 9-4 was plotted using the Program Office bandpass printouts and the GET has been biased by a spacecraft-to-earth RF transmission time.

TABLE 3

EPS Parameter LBR Sampling Sequence

PARAMETER		LBR WORD	
BATTERY 3 CURRENT	-	PRIMARY	- 67
BATTERY 4 CURRENT	-	PRIMARY	- 71
BATTERY 1 CURRENT	-	PRIMARY	- 96
BATTERY 4 CURRENT	-	REDUNDANT	- 99
BATTERY 3 CURRENT	-	REDUNDANT	- 100
BATTERY 1 CURRENT	-	REDUNDANT	- 111
BATTERY 2 CURRENT	-	PRIMARY	- 127
CDR BUS VOLTS	-		- 131
LMP BUS VOLTS	-	PRIMARY	- 139
LMP BUS VOLTS	-	REDUNDANT	- 148
BATTERY 2 CURRENT	-	REDUNDANT	- 172

The comparison plot of water usage rate and battery current rate clearly demonstrates the dependency of the former on the latter. Additionally, the water boiled as indicated by the ΔT across the sublimator is plotted to demonstrate that the water separators contributed water to the sublimator. Under the steady state portions of the mission, the additional water provided by the separators was 0.4 to 0.45 lbs/hr. The total water consumption rate was 2.95 lbs/hr for a selected period of several hours, 1.35 lbs/hr of which was due to electrical loads, about 1.17 of which was due to crew matabolic and LiOH reaction loads (based on an average of 1220 BUT/hr from the crew from the O_2 consumption) and the remainder (0.43 lbs/hr) due to structural heat loads.

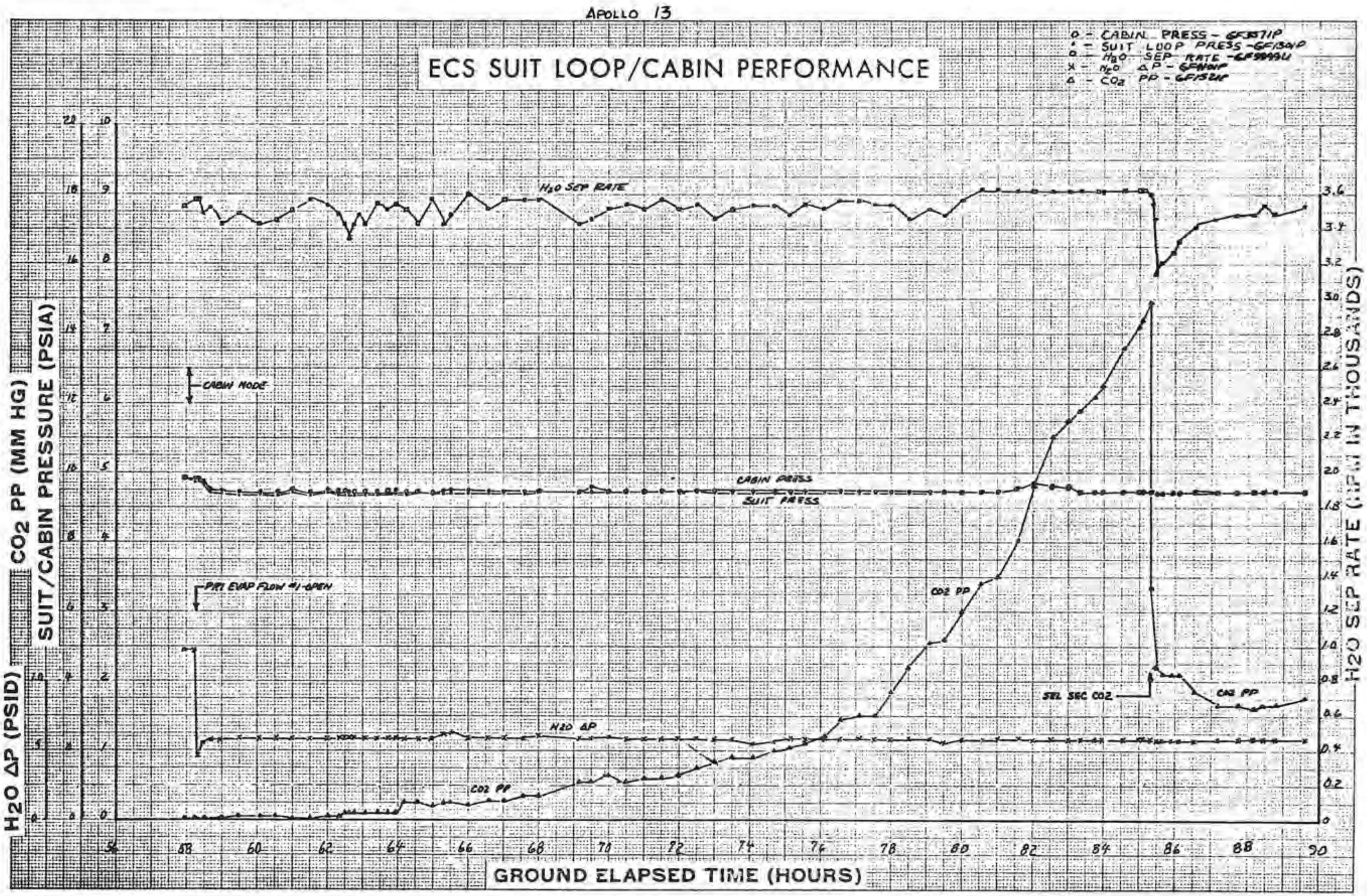

APOLLO 13
ECS SUIT LOOP/CABIN PERFORMANCE
H2O SEP RATE
CABIN MODE
CABIN PRESS
SUIT PRESS
PRI EVAP FLOW #1-OPEN
H2O ΔP
CO2 PP
SEL SEC CO2
H2O ΔP (PSID)
CO2 PP (MM HG)
SUIT/CABIN PRESSURE (PSIA)
H2O SEP RATE (RPM IN THOUSANDS)
GROUND ELAPSED TIME (HOURS)

Figure 1-1

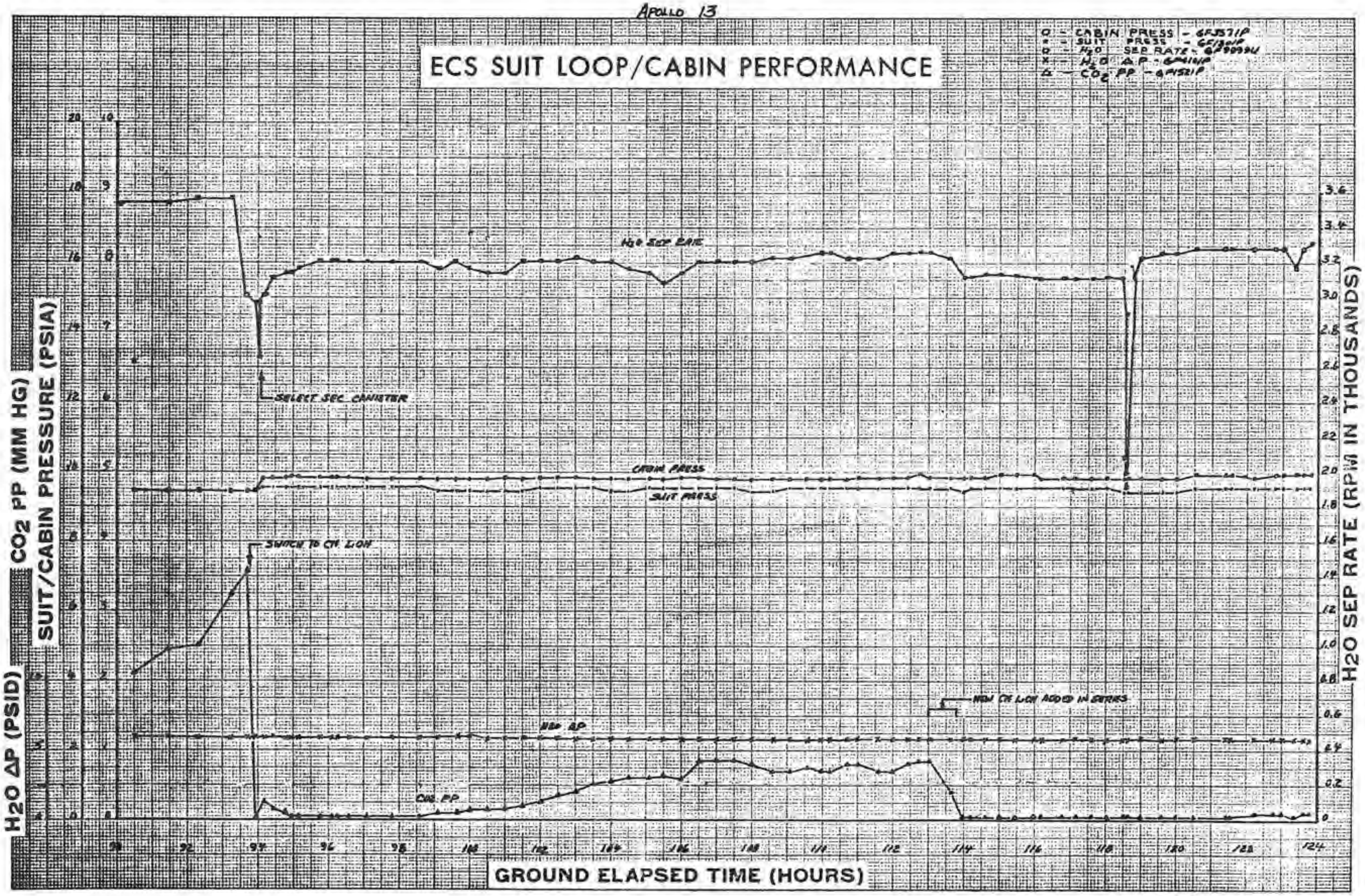

APOLLO 13
ECS SUIT LOOP/CABIN PERFORMANCE
H2O ΔP (PSID)
CO2 PP (MM HG)
SUIT/CABIN PRESSURE (PSIA)
H2O SEP RATE (RPM IN THOUSANDS)
GROUND ELAPSED TIME (HOURS)
SELECT SEC CANISTER
SWITCH TO CM LiOH
CABIN PRESS
SUIT PRESS
H2O SEP RATE
H2O ΔP
CO2 PP
NEW CM LiOH ADDED IN SERIES

Figure 1-2

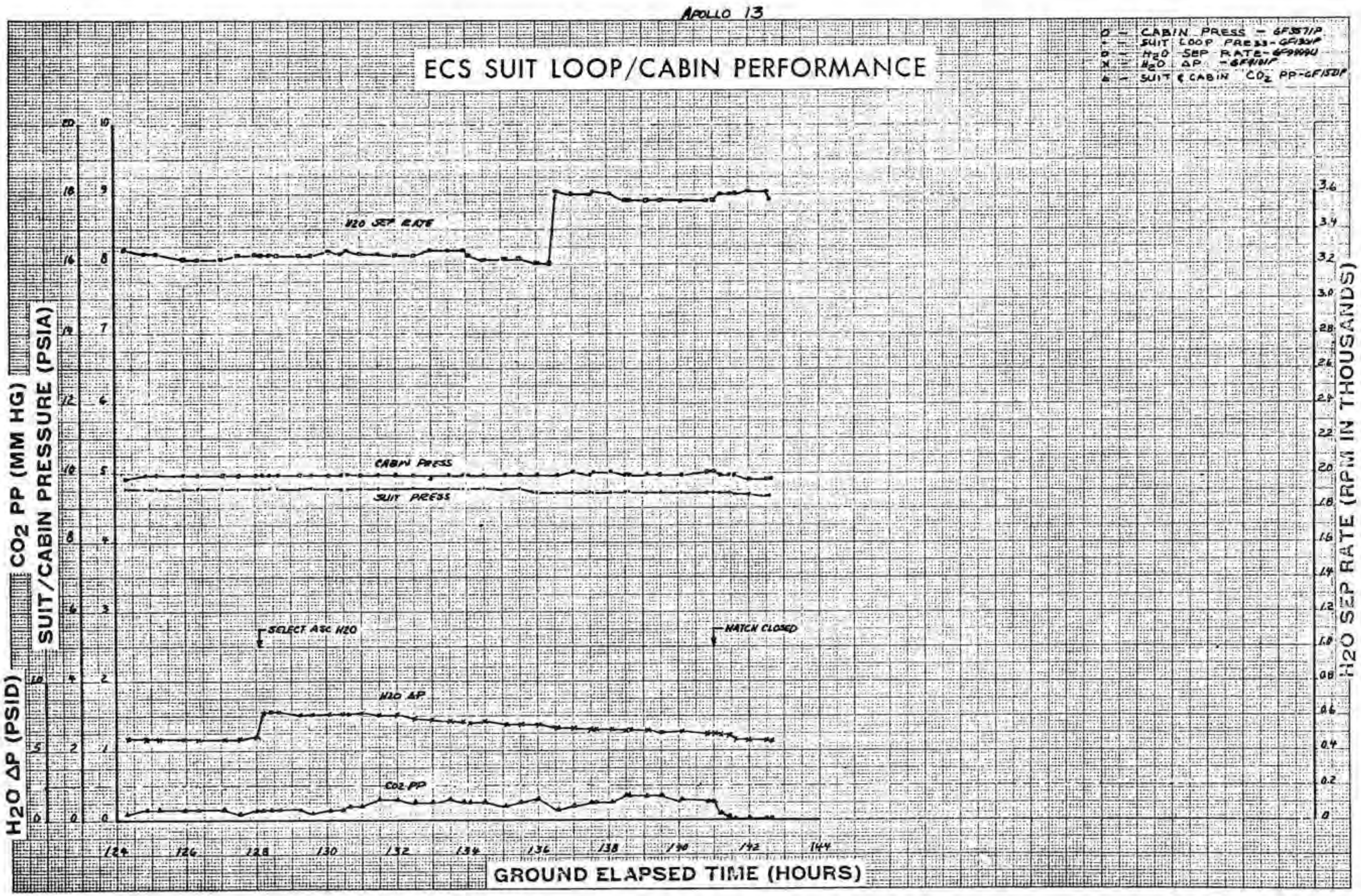

APOLLO 13
ECS SUIT LOOP/CABIN PERFORMANCE
CABIN PRESS
SUIT LOOP PRESS
H2O SEP RATE
H2O ΔP
SUIT & CABIN CO2 PP
H2O SEP RATE
CABIN PRESS
SUIT PRESS
SELECT ASC H2O
HATCH CLOSED
H2O ΔP
CO2 PP
H2O ΔP (PSID)
CO2 PP (MM HG)
SUIT/CABIN PRESSURE (PSIA)
H2O SEP RATE (RPM IN THOUSANDS)
GROUND ELAPSED TIME (HOURS)

Figure 1-3

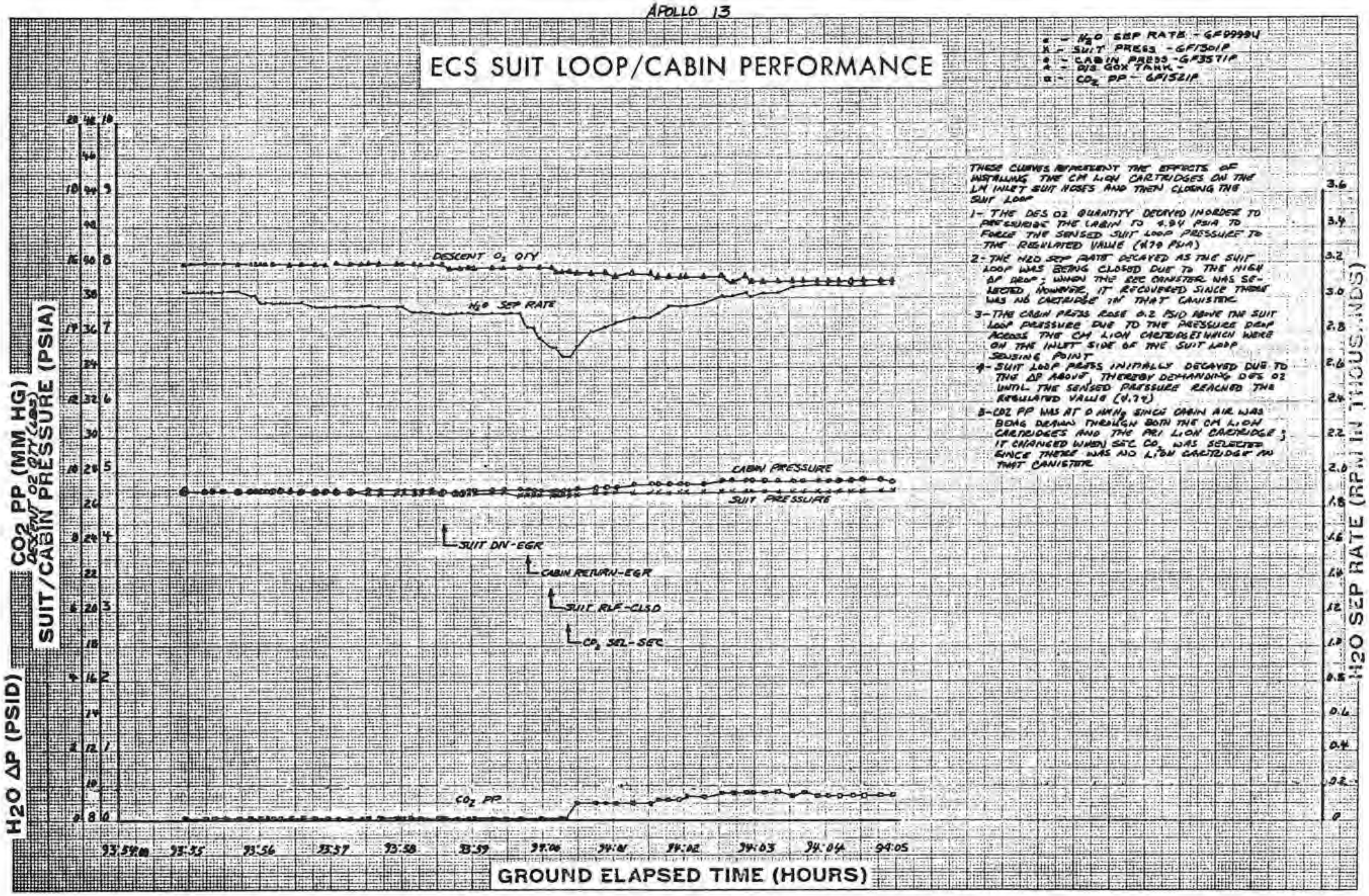

APOLLO 13
ECS SUIT LOOP/CABIN PERFORMANCE
• - H2O SEP RATE - GF9999U
x - SUIT PRESS - GF1301P
⊙ - CABIN PRESS - GF3571P
▲ - DES GOX TANK -
○ - CO2 PP - GF1521P
THESE CURVES REPRESENT THE EFFECTS OF INSTALLING THE CM LiOH CARTRIDGES ON THE LM INLET SUIT HOSES AND THEN CLOSING THE SUIT LOOP
1- THE DES O2 QUANTITY DECAYED INORDER TO PRESSURIZE THE CABIN TO 4.94 PSIA TO FORCE THE SENSED SUIT LOOP PRESSURE TO THE REGULATED VALUE (4.79 PSIA)
2- THE H2O SEP RATE DECAYED AS THE SUIT LOOP WAS BEING CLOSED DUE TO THE HIGH ΔP DROP; WHEN THE SEC CANISTER WAS SELECTED, HOWEVER, IT RECOVERED SINCE THERE WAS NO CARTRIDGE IN THAT CANISTER
3- THE CABIN PRESS ROSE 0.2 PSID ABOVE THE SUIT LOOP PRESSURE DUE TO THE PRESSURE DROP ACROSS THE CM LiOH CARTRIDGES WHICH WERE ON THE INLET SIDE OF THE SUIT LOOP SENSING POINT
4- SUIT LOOP PRESS INITIALLY DECAYED DUE TO THE ΔP ABOVE, THEREBY DEMANDING DES O2 UNTIL THE SENSED PRESSURE REACHED THE REGULATED VALUE (4.79)
5- CO2 PP WAS AT 0 MMHg SINCE CABIN AIR WAS BEING DRAWN THROUGH BOTH THE CM LiOH CARTRIDGES AND THE PRI LiOH CARTRIDGE; IT CHANGED WHEN SEC CO2 WAS SELECTED SINCE THERE WAS NO LiOH CARTRIDGE IN THAT CANISTER
DESCENT O2 QTY
H2O SEP RATE
CABIN PRESSURE
SUIT PRESSURE
SUIT DIV-EGR
CABIN RETURN-EGR
SUIT RLF-CLSD
CO2 SEL-SEC
CO2 PP
H2O ΔP (PSID)
CO2 PP (MM HG)
DESCENT O2 QTY (LBS)
SUIT/CABIN PRESSURE (PSIA)
H2O SEP RATE (RPM IN THOUSANDS)
GROUND ELAPSED TIME (HOURS)
93:54:00
93:55
93:56
93:57
93:58
93:59
94:00
94:01
94:02
94:03
94:04
94:05

Figure 1-4

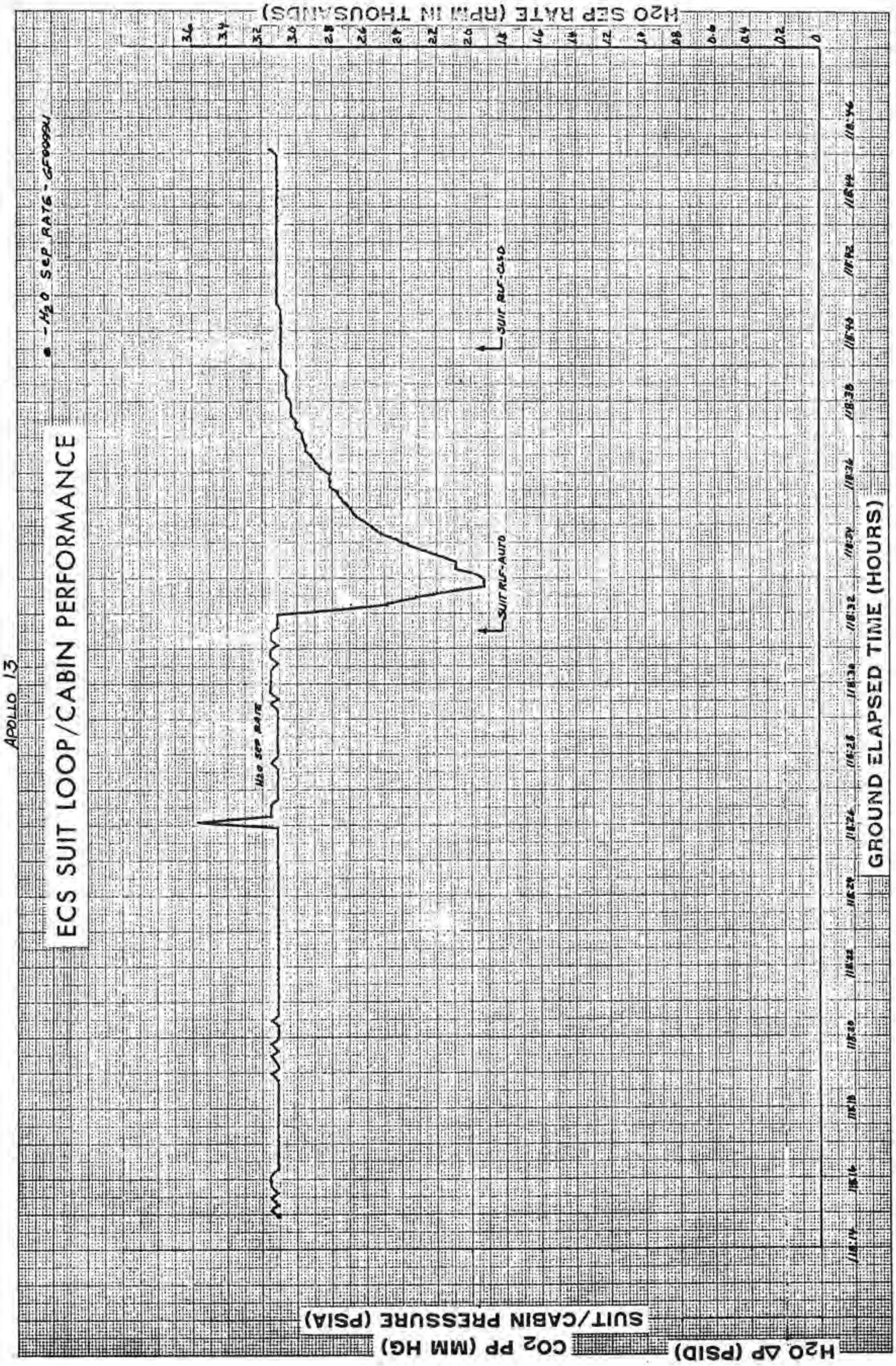

APOLLO 13
ECS SUIT LOOP/CABIN PERFORMANCE
H2O SEP RATE
SUIT RLF-AUTO
SUIT RLF-CLSD
GROUND ELAPSED TIME (HOURS)
H2O SEP RATE (RPM IN THOUSANDS)
SUIT/CABIN PRESSURE (PSIA)
CO2 PP (MM HG)
H2O ΔP (PSID)

Figure 1-5

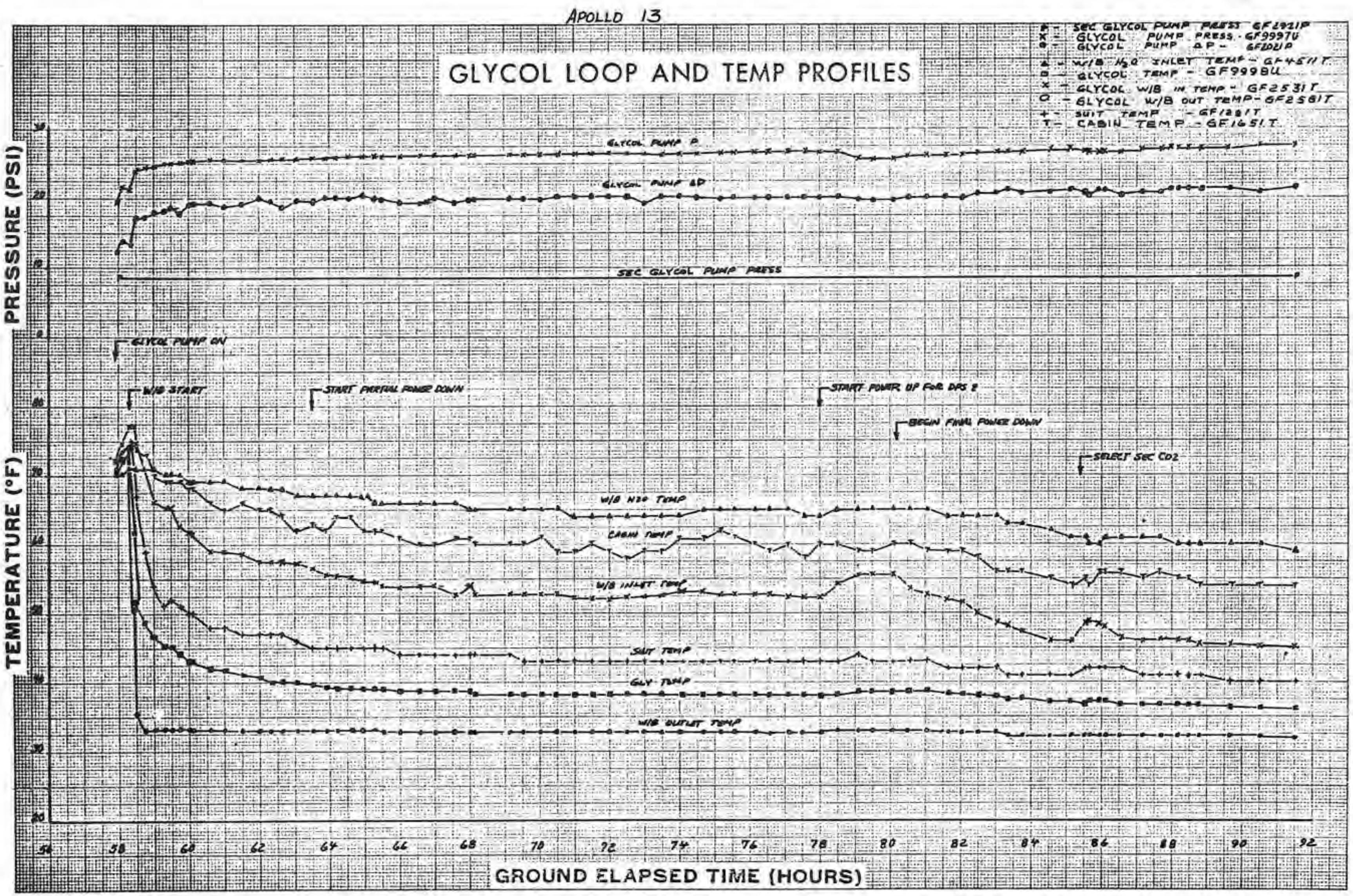
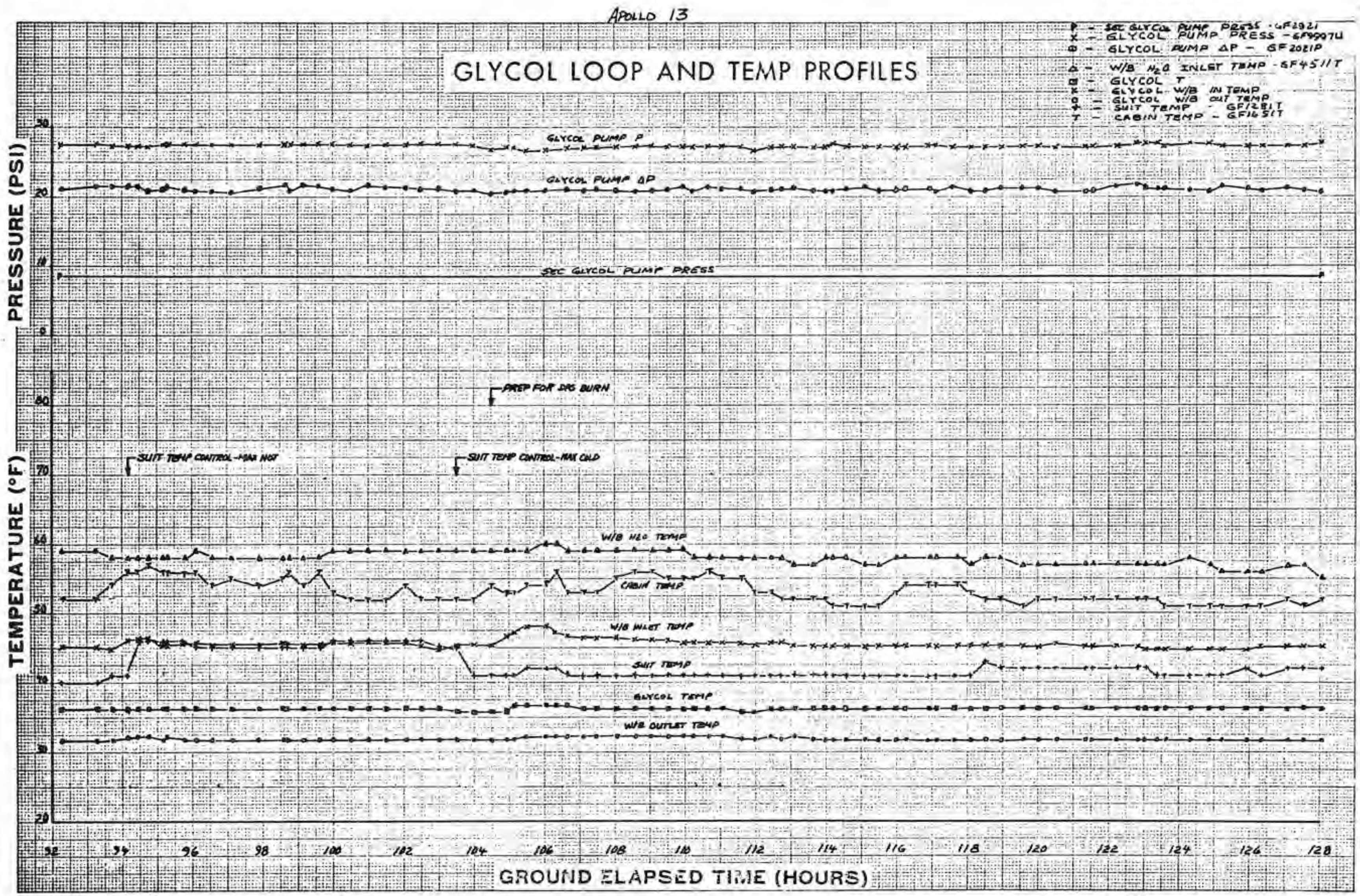

APOLLO 13
GLYCOL LOOP AND TEMP PROFILES
SEC GLYCOL PUMP PRESS GF2921P
X - GLYCOL PUMP PRESS. - GF9997U
GLYCOL PUMP ΔP - GF2021P
▲ - W/B H2O INLET TEMP - GF4511T
□ - GLYCOL TEMP - GF9998U
X - GLYCOL W/B IN TEMP - GF2531T
O - GLYCOL W/B OUT TEMP - GF2581T
+ - SUIT TEMP - GF1281T
T - CABIN TEMP - GF1651T
GLYCOL PUMP P
GLYCOL PUMP ΔP
SEC GLYCOL PUMP PRESS
GLYCOL PUMP ON
W/B START
START PARTIAL POWER DOWN
START POWER UP FOR DPS 2
BEGIN FINAL POWER DOWN
SELECT SEC CO2
W/B H2O TEMP
CABIN TEMP
W/B INLET TEMP
SUIT TEMP
GLY TEMP
W/B OUTLET TEMP
PRESSURE (PSI)
TEMPERATURE (°F)
GROUND ELAPSED TIME (HOURS)

Figure 2-1



APOLLO 13
GLYCOL LOOP AND TEMP PROFILES
P - SEC GLYCOL PUMP PRESS - GF2921
X - GLYCOL PUMP PRESS - GF9997U
⊕ - GLYCOL PUMP ΔP - GF2021P
Δ - W/B H2O INLET TEMP - GF4511T
⊠ - GLYCOL T
X - GLYCOL W/B IN TEMP
O - GLYCOL W/B OUT TEMP
+ - SUIT TEMP - GF1281T
T - CABIN TEMP - GF1651T
GLYCOL PUMP P
GLYCOL PUMP ΔP
SEC GLYCOL PUMP PRESS
PREP FOR DPS BURN
SUIT TEMP CONTROL - MAX HOT
SUIT TEMP CONTROL - MAX COLD
W/B H2O TEMP
CABIN TEMP
W/B INLET TEMP
SUIT TEMP
GLYCOL TEMP
W/B OUTLET TEMP
PRESSURE (PSI)
TEMPERATURE (°F)
GROUND ELAPSED TIME (HOURS)

Figure 2-2

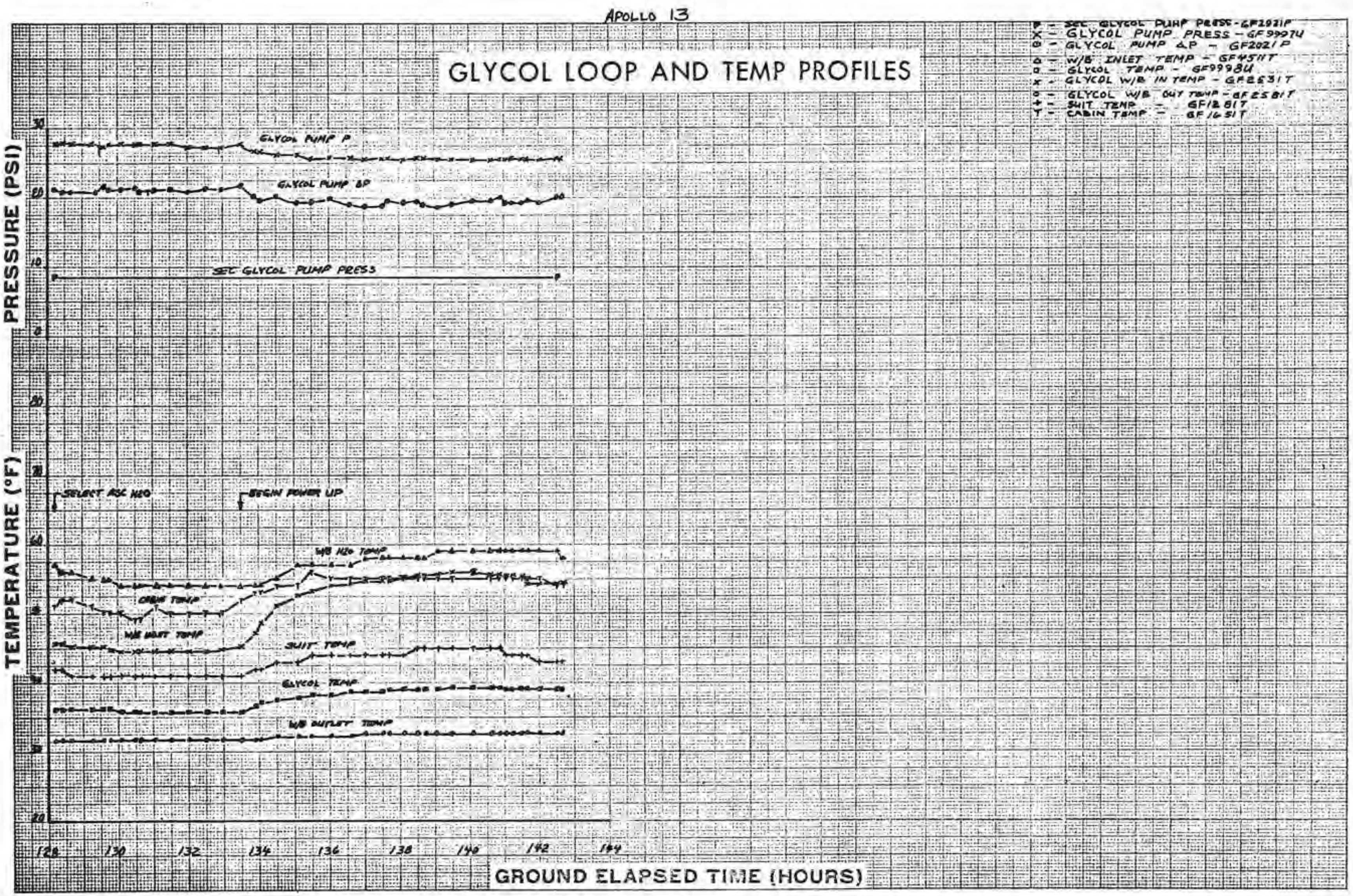

APOLLO 13
GLYCOL LOOP AND TEMP PROFILES
X - GLYCOL PUMP PRESS - GF9997U
GLYCOL PUMP ΔP - GF2021P
W/B INLET TEMP - GF4511T
GLYCOL TEMP - GF9998U
GLYCOL W/B IN TEMP - GF2531T
GLYCOL W/B OUT TEMP - GF2581T
SUIT TEMP - GF1281T
CABIN TEMP - GF1651T
PRESSURE (PSI)
TEMPERATURE (°F)
GLYCOL PUMP P
GLYCOL PUMP ΔP
SEC GLYCOL PUMP PRESS
SELECT ASC H2O
BEGIN POWER UP
W/B H2O TEMP
CABIN TEMP
W/B INLET TEMP
SUIT TEMP
GLYCOL TEMP
W/B OUTLET TEMP
30
20
10
0
80
70
60
50
40
30
20
128
130
132
134
136
138
140
142
144
GROUND ELAPSED TIME (HOURS)

Figure 2-3

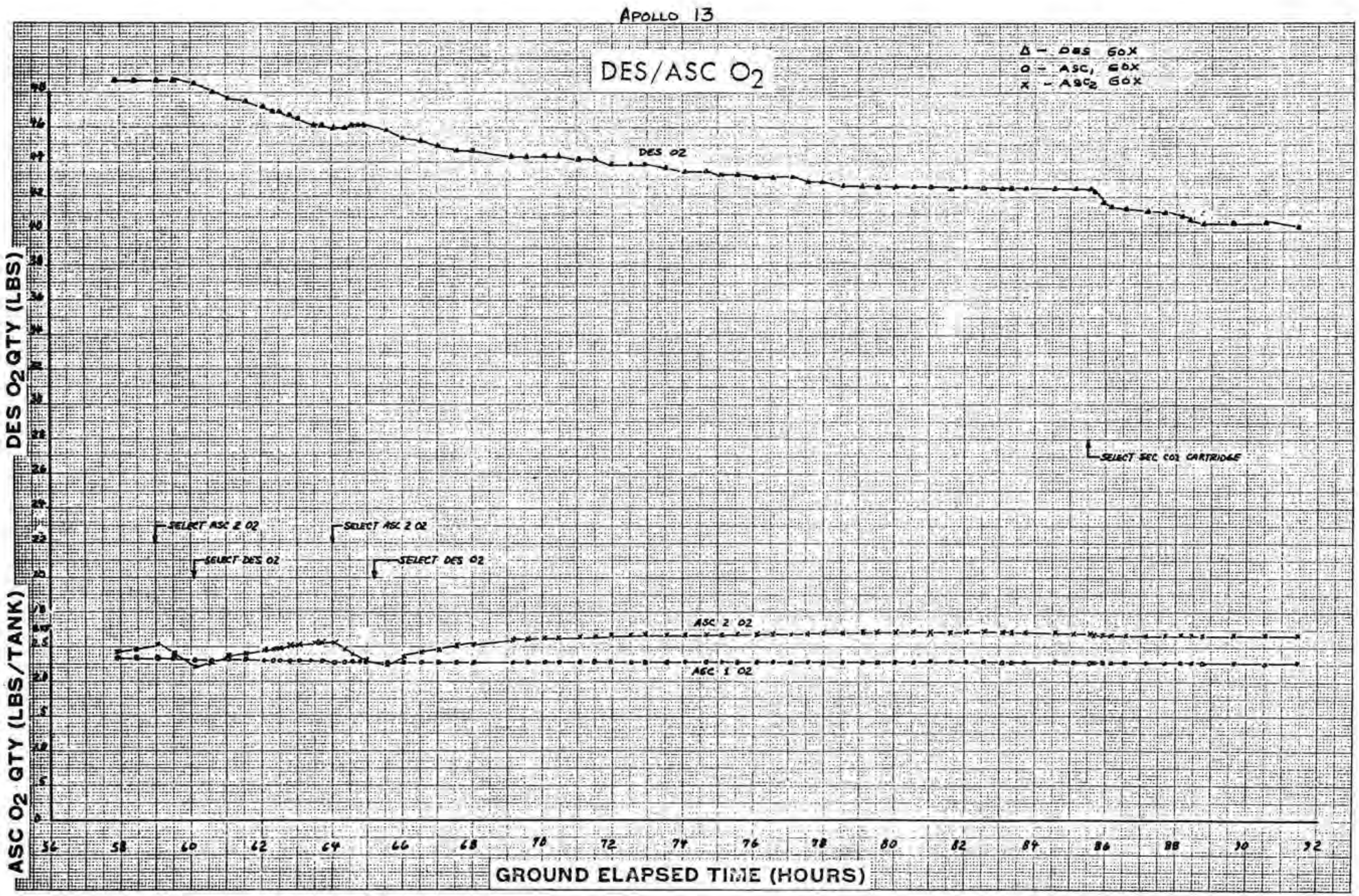

APOLLO 13
DES/ASC O_2
Δ – DES GOX
O – ASC1 GOX
X – ASC2 GOX
DES O2
SELECT ASC 2 O2
SELECT DES O2
SELECT ASC 2 O2
SELECT DES O2
SELECT SEC CO2 CARTRIDGE
ASC 2 O2
ASC 1 O2
DES O_2 QTY (LBS)
ASC O_2 QTY (LBS/TANK)
GROUND ELAPSED TIME (HOURS)

Figure 3-1

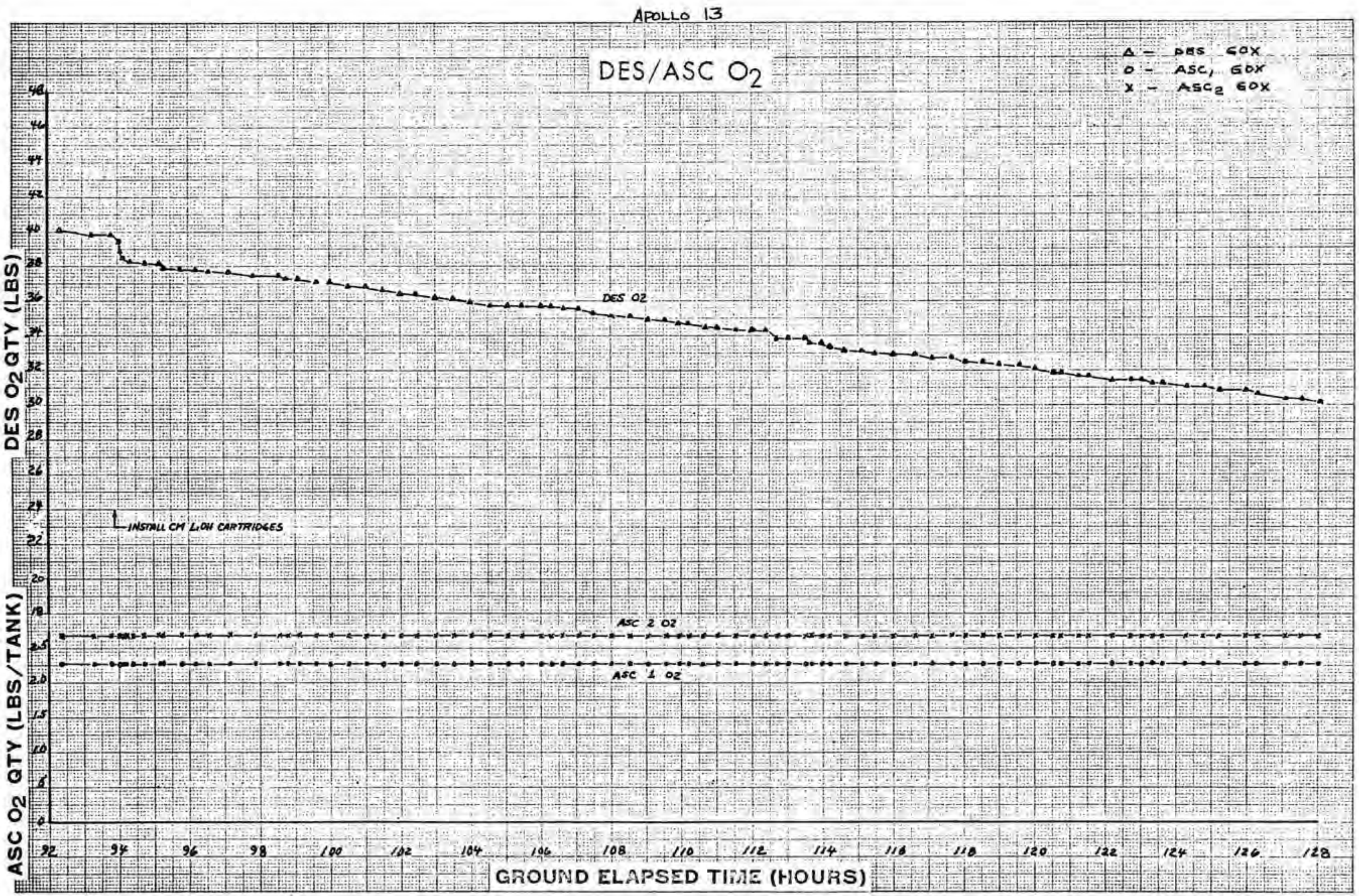

APOLLO 13
DES/ASC O_2
Δ - DES GOX
O - ASC1 GOX
X - ASC2 GOX
DES O2
INSTALL CM LiOH CARTRIDGES
ASC 2 O2
ASC 1 O2
DES O2 QTY (LBS)
ASC O2 QTY (LBS/TANK)
GROUND ELAPSED TIME (HOURS)

Figure 3-2

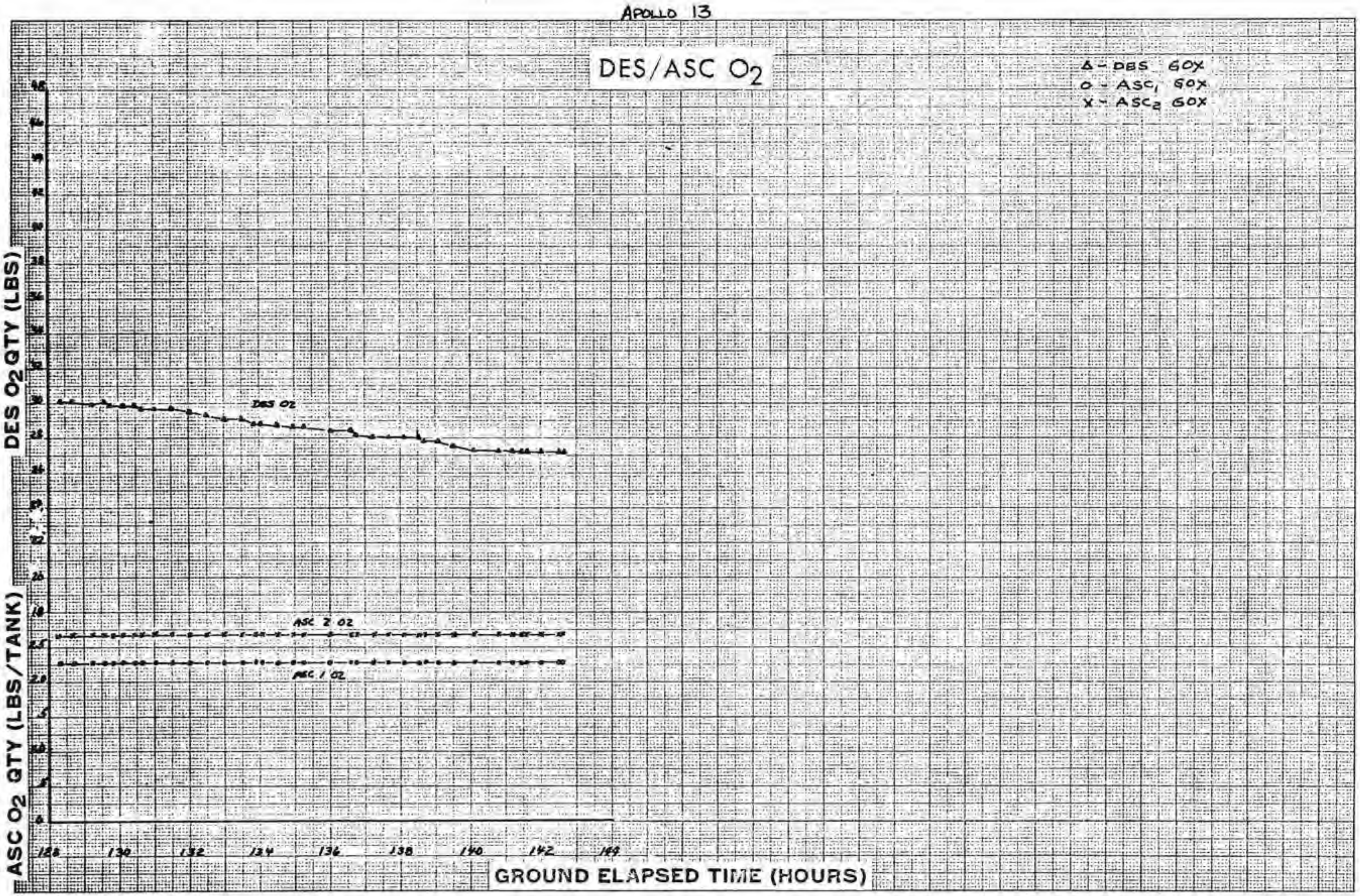

APOLLO 13
DES/ASC O2
Δ - DES GOX
O - ASC1 GOX
X - ASC2 GOX
DES O2
ASC 2 O2
ASC 1 O2
DES O2 QTY (LBS)
ASC O2 QTY (LBS/TANK)
130
132
134
136
138
140
142
144
GROUND ELAPSED TIME (HOURS)

Figure 3-3

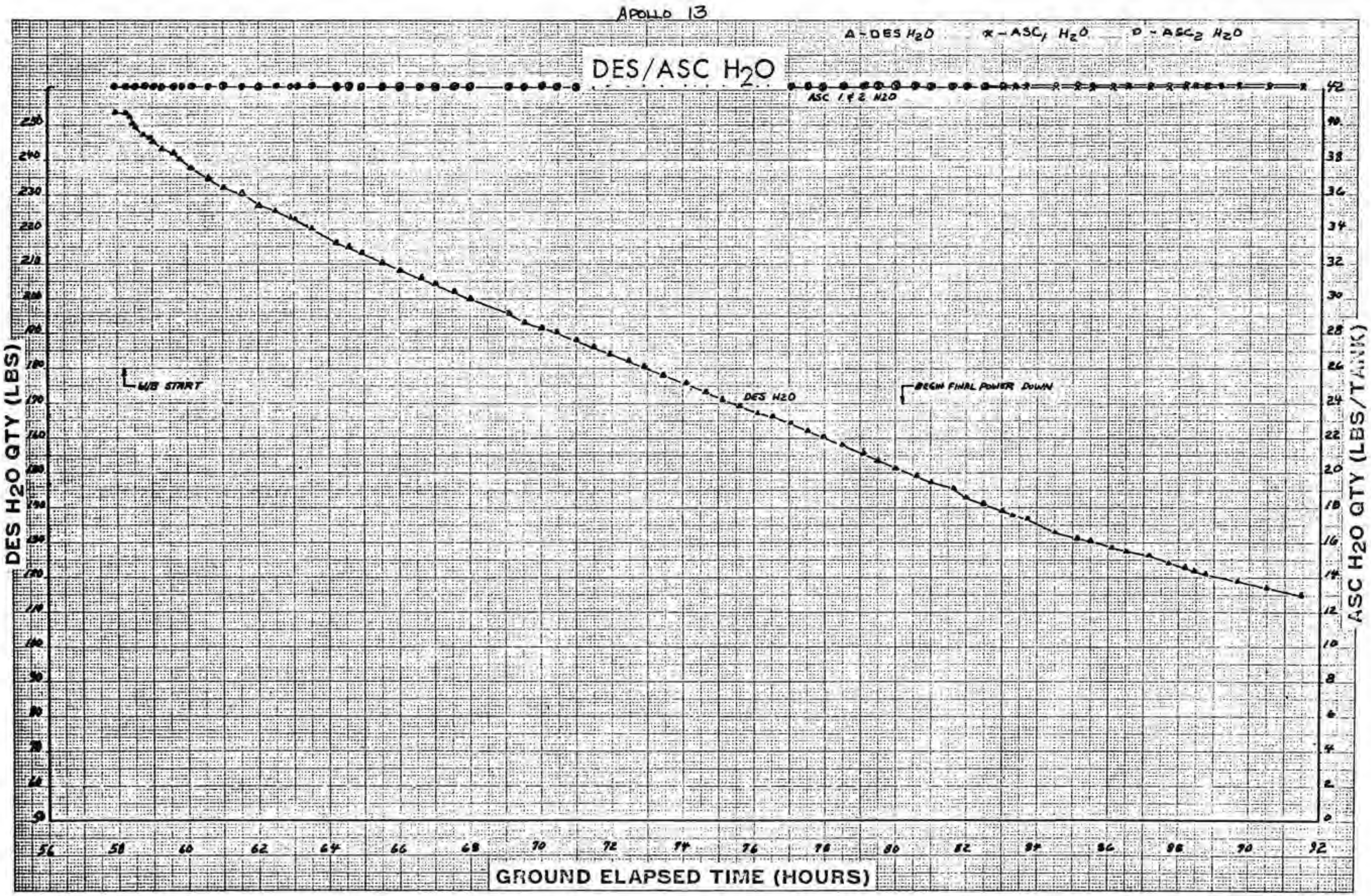

APOLLO 13
DES/ASC H2O
Δ - DES H2O
x - ASC1 H2O
O - ASC2 H2O
ASC 1 & 2 H2O
W/B START
DES H2O
BEGIN FINAL POWER DOWN
DES H2O QTY (LBS)
ASC H2O QTY (LBS/TANK)
GROUND ELAPSED TIME (HOURS)

Figure 4-1

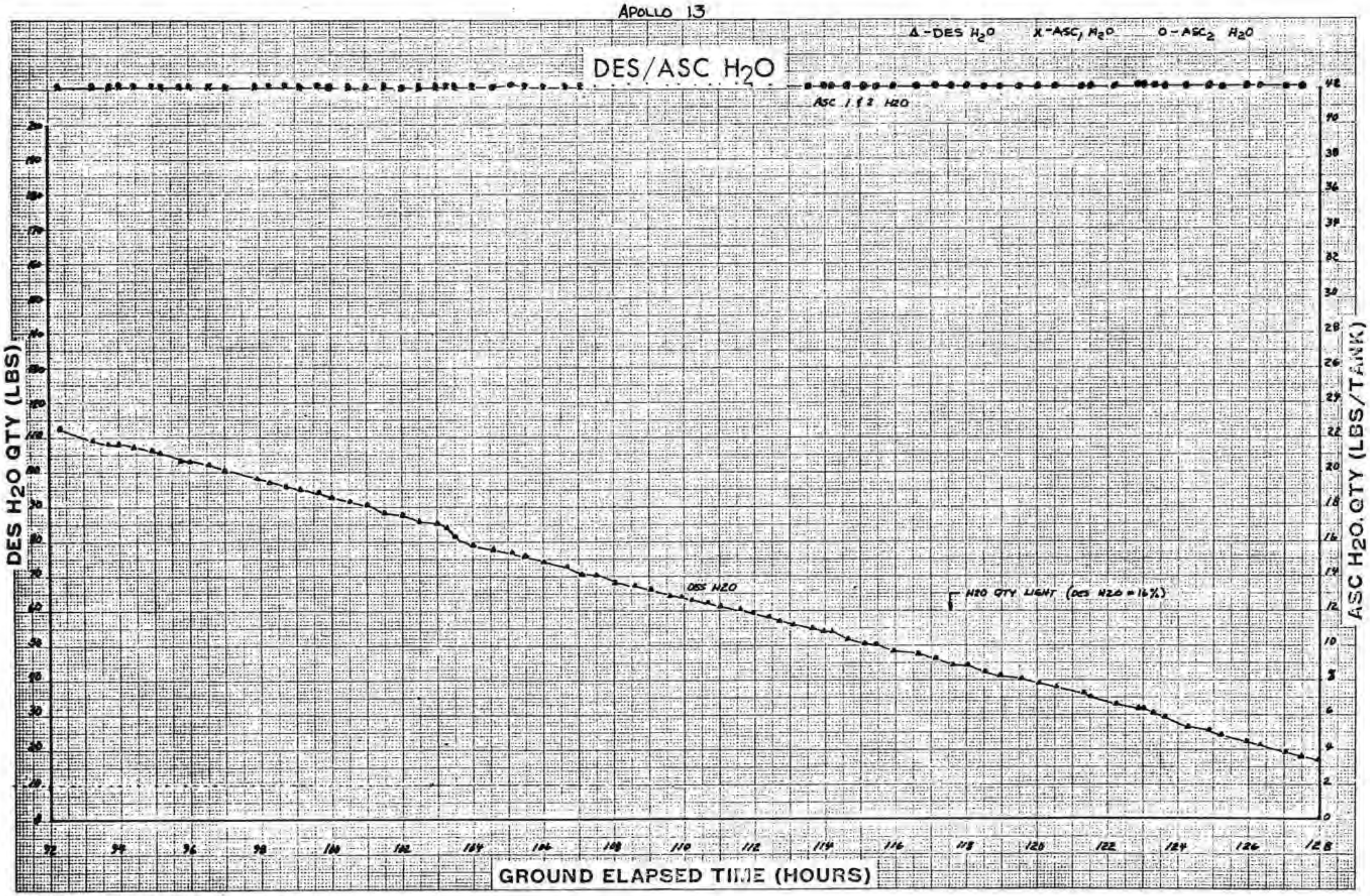

APOLLO 13
DES/ASC H_2O
Δ-DES H_2O
X-ASC1 H_2O
O-ASC2 H_2O
ASC 1 & 2 H2O
DES H2O
H2O QTY LIGHT (DES H2O = 16%)
DES H2O QTY (LBS)
ASC H2O QTY (LBS/TANK)
GROUND ELAPSED TIME (HOURS)

Figure 4-2

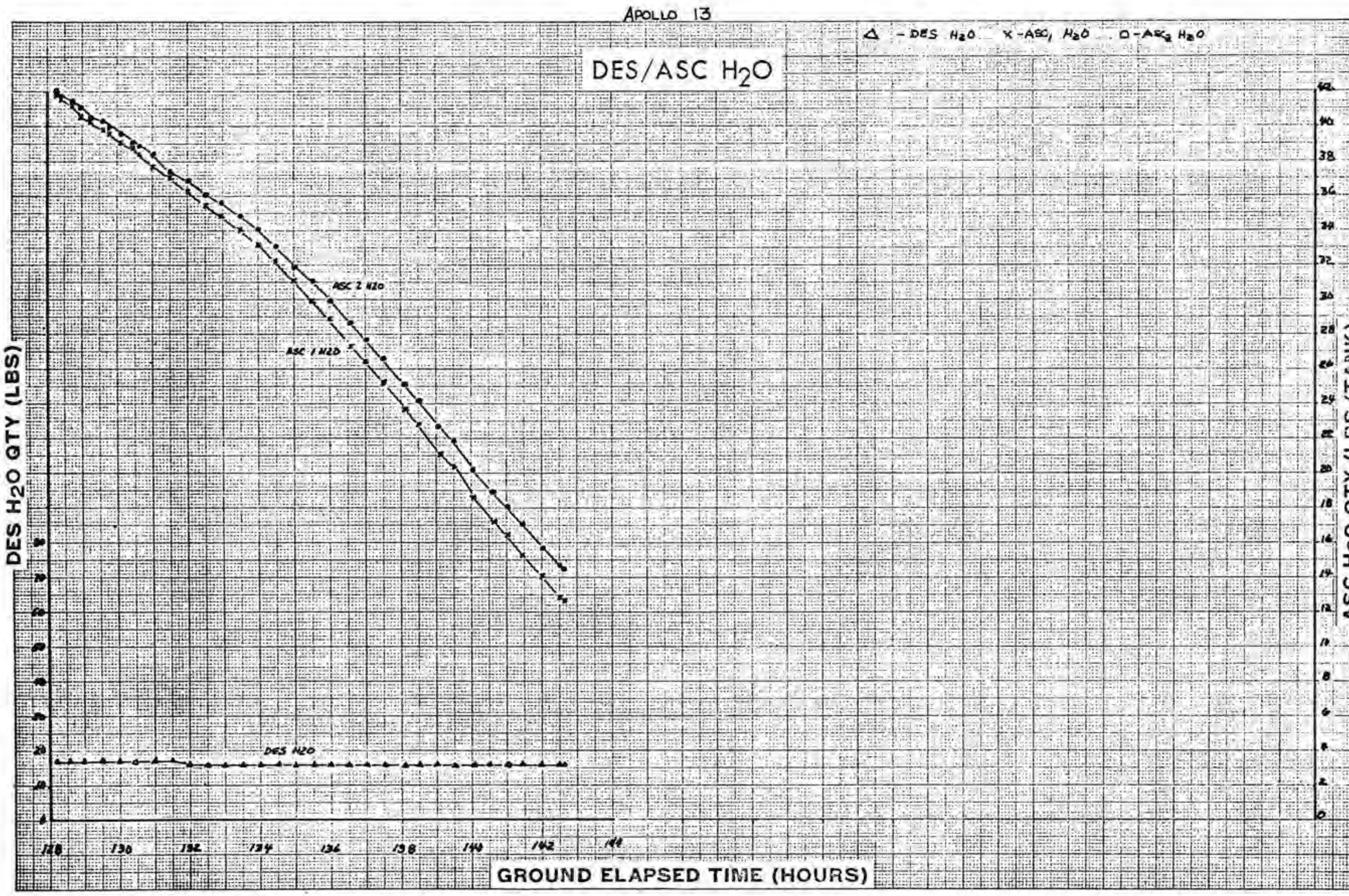

APOLLO 13
DES/ASC H_2O
Δ - DES H_2O X - ASC_1 H_2O □ - ASC_2 H_2O
ASC 2 H2O
ASC 1 H2O
DES H2O
DES H2O QTY (LBS)
ASC H2O QTY (LBS/TANK)
GROUND ELAPSED TIME (HOURS)
128
130
132
134
136
138
140
142
144
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0

Figure 4-3

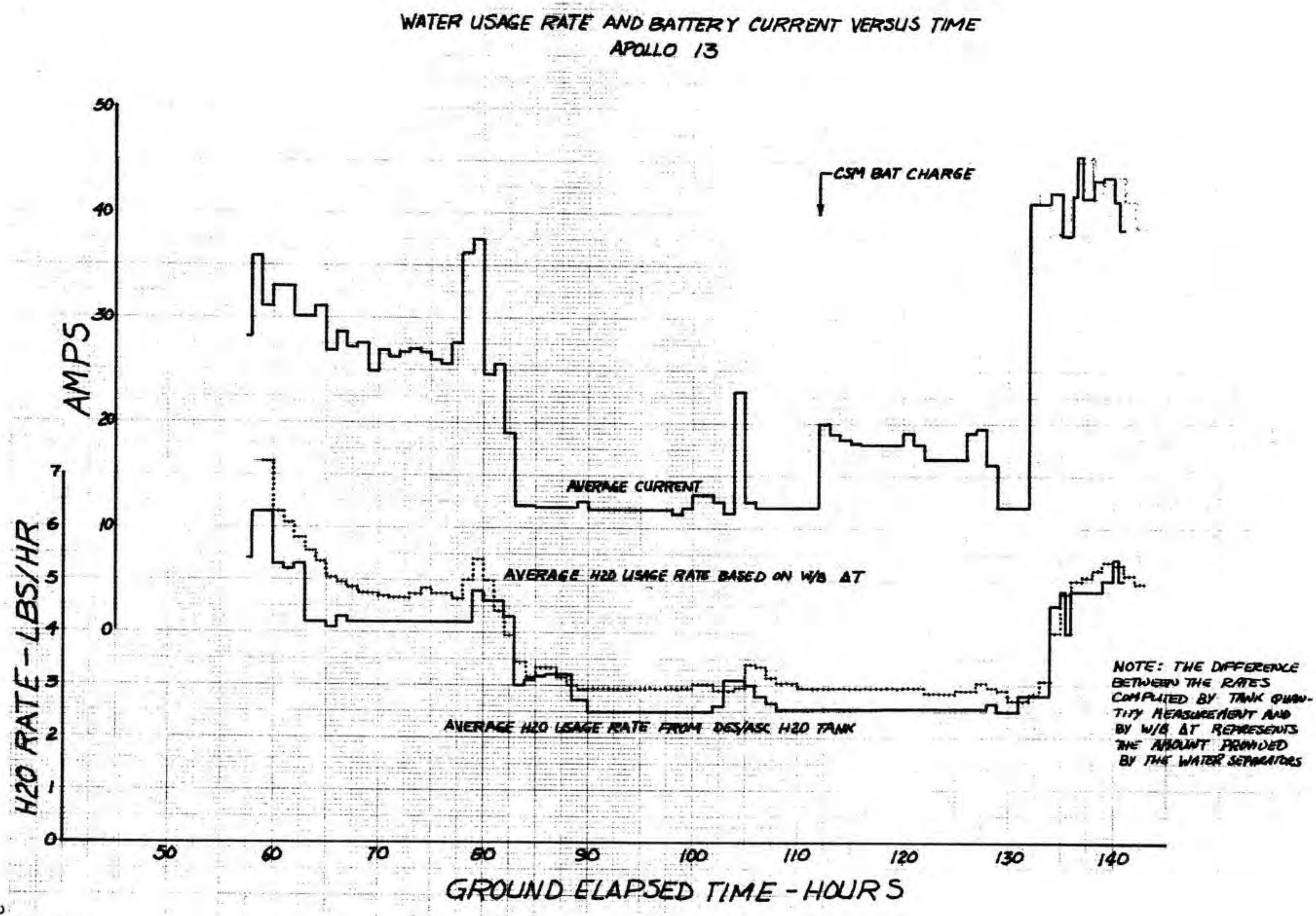

WATER USAGE RATE AND BATTERY CURRENT VERSUS TIME
APOLLO 13
AMPS
50
40
30
20
10
0
CSM BAT CHARGE
AVERAGE CURRENT
AVERAGE H2O USAGE RATE BASED ON W/B ΔT
AVERAGE H2O USAGE RATE FROM DES/ASC H2O TANK
NOTE: THE DIFFERENCE BETWEEN THE RATES COMPUTED BY TANK QUANTITY MEASUREMENT AND BY W/B ΔT REPRESENTS THE AMOUNT PROVIDED BY THE WATER SEPARATORS
H2O RATE-LBS/HR
7
6
5
4
3
2
1
0
50
60
70
80
90
100
110
120
130
140
GROUND ELAPSED TIME - HOURS

Figure 5

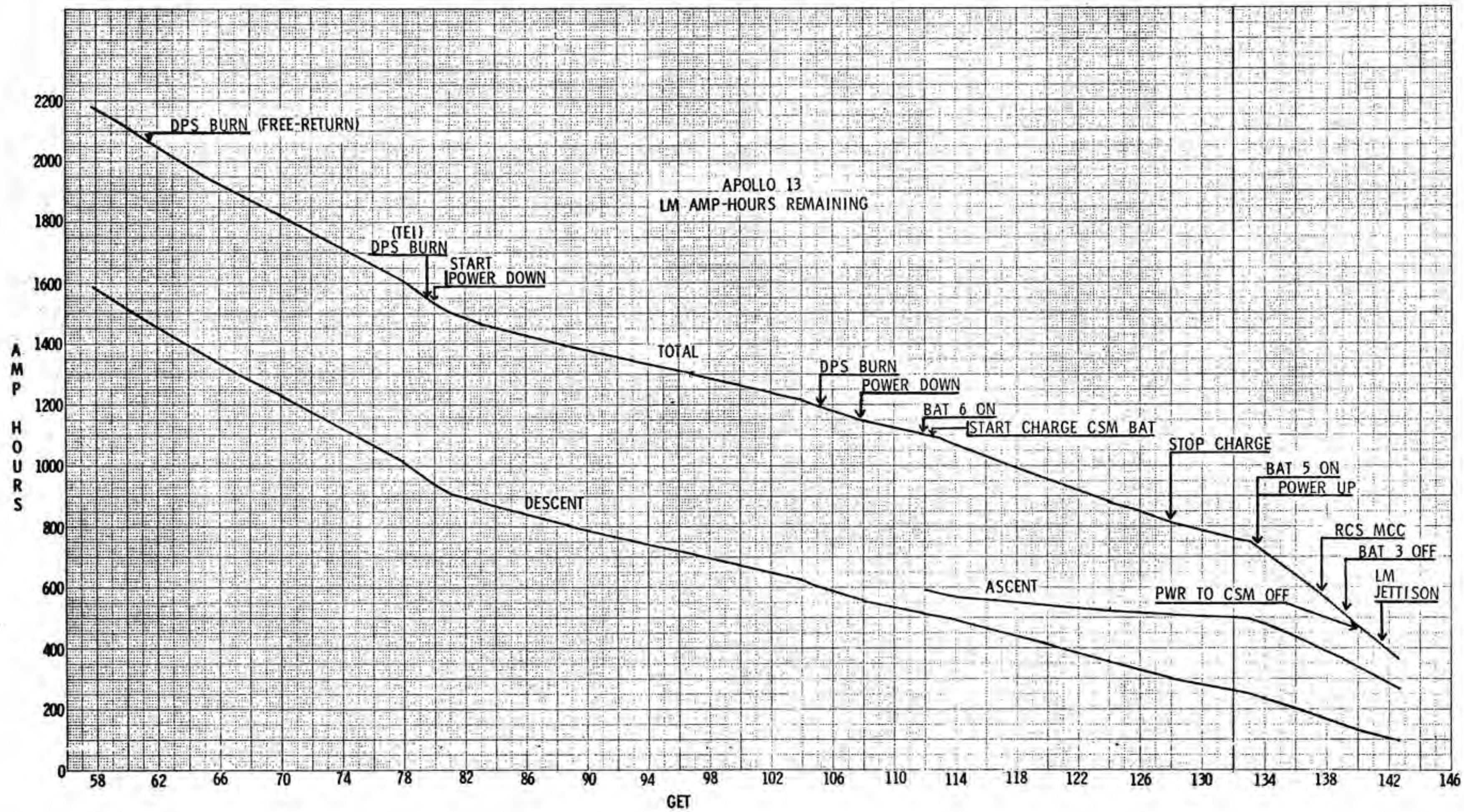

APOLLO 13
LM AMP-HOURS REMAINING
DPS BURN (FREE-RETURN)
(TEI)
DPS BURN
START
POWER DOWN
TOTAL
DPS BURN
POWER DOWN
BAT 6 ON
START CHARGE CSM BAT
STOP CHARGE
BAT 5 ON
POWER UP
RCS MCC
BAT 3 OFF
LM
JETTISON
DESCENT
ASCENT
PWR TO CSM OFF
AMP HOURS
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
58
62
66
70
74
78
82
86
90
94
98
102
106
110
114
118
122
126
130
134
138
142
146
GET

Figure 6

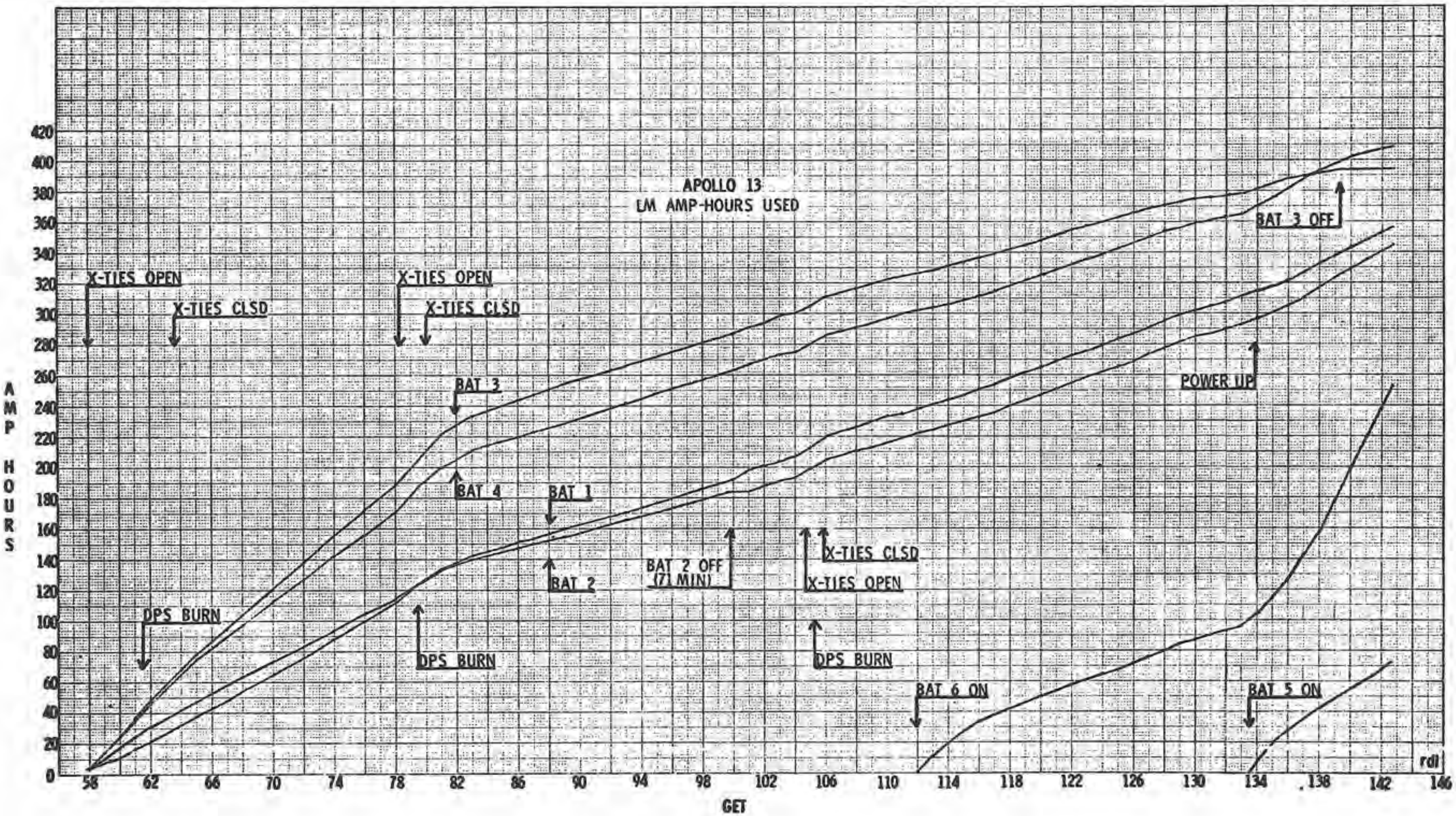

APOLLO 13
LM AMP-HOURS USED
AMP HOURS
GET
X-TIES OPEN
X-TIES CLSD
DPS BURN
X-TIES OPEN
X-TIES CLSD
BAT 3
BAT 4
BAT 1
BAT 2
DPS BURN
BAT 2 OFF
(71 MIN)
X-TIES CLSD
X-TIES OPEN
DPS BURN
BAT 6 ON
POWER UP
BAT 3 OFF
BAT 5 ON
rdl
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
58
62
66
70
74
78
82
86
90
94
98
102
106
110
114
118
122
126
130
134
138
142
146

Figure 7

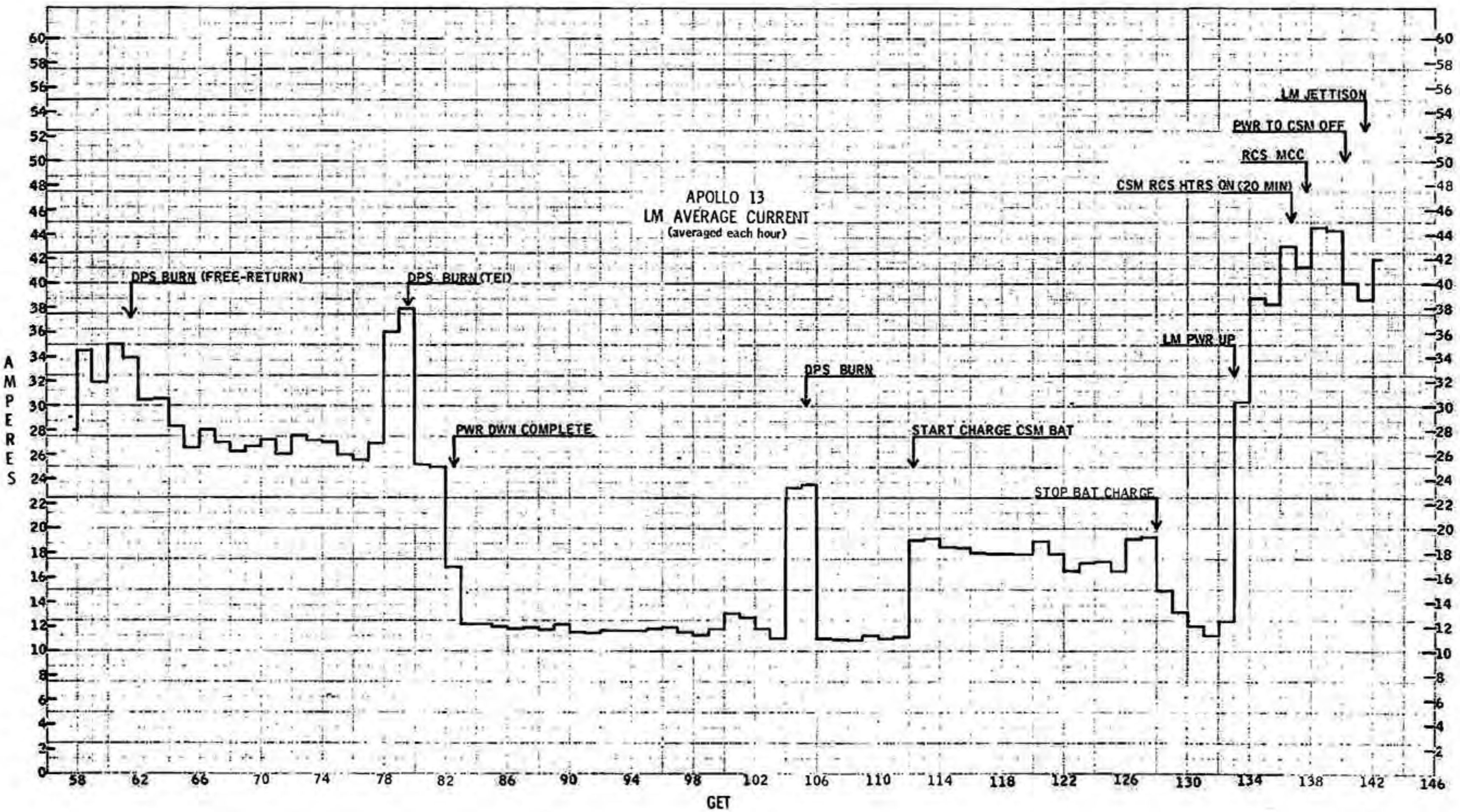

APOLLO 13
LM AVERAGE CURRENT
(averaged each hour)
DPS BURN (FREE-RETURN)
DPS BURN (TEI)
PWR DWN COMPLETE
DPS BURN
START CHARGE CSM BAT
STOP BAT CHARGE
LM PWR UP
CSM RCS HTRS ON (20 MIN)
RCS MCC
PWR TO CSM OFF
LM JETTISON
AMPERES
GET

Figure 8

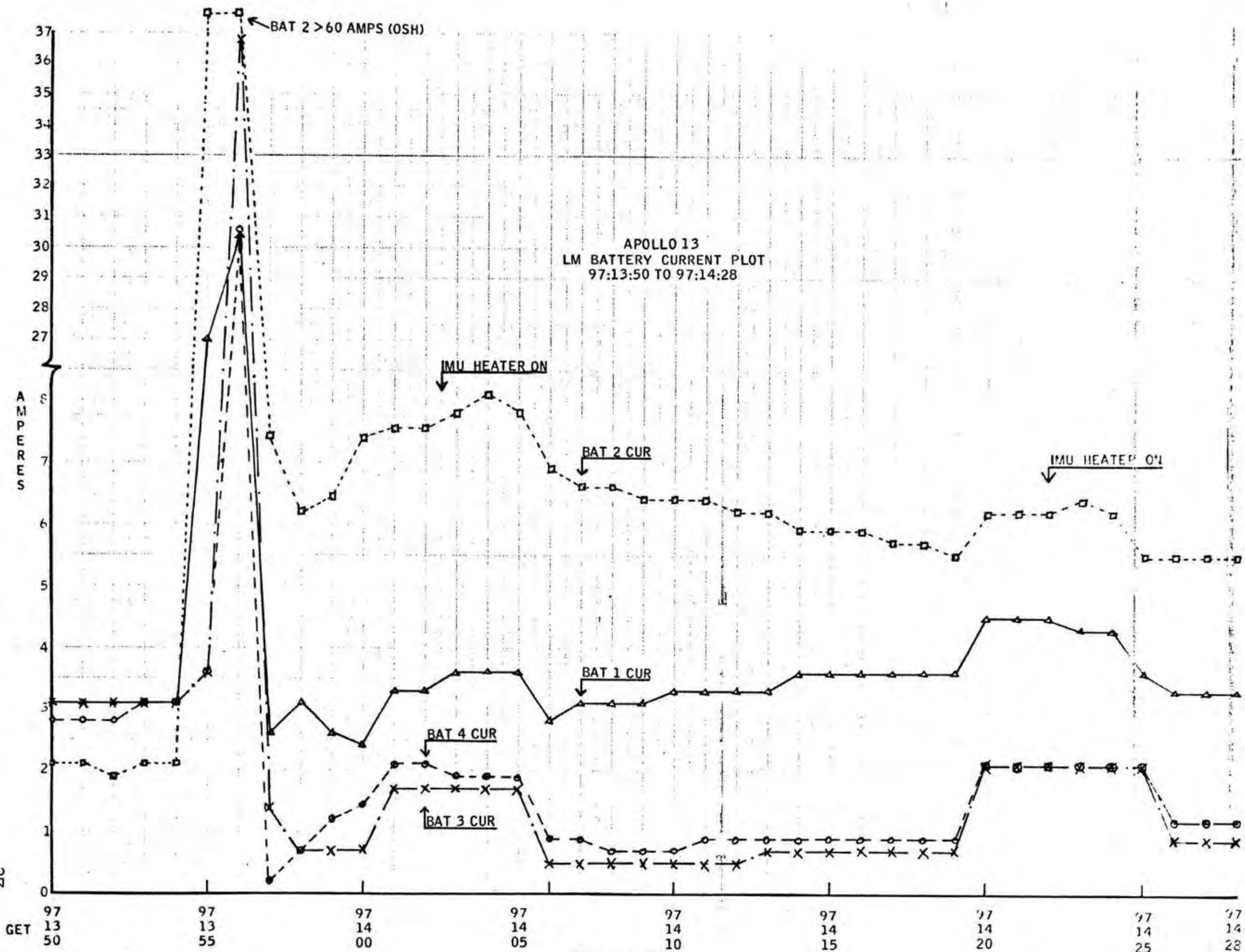

APOLLO 13
LM BATTERY CURRENT PLOT
97:13:50 TO 97:14:28
BAT 2 >60 AMPS (OSH)
IMU HEATER ON
BAT 2 CUR
IMU HEATER ON
BAT 1 CUR
BAT 4 CUR
BAT 3 CUR
AMPERES
GET

Figure 9-1

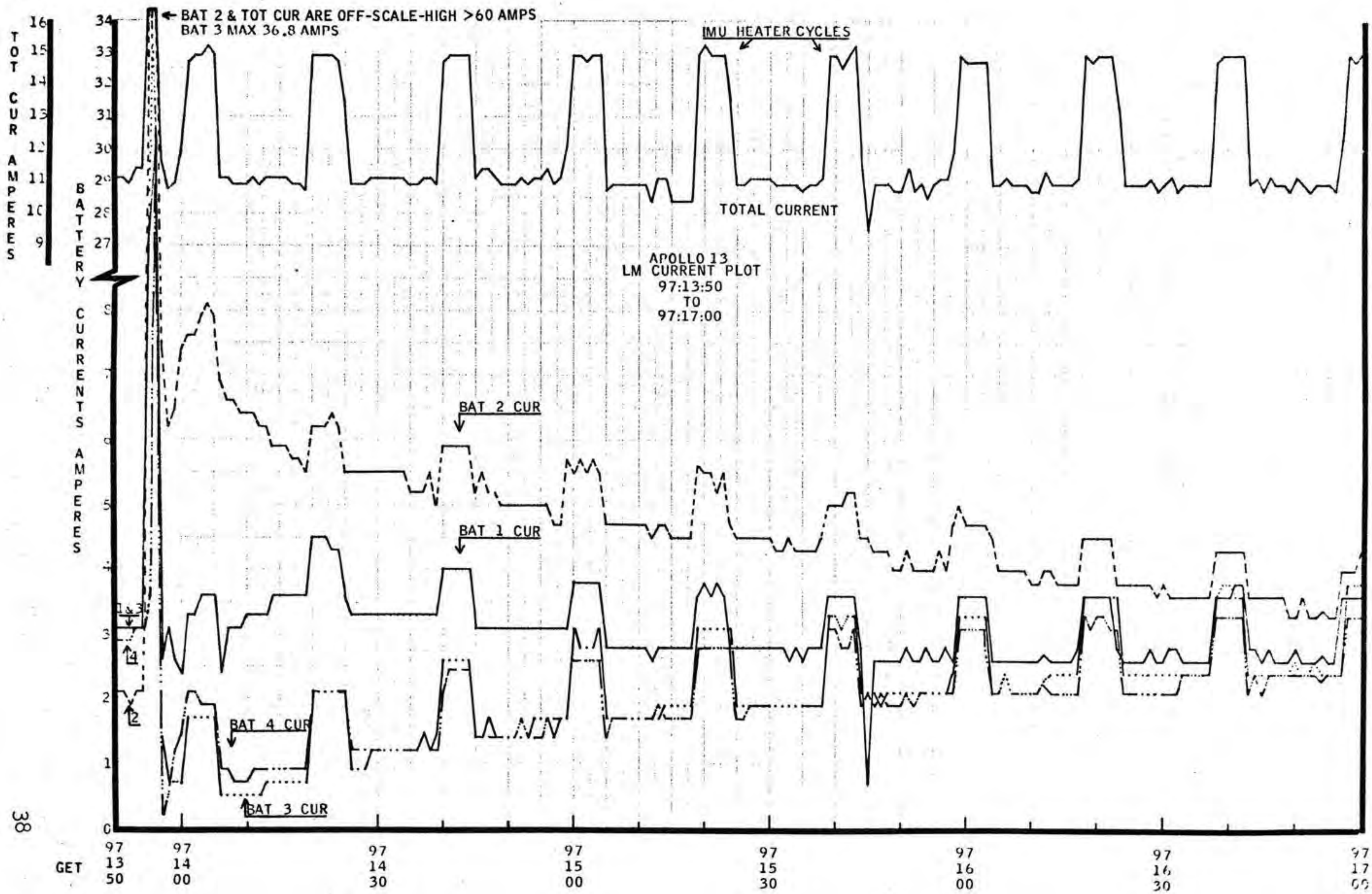

BAT 2 & TOT CUR ARE OFF-SCALE-HIGH >60 AMPS
BAT 3 MAX 36.8 AMPS
IMU HEATER CYCLES
TOTAL CURRENT
APOLLO 13
LM CURRENT PLOT
97:13:50
TO
97:17:00
BAT 2 CUR
BAT 1 CUR
BAT 4 CUR
BAT 3 CUR
TOT CUR AMPERES
BATTERY CURRENTS AMPERES
GET
97 13 50
97 14 00
97 14 30
97 15 00
97 15 30
97 16 00
97 16 30
97 17 00

Figure 9-2

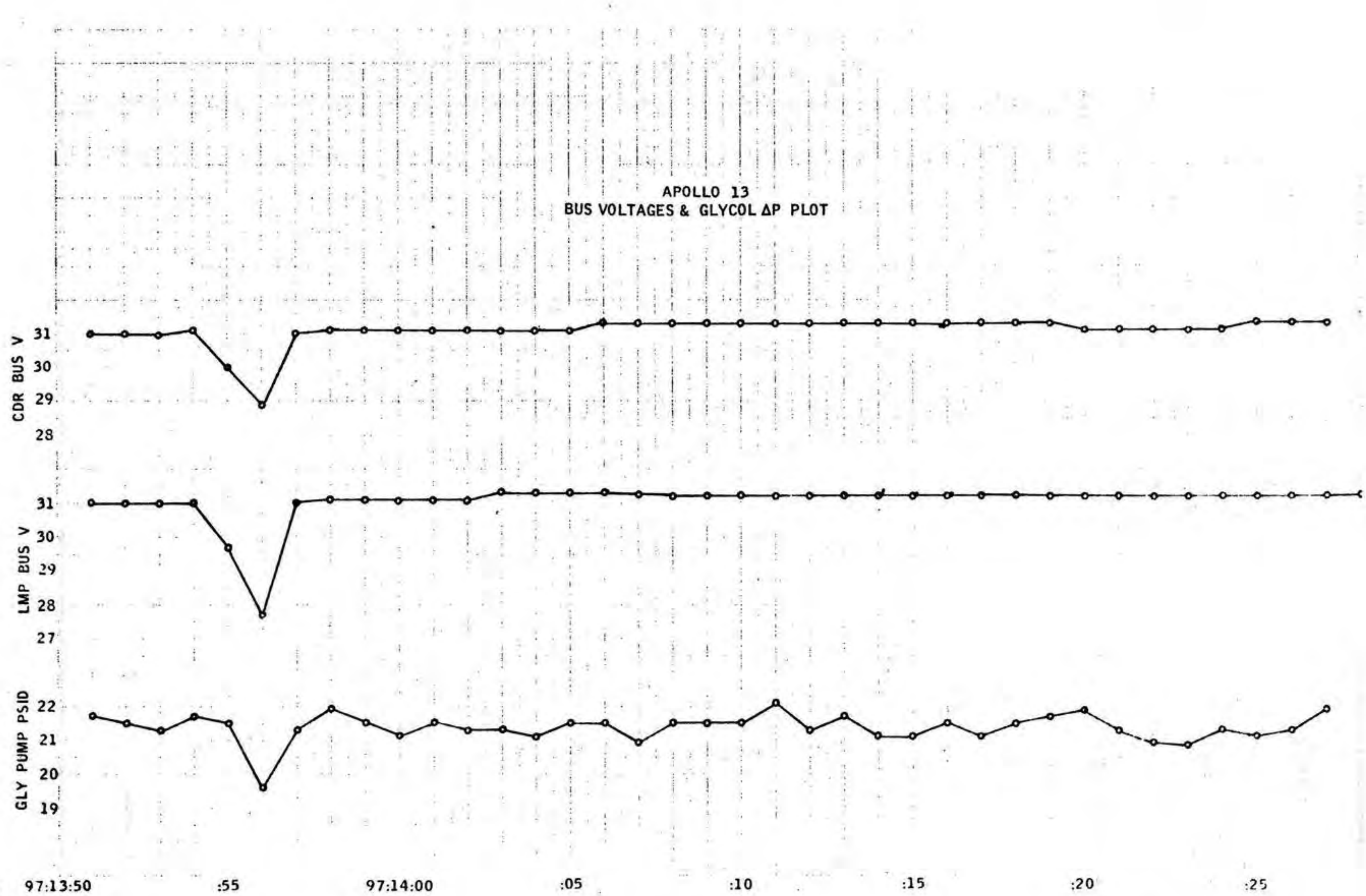

APOLLO 13
BUS VOLTAGES & GLYCOL ΔP PLOT
CDR BUS V
31
30
29
28
LMP BUS V
31
30
29
28
27
GLY PUMP PSID
22
21
20
19
97:13:50
:55
97:14:00
:05
:10
:15
:20
:25

Figure 9-3

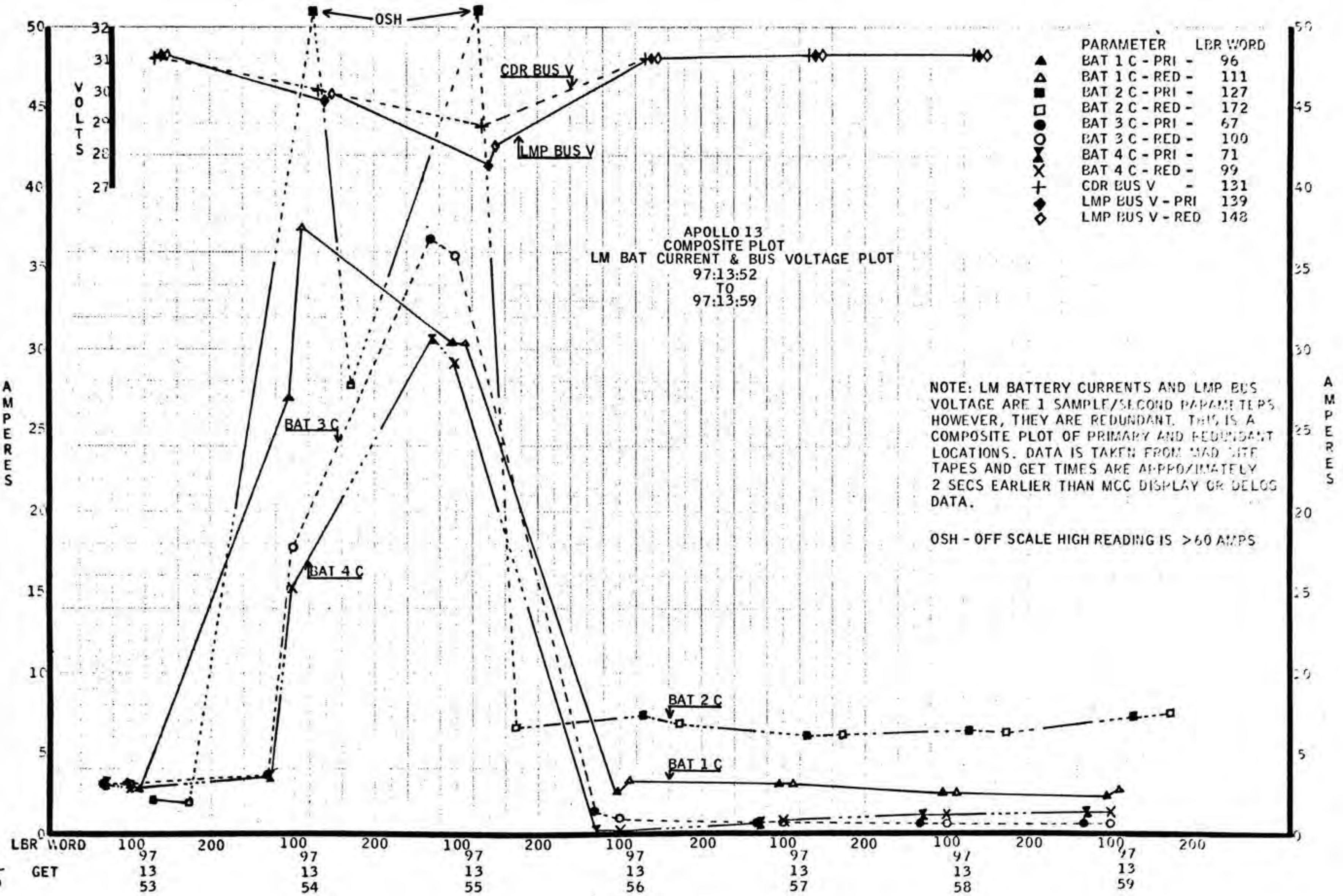

APOLLO 13
COMPOSITE PLOT
LM BAT CURRENT & BUS VOLTAGE PLOT
97:13:52
TO
97:13:59
PARAMETER LBR WORD
BAT 1 C - PRI - 96
BAT 1 C - RED - 111
BAT 2 C - PRI - 127
BAT 2 C - RED - 172
BAT 3 C - PRI - 67
BAT 3 C - RED - 100
BAT 4 C - PRI - 71
BAT 4 C - RED - 99
CDR BUS V - 131
LMP BUS V - PRI 139
LMP BUS V - RED 148
NOTE: LM BATTERY CURRENTS AND LMP BUS VOLTAGE ARE 1 SAMPLE/SECOND PARAMETERS HOWEVER, THEY ARE REDUNDANT. THIS IS A COMPOSITE PLOT OF PRIMARY AND REDUNDANT LOCATIONS. DATA IS TAKEN FROM MAD SITE TAPES AND GET TIMES ARE APPROXIMATELY 2 SECS EARLIER THAN MCC DISPLAY OR DELOG DATA.
OSH - OFF SCALE HIGH READING IS >60 AMPS
OSH
CDR BUS V
LMP BUS V
BAT 3 C
BAT 4 C
BAT 2 C
BAT 1 C
AMPERES
VOLTS
LBR WORD
GET
97 13 53
97 13 54
97 13 55
97 13 56
97 13 57
97 13 58
97 13 59

Figure 9-4

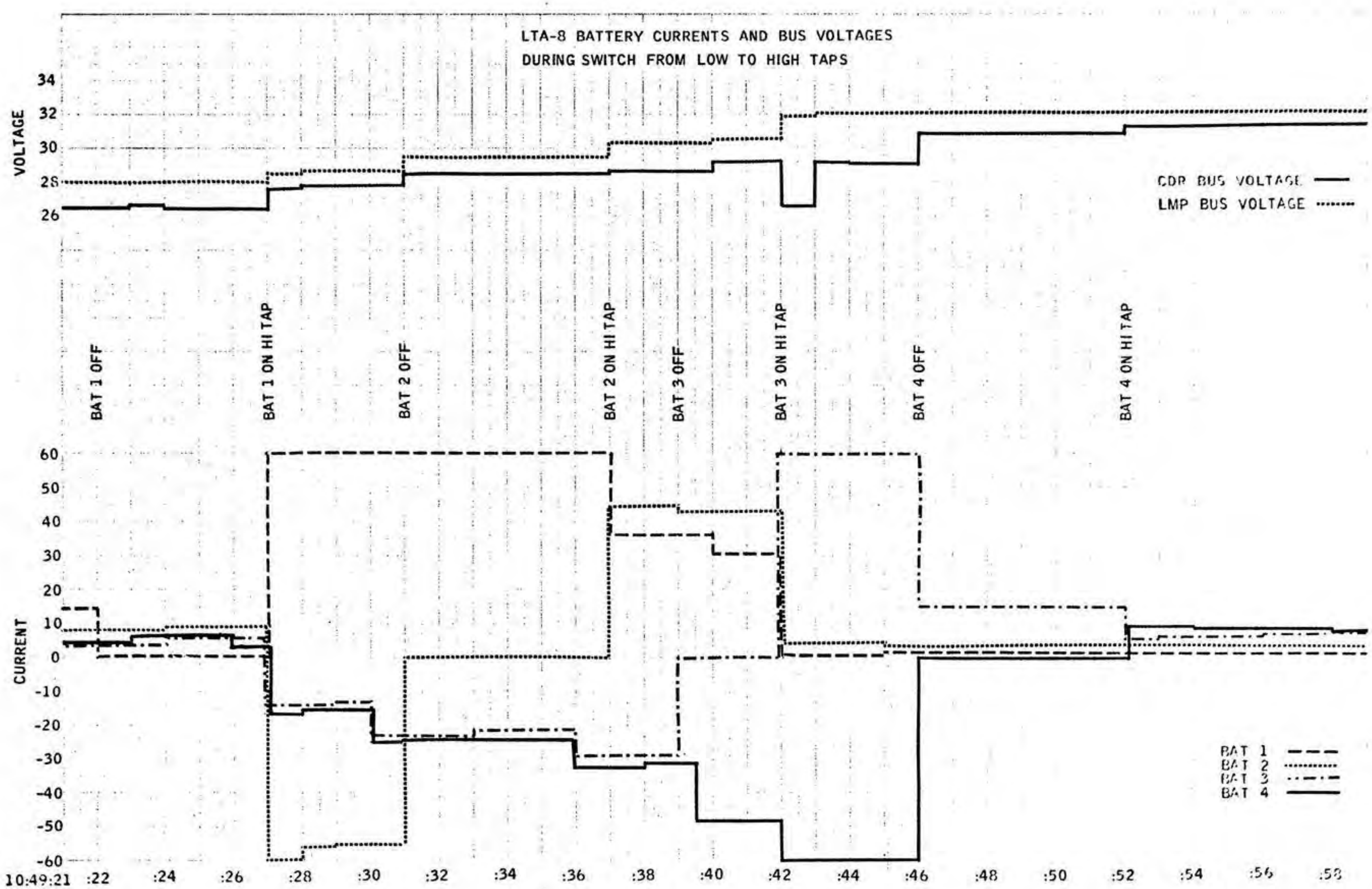

LTA-8 BATTERY CURRENTS AND BUS VOLTAGES
DURING SWITCH FROM LOW TO HIGH TAPS
VOLTAGE
34
32
30
28
26
CDR BUS VOLTAGE
LMP BUS VOLTAGE
BAT 1 OFF
BAT 1 ON HI TAP
BAT 2 OFF
BAT 2 ON HI TAP
BAT 3 OFF
BAT 3 ON HI TAP
BAT 4 OFF
BAT 4 ON HI TAP
CURRENT
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
BAT 1
BAT 2
BAT 3
BAT 4
10:49:21
:22
:24
:26
:28
:30
:32
:34
:36
:38
:40
:42
:44
:46
:48
:50
:52
:54
:56
:58

Figure 9-5

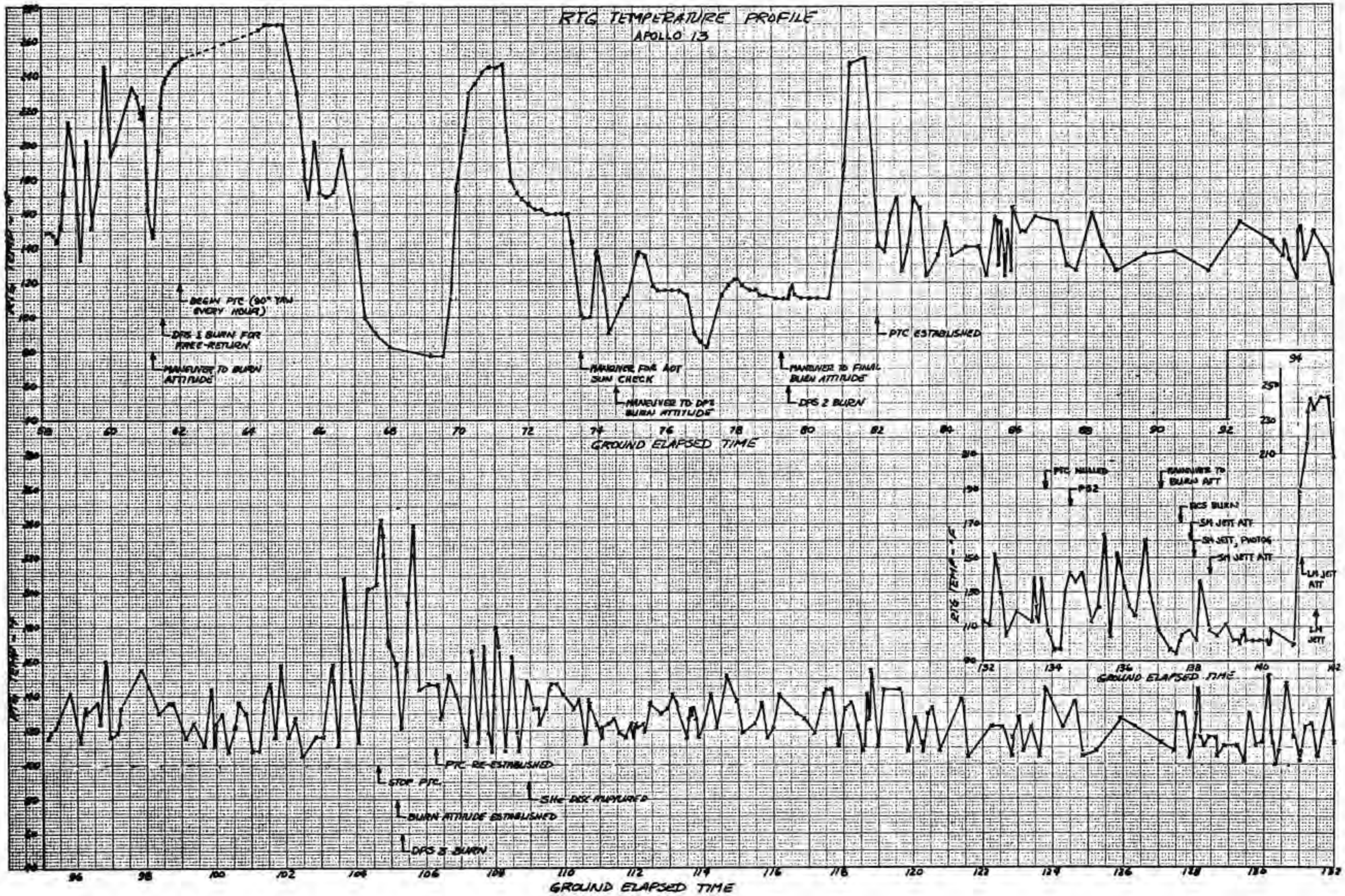


Figure 10

NASA — MSC — Coml., Houston, Texas

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

IN REPLY REFER TO: 70-FC41-75

April 30, 1970

MEMORANDUM TO: FC/Apollo 13 Flight Director

FROM : FC4/Apollo 13 TELMU Team

SUBJECT : Apollo 13 Post Mission Report

Attached is the Apollo 13, Phase II TELMU Post Mission Report. Any questions concerning this report may be directed to Jack Knight, extension 4576.

Jack Knight, Jr
Jack Knight

William L. Peters
William L. Peters

W. Merlin Merritt
W. Merlin Merritt

Robert H. Heselmeyer
Robert H. Heselmeyer

Enclosure

FC4:JKnight:dh

III. RECOMMENDATIONS

Recommendations are made in the following areas:

A. Crew Checklists/Procedures Additions

1. Block Procedures - These are procedures which could be required in contingency situations and are independent of timeline:

a. Life support activation and configuration.

b. Specific readout procedures for onboard display groups.

2. Contingency Timeline Procedures - These are procedures for operation of the LM should both redundant components be lost where compensation for this loss has a significant timeline impact. These are required where the mission will be continued with only one component remaining.

a. Loss of both suit fans

b. Loss of all ascent H_2O (and coolant loops) timeline

c. Loss of both ascent O_2 tanks

3. LM/CM Interface Procedures

a. LM to CM power transfer on/off

b. PLSS H_2O for LM sublimator and drinking

c. Combined LM/CM CO_2 control

d. Two-way transfer of H_2O to LM/CM

B. Mission Operations Considerations

1. Prelaunch Waiver Guidelines

a. Waivers should not be given where severe impact on the flight plan and/or crew procedures results.

b. Before a waiver is granted, corrective inflight procedures should be written and verified.

c. Waivers should not be granted where a subsequent single failure may seriously degrade the system capability. For example, the ascent O_2 #2 tank shutoff valve was waivered with a significant leak. Should it have subsequently been lost during an EVA, the entire descent O_2 tank may have been lost and the manifold continually open to a vacuum condition. The remaining ascent O_2 tank would then have been practically useless since it would not be capable of being left on line. This would have required using the OPS or PLSS for a subsequent rendezvous.

2. Consider the trade-off of lengthening the TEC in order to retain the LM ascent stage for possible "lifeboat" use during that phase.

C. Vehicle or GFE Hardware Modifications

1. In support of item B.2., modify LM's 8 and 9 such that LM power can be provided to the CM for an ascent-stage-only configuration, or

2. Construct an "extension cord" capable of interfacing between the GSE power connectors on the LM and the CM Main Bus(es) such that power can be applied to other than the CM MAIN BUS B.

3. Provide a hose interconnect with a removable plug such that the CM O_2 transfer umbilical can be vented with a LM hose or a LM Hose/ CM LiOH Cartridge adaptor for CO_2 scrubbing without extensive "jury-rigging."

4. Consider a modification such that KSC can verify all contacts of the LM prelaunch instrumentation power relay have opened at instrumentation shutdown (reference Memorandum PD7/M174-70, Launch mission rules for LM PCM remaining on at liftoff).

D. Simulations

1. Simulations should be spaced closer together; at least two a week for each team with a major mission phase responsibility.

2. At least two days of EVA math model simulations are recommended for systems personnel training.

3. Efforts should be expended to make the math model more similar to the LMS. Present differences between the two result in skeptical interpretation of data; i.e., the same problem on the Math Model often manifests itself differently on the LMS.

APPENDIX H

LM Control Officer (Control)

APPENDIX H

LM CONTROL

APOLLO 13

POST MISSION REPORT

PART I - FINAL

April 24, 1970

Prepared by:

John A. Wegener

Harold A. Loden

Richard A. Thorson

Larry W. Strimple

PRELAUNCH

(T-4 to L/O)

All prelaunch LM CONTROL data was nominal. The SHe pressure rise rate was approximately 8 psi/hr which gave a T-10 minute (time at which LM data was ended) readout of 356 psia.

LM ENTRY

(50:00 - 55:50 GET)

Due to the erratic behavior noticed in SHe loading during CDDT, it was decided to obtain an onboard readout of SHe pressure during LM entry. A number of alternatives were agreed upon depending upon the value of this readout: (1) If the SHe pressure was less than 770 psia and greater than 660 psia (nominal ~715 psia), no further action would be required. (2) If the SHe pressure was higher than 770 psia but less than 800 psia, a second onboard readout would be requested two to three hours later to ensure that an excessively high rise rate did not exist. (3) If the pressure was greater than 800 psia, TM would be turned on periodically over the next few hours allowing the ground to compute an accurate rise rate and extrapolate the SHe pressure to PDI ignition at 103 hr. GET. (4) If the predicted rise rate at PDI was equal to or greater than 1800 psia, it was proposed that a short duration DPS burn (5 sec) be performed with a subsequent vent of the SHe tank.

To encompass these procedures, the time for LM entry was moved forward to 55:00 GET such that the crew sleep period would not be disturbed. The crew, however, offered to enter the LM early and perform the SHe readout as well as the normal LM entry procedures. The crew entered the LM shortly after 54:00 GET and immediately powered up the onboard readout of SHe pressure per the procedure sent up from the ground. The onboard readout was cycling between 710 and 720 psia corresponding to a nominal rise rate of 6.5 psia/hr from launch (pre-launch was approximately 8 psi/hr). After the SHe readout, the crew continued with the remainder of the LM entry procedures.

CSM ANOMALY

(55:50 - 57:57 GET)

Immediately following the CSM problem and the resultant degradation of CSM electrical power, the LM heater current became static at 1.3 amps. Shortly thereafter, the current went to zero when the CM main Buss B lost complete power. At this time, it was decided that total LM console manning was required. The LM was without heater current for the next hour and one-half. Current was restored via LM power up at 57:37 GET when the crew re-entered the LM as a contingency backup to their return to earth and life support systems.

LM POWER UP

(57:57 - 61:00 GET)

LM TM was received at 57:57 GET with all systems and temperatures nominal. The crew, using a 2 hour contingency checklist began powering up those systems which were deemed of highest priority. Upon powering up the LGC and IMU, they performed a successful docked alignment with the CSM. Next, the crew attempted to assume attitude control, however, the ATCA-PGNS C/B had not been closed. Upon closing this C/B, PGNS attitude control became available. Two minutes later, at 58:35 GET an RCS TCP switch (A1U) failed closed and remained closed throughout the mission. This was not an unexpected failure, as there had been similar failures on all LM missions to date. The only effect of this failure was to compromise the RCS C&W failed-off indication for that jet.

Planning at this point centered on a return to earth profile using the LM DPS + RCS. To accomplish this objective, a DPS burn of 40 ft/sec was scheduled at 61:30 GET as MCC-3. This would place the vehicles on a free-return trajectory with a landing time of 155 hours GET.

MCC-3 - DPS 1

(61:00 - 62:00 GET)

Once the plan for performing MCC-3 with the DPS had been established, the remainder of the 2 hour contingency checklist was completed. This included pressurizing the DPS and trimming the GDA's.

At 61:14 GET, the DPS burn checklist using PGNS guidance was completed. The remaining 15 minutes was used by the crew in maneuvering to the burn attitude (via the TTCA) and performing final checkout procedures. The 40 ft/sec burn at 61:29:48 was preceded by 10 seconds of ullage. The thrust profile was 5 seconds at 12.6 percent and 27 sec at 40 percent which required manual throttling by the crew. The burn was nominal except for the large amount of vertical ($\pm$ X) jet firings throughout the burn. The reason for these firings was due to not disabling the U-V jets via an extended verb (V65) called out in the checklist. Following the burn, LM propellant consumables were: DPS ΔV available = 1973 ft/sec. RCS quantity 86 percent; 73 percent useable (average of A and B systems).

POST MCC-3 TLC
(62:00 - 78:00 GET)

Following MCC-3, the LM was partially powered down in an attempt to conserve electrical energy and water. The IMU and LGC were left in the operate mode for PTC attitude control and as a reference for the next DPS burn; PC+2. Since this power down included the disabling of the DSKY caution lights, a revision was sent to the crew which had them close one ANNUN/DOCK/COMPNT C/B.

A manual PTC mode was agreed upon which had the crew rotate in yaw by 90° every hour and maintain attitude hold the remainder of the time. However, the LGC DAP logic in the docked mode uses a $\pm$ 1.4° deadband and in this mode RCS usage was very high, approximately 1 percent per hour. Based on simulation runs, a procedure was passed the crew which, via a software load, the docked deadband was increased to $\pm$ 5°. In addition, all +X jets (downward firing) were disabled since the plume deflectors were nullifying their effective thrust also causing increased RCS usage.

At 73 hrs. GET, the RR antenna was designated automatically to the AOT position (283°, 0°) for the purposes of a P52 platform re-alignment. However, it was determined that with a successful sun check, the P52 alignment would not be necessary. At 73:30, the crew maneuvered to the desired attitude and completed a successful sun check. At 74:30, the crew maneuvered to the burn attitude for PC+2 to be performed at approximately 79:28. The PC+2 to be performed by the DPS would shorten the landing time from 155 GET to 142 GET.

A revised 2 hour activation checklist was passed to the crew at 75:30 GET, which included a recommendation that the DPS NO. 1 Reg SOV be closed 10 seconds prior to termination of the impending DPS burn. This procedure was requested to prevent freezing of the fuel (in the fuel to helium heat exchanger) in the event of a regulator lock-up at shutdown due to the large ullage volume.

In addition, a number of mission rules were passed to the crew which concerned the PC+2 DPS burn. These rules were based on tight limits (i.e., shutdown the burn for any apparent anomalies) since the vehicles were already on a free-return trajectory. Those mission rules were:

Shutdown the DPS for:

1. Thrust $<$ 77 percent (onboard)
2. Engine inlets $<$ 160 psia (onboard)
3. ΔP between fu and ox inlets $>$ 25 psia (ground callout only)
4. Rates $>10^\circ$/sec and/or attitude errors $>10^\circ$
5. LGC warning, GDA warning or CES DC Fail
6. ISS warning with a program alarm

In addition, it was agreed, that if a premature shutdown occurred, the engine would be reignited if shutdown was not due to any of the reasons stated above.

At LOS, as the LM went behind the moon, RCS Quantity was 70 percent with 57 percent usable (average of systems A and B).

PC+2 - DPS 2

(78:00 - 79:30 GET)

Hi-bit rate data was received from the LM at 78:00 GET as the crew performed the steps in the revised checklist. The power up was nominal and the burn was set up in the auto PGNS (P40) mode. The crew maneuvered the LM to the final burn attitude at 79:17 GET and a "GO" was given for the burn. TIG occurred at 79:27:38 GET with 12.6 percent thrust for 5 sec, 40 percent for 21 seconds and 235 sec at maximum thrust, which the crew backed up manually. At ignition, the roll GDA drove to approximately - 2°, a delta of - 1.2° from its pre-ignition value. This event was unexpected since the ground felt that the GDA settings at the end of MCC-3 with its 40 percent thrust compliance would provide the optimum GDA alignment. The maximum error seen during the burn was 7° in the roll axis with rates never exceeding 1°/sec. The descent NO. 1 REG SOV was closed on time and the engine went into a blowdown mode of operation for the last few seconds of the 851 ft/sec burn.

Consumables at the end of DPS-2 were:

DPS ΔV capability - 1190 ft/sec (nominal); 834 ft/sec (blowdown). RCS quanity - 63 percent total; 50 percent usable (average of A and B systems).

POST PC+2 TEC

(79:30 - 104:00 GET)

The LM was partially powered down except for the PGNS and RCS systems following the PC+2 DPS burn. These systems were left enabled in an attempt to establish an automatic PTC. The procedure used was one designed to obtain an optimum PTC with a minimum of RCS usage. The objective of this procedure was to use PGNS minimum impulse (small RCS usage) to obtain the PTC attitude. Having obtained the attitude with a small rate, a 15 minute limit cycle within the attitude deadband would ensure a rate small enough to ensure a good PTC. However, the procedure proved to be very time consuming for two reasons. First, the minimum impulse mode in the docked configuration was very slow due to the small moment arm used in the pitch and roll axes. Second, compounding the problem was the cross-coupling in the FDAI due to the large yaw angle (outer gimbal). When the crew attempted to roll, the commands would cross-couple into pitch. Once recognizing the problem, the crew zeroed the yaw angle and attempted to go to attitude in the pitch and roll axes. Via this method, a gross PTC attitude was reached and PTC was begun. With PTC established, the LGC and IMU were powered down to conserve consumables. The total power down configuration left heater current on the IMU only. The AGS and RCS heaters were turned off. The attitude Direct Control CB, however, was left in to provide RCS capability via the secondary coils.

During this phase, planning began for a 7.9 ft/sec MCC-5 maneuver scheduled for 105:30 GET. The decision was made to perform this maneuver with the DPS at 12.6 percent thrust since an RCS burn of this magnitude would exceed the impingement constraint on the RCS plume deflectors (40 secs). It was further decided to do the burn with the GDA's disabled and with an AGS body axis reference using the TTCA to control attitude in pitch and roll. Calculations were made to determine the affects of GDA mistrim since the previous DPS burn had established engine compliance at FTP and MCC-5 was planned for 12.6 percent. The calculations revealed very low angular acceleration could be expected, therefore the decision to leave the GDA's disabled during MCC-5 was upheld. The burn was planned in blowdown since the crew did not have time to open and close DSC REG 1 during the short burn (14 secs).

Also, during the pre-burn planning, a discrepancy arose between FIDO and CONTROL over the required burn time for a 7.9 ft/sec burn. This was resolved with the use of the high-speed analog chart recorder which indicated that engine buildup (from 0 to 12.6 percent thrust) was slower than CONTROL had thought it to be. Once this was resolved, it was agreed that the crew would shut the burn down on time, one second earlier than the calculated burn time so as to prevent an overburn. Shutting down early would leave the crew with a +X residual which would not violate impingement constraints. An overburn with a resultant -X trim could have exceeded the 15 sec impingement constraint on the CSM.

The SHe pressure now began to show the affects of PC+2 (DPS 2). The coast rise rate calculated between MCC-3 (DPS 1) and PC+2 (DPS 2) had been 10 psi/hr. Now, after PC+2 (DPS 2) the SHe was exhibiting an average rise rate of 33 psi/hr. With this rise rate the lower limit on the SHe burst disc (1881 psi) was predicted to be reached at approximately 107 hrs. GET. According to SPAN, the history of burst discs of the same lot ruptured in test at pressures of 1900 $\pm$ 20 psia.

At this time, work was begun on a procedure to establish PTC after MCC-5 utilizing the AGS. The question addressed was whether the burn and subsequent PTC mode should be accomplished before or after the predicted time of SHe burst disc rupture. It was feared that the SHe vent would perturb the PTC. SPAN, however, indicated that no impulsive ΔV would be imparted through the thrust nullified SHe vent. Therefore, it was decided to perform MCC-5 on schedule.

There was also some concern over the cool down rate of the descent stage with resultant freezing of LM descent water. To obtain some idea of the cool down rate, the crew was requested to obtain DPS fuel and oxidizer temperature readouts every five hours. These readouts indicated a steady temperature of $65^{\circ} \pm 2^{\circ}$ over a twenty-three hour period. From these readouts, SPAN concluded that there was no danger in freezing LM descent water.

<u>MCC-5 - DPS 3</u>

(104:00 to 106:00 GET)

LM power-up for MCC-5 was begun at 104:36 using an updated 30-minute contingency checklist. After the RCS quads had reached 120°F, the crew stopped the PTC mode. The AGS was then powered up with the ASA temperature verified to be at 70°F before going to AGS operate. Five minutes was allowed for gyro spin-up before the AGS was body-axis aligned. The crew then maneuvered to burn attitude and performed another AGS body axis align at 105:11 GET. The ground then advised the crew that they could start the burn early. DPS ignition occurred at 105:18:32 GET. The burn was nominal with the crew having no trouble keeping errors and rates nulled. The 7.9 ft/sec burn was performed at 12.6 percent throttle and lasted 13.8 seconds (from strip chart). The crew then nulled the +X residual to the desired ΔV less the uncompensated AGS accelerometer bias noted prior to the burn (- .2 ft/sec).

Following the burn, the crew maneuvered to PTC attitude via the TTCA in AGS PLSD and nulled rates in pitch and roll. Once the rates were nulled ($< .05^{\circ}$/sec), the crew applied 12 pulses in yaw to establish PTC. After establishing PTC, the crew went to lo bit rate TM. However, the ground's last look at attitude data on high bit rate did not agree with the desired attitude and the crew was asked to go back to high bit rate data. At this time, it became apparent that the RTCC was incorrectly processing AGS body angles. The ground then disregarded the improper readout and observed PTC in the FDAI reference system to be properly established. LM power down was initiated. RCS remaining after MCC-5 and PTC initiate was 55.5 percent total; 42 percent usable (average of A and B systems).

POST MCC-5 - TEC

(106:00 - 133:00 GET)

After completion of MCC-5 and subsequent LM power-down at 106:02 GET, emphasis was placed on a contingency method of relieving the SHe tank pressure in the event the burst disc failed to operate. The time of implementing this procedure was based on the tank fracture mechanics pressure/temperature limit, 2200 psia, and the transducer upper limit of 2000 psia. The pressure selected for implementing the contingency vent procedure was 2000 psia. The method of accomplishing this vent operation was discussed at great length by SPAN and CONTROL personnel.

In order to maintain DPS burn capability, SPAN recommended a multi-step vent to prevent freezing the fuel in the fuel/helium heat exchanger. Freezing of the fuel would prevent further DPS burns. SPAN maintained that the vent would have to be accomplished in a positive "g" environment. This point was contested by CONTROL as any acceleration could seriously affect the trajectory. The reason for maintaining the positive "g" acceleration, according to SPAN, was that in one ground test, a vent valve was closed by a high ΔP across the valve and could not be reopened.

In order to preclude perturbation of the trajectory, alteration of PTC, and to conserve consumables, CONTROL proposed a single vent procedure using only the fuel vent valve without positive acceleration. In case the DPS vent did not succeed with the fuel vent valve, a positive acceleration could be set up and the vent completed using the oxidizer vent valve.

The SHe burst disc ruptured at approximately 108:54, venting the remaining 27.5 pounds of helium overboard. The pressure at time of disc rupture was approximately 1940 psia, which was above the predicted rupture range. The venting required approximately 4 minutes to vent to below 100 psia. A total of 10.5 minutes was required to vent to zero. The venting imparted a propulsive force to the vehicle such that the PTC yaw (0.3°/sec) was stopped, reversed, and a yaw rate set up such that the crew reported two revolutions of the spacecraft occurred in 3 minutes, 50 seconds. This was an unexpected event as the SHe overboard vent is thrust nullified, and SPAN stated that the vent would impart less than 0.003 ft/sec velocity to the vehicle.

At 129:50 GET, the MCC-7 and entry sequence checklists were finalized, read up to the crew, and were awaiting activation for EI-6 hours (approximately 136:30 GET). At this time, the MCC-7 checklists provided for either a DPS or RCS burn, depending on the ΔV required. An RCS burn was decided at 132:32 GET when the ΔV was calculated to be 2.8 ft/sec.

<u>MCC-7 - RCS 1</u>

(133:00 - 137:40 GET)

During a discussion with the crew at 133:19 GET, the crew reported that the PTC mode had degraded considerably such that the sun was behind the engine bell and no sun ever came in the windows. Because of this, they were very cold. Therefore, the possibility of getting out of PTC early and powering up was discussed so the crew could warm up. CONTROL had no reason not to power up early as long as sufficient power and water was available. Power-up was begun at 133:24 GET (about 3 hours early).

First effects of the power-up were noted in the RCS QUAD and ASA temperatures beginning to rise. The LGC was powered up and IMU turn-on was complete at 133:38 GET. At 133:45, the RCS QUAD temperatures were all above 120° and a "GO" was given for the crew to stop PTC. Prior to nulling the PTC rates, RCS system A and B both indicated 55 percent total quantity remaining. The PTC rates were nulled at 133:49. By 133:57, the ASA was up to operating temperature (120°) and a "GO" was given the crew to start AGS activation. PGNS was initialized at 134:16 and the PIPA bias looked good. After some discussion, it was decided to do a P52 in the LM and a docked alignment for the CSM, rather than doing the P52 for the CSM using the LM to maneuver to the desired attitudes.

At 134:37 the P52 option 1 was started. Marks were taken on the sun and moon. The P52 resulted in large torquing angles which were torqued out at 135:04:35. The crew reported a good IMU alignment at 135:16. At this time all thinking was along the line of performing the MCC-7 burn under PGNS control in P41. This seemed reasonable since the PGNS was powered up and aligned; however, this thinking was not reflected in the procedure for the burn which had been passed up to the crew. The procedure the crew had, called for the burn to be in AGS using TTCA for attitude control and the PGNS in a monitor mode. The crew also expressed a desire to use PGNS for the burn which we concurred with. The crew was asked to perform an AGS to PGNS alignment so the AGS would have the best possible alignment in the event it had to be used for the maneuver. The alignment was performed at 137:06. The crew maneuvered the vehicle to roughly the MCC-7 burn attitude in PGNS minimum impulse and then went to AUTO to perform the final auto maneuver to the burn attitude. This resulted in an excessive use of RCS propellant so the crew was requested to go back to the minimum impulse mode which they did. For an unexplained reason the PGNS error needles were not zeroed at the burn attitude, causing some concern over the validity of the PGNS. At 137:15 a recommendation was made to use the AGS for the MCC-7 burn since it was already reflected in the crew's checklist and they had successfully used it before. The crew selected AGS, went to pulse and then maneuvered to the burn attitude via the TTCA at 137:26. At 137:39:48 the MCC-7 burn was performed using the +X TRANS O/R button. The ΔV was + 3.1 fps. RCS quantity remaining after MCC-7 was 40 percent total; 27 percent usable (average of A and B systems).

ENTRY SEQUENCE

(137:40 to 142:38 GET)

Immediately after the MCC-7 burn, the crew started the maneuver to the service module jettison attitude. This maneuver was accomplished using AGS pulse mode via the TTCA. At 137:57, the jettison attitude was achieved and PGNS minimum impulse was selected. At 137:58, the command module RCS hot fire was performed successfully and then the AGS pulse mode was again selected at 138:01. The service module jettison maneuver started at 138:02 using the +X TRANS O/R button for + 0.5 fps. The service module was then jettisoned and the TTCA was used to command a -X translation of -0.5 fps. Immediately, the crew pitched to visually acquire the service module for photography. The AGS Attitude Control switches were placed to MODE CONTROL and deadband maximum for maintaining the attitude for picture taking. All attitude maneuvers after service module jettison were performed with the ACA since the TTCA would not produce the desired effects now that the service module was gone. An RCS redline to terminate photo taking was previously established at 25 percent which was not approached during the picture taking. The photo activity was terminated at 138:14 and a maneuver back to the service module jettison attitude was started. At 138:19, the jettison attitude was achieved. At this time, the systems in the command module were starting to be powered up. The LM DAP was loaded to reflect a ficticious CM weight of 9050 pounds at 138:20. MIT simulations showed this to be the optimum DAP load for the LM/CM configuration. At 138:52, a PGNS minimum impulse was selected for maneuvers to perform the CM IMU alignment check. The DAP had been loaded to use RCS system B when in the minimum impulse mode and consequently more RCS system B propellant was being used than expected. At 140:33, PGNS rate command attitude hold was selected which slowed the usage in RCS system B. At 140:39, PGNS minimum impulse was again selected.

At 140:47, the crew was advised to expect a RCS Caution light since the RCS system B helium pressure was approaching the limit of 1700 psi.

At 140:50, PGNS rate command attitude hold was again selected. The RCS Caution light was reported by the crew at 140:52. The crew reported an excellent CM IMU alignment at 140:53 and immediately started the attitude maneuver to the LM jettison attitude. At 140:56, AGS pulse mode was selected and then right back to PGNS minimum impulse at 140:57. The crew was requested to change the DAP load to 30021 at 141:00 to start using RCS system A for the minimum impulse firings. At the time the DAP was changed there was approximately 10 percent delta between RCS system A and B propellant quantities. The LM jettison attitude was reached at 141:02 and at 141:03 AGS, attitude hold, wide deadband was selected. The attitude was off by approximately 100 degrees in roll. The desired attitude was 135 degrees but the actual was 235 degrees. Jettison occurred at this attitude.

At 141:18 an early go for LM jettison was passed up to the crew. At 141:30, LM jettison occurred. The separation was very stable and the sensed velocity was X axis -0.75 fps and Y axis -0.25 fps. The RCS quantities remaining at jettison were RCS system A 31 percent and RCS system B 21 percent for an average total of 26 percent (13 percent usable). The LM was very stable within the AGS 5 degree deadband until final LOS at 142:38.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

IN REPLY REFER TO:

May 4, 1970

MEMORANDUM TO: FC/Apollo 13 Flight Director

FROM : FC4/Apollo 13 CONTROL Team

SUBJECT : Apollo 13 Post Mission Report

Attached is the Apollo 13, Part II Post Mission Report. Any questions concerning this report may be directed to John Wegener, extension 4717.

John A. Wegener

Harold A. Loden

Richard A. Thorson

Larry W. Strimple

attachment

FC42:HALoden:drd

LM CONTROL

APOLLO 13

POST MISSION REPORT

PART II - RECOMMENDATIONS

MAY 4, 1970

1. Checklists and Procedures

The Apollo 13 mission pointed out many discrepancies associated with the present contingency checklists and crew procedures. These checklists were designed within the concept of a nominal LM power up and a DPS burn. Experience has now shown that the checklists should be designed to be more flexible in their content and use. For example, on Apollo 13, the 2 hour contingency checklist was used two times. However, extensive ground generated updates were made to the crew prior to the PC + 2 DPS burn to ensure that the present systems configuration was not disturbed by utilizing the checklist a second time. The problem could be circumvented by simply modularizing the present checklist into a number of easily recognized blocks. To illustrate, the 2 hour checklist could be generated from a baseline that would bring on only those systems needed for life support and a manual RCS attitude control capability. From this baseline, activation requirements for the PGNS, AGS, DPS, APS, RCS (PGNS/AGS), displays, etc., could be interspersed at appropriate times in easily identified block form.

If this concept had been available on Apollo 13, the crew could easily have implemented the checklist requirements knowing that the baseline included those systems already activated. This same concept could have been implemented into the 30 minute contingency checklist since the baseline is identical for life support. In fact, one checklist with this concept could be used for all types of contingencies regardless of time and operational mode by simply incorporating only those blocks appropriate for any particular sequence of desired operations.

In support of this type of modularization, will be the requirement for additional contingency procedures and techniques (i.e. auto and manual PTC procedures, spin stabilization of CM by the LM for re-entry, etc.). These procedures would be in a form easily adapted into the one general contingency checklist.

The present ascent checklist should be modified to give the crew more time to terminate ascent feed. The current procedures do not allow the ground time to verify ascent feed termination and inform the crew to try the other set of valves if the first set did not terminate ascent feed. By changing the procedure from a VG = 500 fps to 1500 fps, there would be plenty of time to verify ascent feed termination. This would use only 2.8 lbs. of RCS ($<$1/2%) and would aid the crew by moving this function to a less time critical period.

2. Pre-Launch Operations Support (SPAN)

During CDDT, a heat leak problem was discovered while loading the SHe tank. Within a few days, a waiver was issued on this anomaly although the extent of the problem was not completely determined. This decision definitely showed a lack of consideration concerning possible impact to the mission and deserved a closer examination. In this case, a waiver was granted before the problem was fully understood and before corrective inflight procedures were written and verified. It was quite obvious from FCD's position that the problem was not fully understood by the piece meal method in which data was received. For the most part, the data was sketchy, not coordinated, contradictive, and varied depending upon who was the source of information. It is a point of fact that the crew knew virtually nothing of the possible impact of this problem. Thus, when procedures were finalized shortly before LM entry, the crew expressed surprise at the proposal for a SHe vent. It should also be noted that these procedures which were designed to recognize a SHe problem at LM entry would only have been valid if the SHe tank anomaly occurred early in the TLC period. In fact, the anomaly was not expected to manifest itself until some later period. Thus, this procedure would not have guaranteed that PDI could have been normally performed. Subsequent events indicated that the problem did exist and was more serious than thought to be by noting the SHe rise rate after MCC-3 (10 psia/hr) and after PC + 2 (33 psia/hr).

From LSB's viewpoint, this method of operation was completely unsatisfactory. The problem should have been completely identified, procedures written and the crew informed of the problem and its implication prior to the granting of a waiver.

3. Post-Launch Operations Support (SPAN)

In general, SPAN support (Bldg 45) during post-launch operations was adequate. However, there were a number of specific instances in which disagreements arose between GAC Support and LSB. These disagreements arose mainly from the fact that the data base used by both parties differed, and in some cases GAC presented new information which had not been provided LSB pre-mission. The following illustrates a number of examples.

DPS Vent (Parker) Valves - During the heated and hurried discussions concerning the SHe vent (prior to LM entry), GAC stated that the Parker Valves would not inadvertently close if liquid was vented along with helium gas. When LSB pointed out that this was contradictory to what GAC had stated on earlier missions (Apollo 10), GAC reversed their stand and argued the opposite was true, leaving doubts in many minds as to what really happens during a vapor-liquid vent. This argument again occurred after MCC-5, where the SHe burst disc limits were being approached. Both GAC and ASPO refused to concur with LSB on DPS venting without +X ullaging because of fear of Parker Valve closure. LSB did not want to ullage and perturb tracking.

DPS blowdown ΔV capability - Once it became apparent that the SHe would be lost, a knowledge of the DPS ΔV capability in a blowdown mode of operation was needed. SPAN's (Bldg 45) calculation of ΔV in this mode was in error from LSB's calculation by a factor of one-half. After much discussion, SPAN conceded that their calculations were not based on actual engine performance data as were the calculations performed by the SSR propulsion personnel. Thus, after a day of indecision and arguments, a ΔV blowdown capability was finally obtained, which agreed very closely with the original LSB calculation.

SHe tank rupture - Prior to this mission, the advertized figures on the SHe tank gave the design burst pressure as 3000 psia and the proof pressure as 2200 psia. Once it became apparent that the SHe tank was going to exceed its minimum burst disc pressure of 1881 psia, thoughts turned to protecting against the SHe tank bursting in case the burst disc did not rupture. It then became known via SPAN (Bldg 45) that the fracture mechanics limit on this tank was 2240 psia making it imperative to vent prior to this limit being reached.

SHe pressure curves - Computer runs of SHe pressure rise characteristics are supplied to LSB through TRW. It became apparent during the SHe anomaly discussion that the GAC data and the TRW data differed significantly. When questioned on this, GAC stated that TRW was using an older math model (supplied by GAC, incidently) rather than GAC's improved model; thus TRW's curves were invalid. This points out the mandatory need for the contractors and their sub-contractors to coordinate with each other before supplying information to be used operationally. In this case, the crew and LSB had simulated procedures based on the TRW data which was not declared invalid until after launch.

RCS Impingement - SPAN (Bldg 45) during the mission, tendered an RCS burn schedule designed to utilize the maximum amount of RCS +X burn time and not violate impingement constraints. This schedule utilized a duty cycle completely unheard of by the LM propulsion personnel. Inputs of this nature, although invaluable, are needed pre-mission not as last minute stop-gap measures.

LSB's recommendations for SPAN improvement can be stated thusly:

1. All data supplied by sub-contractors should be reviewed by the major contractor prior to its use in mission planning by the LM systems people.

2. All constraints and their associated "relaxed" limits for contingency measures should become known, documented in the SODB, and made available to the flight controllers well in advance of launch.

3. Contractor should inform NASA of any and all fracture mechanics limits and changes in the operational use of systems or hardware (Parker Valves) when they become known. These should also be documented in the SODB.

4. Contractors should fully explain the assumptions used when passing out calculated data, i.e., based on worst case, expected, best case, etc. When data is preliminary, and a more detailed analysis will follow, the systems engineers should be so informed to prevent the passing out of the data as the best obtainable.

4. Mission Manning

a. LM MOCR consoles should be manned around the clock

LM support on previous lunar missions centered only on times of LM activity. While the LM was powered down during lunar coast, LM MOCR personnel reported in at some time during their shift while the crew was awake for mission continuity. If the potential DPS SHe pressure problem had not been present, requiring LM entry four hours earlier than planned, no LM consoles would have been manned when the CSM problem occurred. Since the LM may be needed at anytime, the MOCR consoles should be manned at all times, with the supporting SSR personnel in the area during their respective shift times.

b. Retain Apollo 13 CONTROL lunar descent and ascent teams for Apollo 14

Since the Apollo 13 teams did not support the lunar landing and Ascent, the same CONTROL teams should fly Apollo 14. These teams have not yet had the opportunity to support these mission phases and the hours of training and preparation for Apollo 13 should be carried over to the next mission.

5. SODB Update

A new section should be added to the SODB to include actual "hard" hardware limitations for contingency or emergency situations. These realistic hardware limits should be submitted by the contractors with the understanding that these limits will only be used in contingency situations when the systems must be taxed to their maximum to insure crew safety.

6. Simulations

Simulations for the previous missions have been excellent from both a technical accuracy and problem solving view point. The simulations prior to Apollo 13 were adequate in quantity but were spread out over too long a period of time. It is our recommendation that simulations for the activation and descent phase for future missions be conducted on a schedule of a minimum of two each week starting at least six weeks before launch.

There is one area of mission planning that has been covered by the generation of crew checklists but has never been exercised by simulations. This is the situation when the crew is out EVA and some problem arises that requires an immediate lift off. This timeline should be simulated to determine if the checklists and crew procedures are adequate.

7. Spacecraft Changes

Recommend that a design review of the SHe tank and its venting capabilities be performed to explore the possibility of providing additional controls such as described in the following examples.

a. Provide some means of venting the SHe tank annulus to space after launch. This would release any gases trapped in the annulus; therefore, reducing the possibility of excessive heat leaks.

b. Provide the capability of bypassing the SHe burst disc assembly so that the SHe tank could be vented under controlled conditions. This would only be used when it became apparent that the SHe burst disc were going to rupture in any event, and would allow the vent to occur where it would have least effect on crew activities and trajectory.

8. Spacecraft Waivers

The following should be part of the ground rules for granting spacecraft waivers:

a. Waivers should not be given where severe impact on the flight plan and/or crew procedures results.

b. Waivers should not be given where a subsequent single failure may seriously degrade the system capability.

An example is the anomaly noted in the SHe loading prior to launch. The data indicated a definite heat leak problem of some type but the possible impact on the mission and procedures to correct the problem inflight were not finalized and verified prior to granting the waiver. Additional criteria on granting waivers should be prepared and coordinated throughout all Center elements.

c. Before a waiver is granted, corrective inflight procedures should be written and verified, and the flight operations people should be consulted in the decision-making.

LM CONTROL

APOLLO 13

POST MISSION REPORT

PART III

May 28, 1970

Prepared by:

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PGNS/AGS APOLLO 13 REPORT

PART III

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MISSION APOLLO 13 TIME START 61 : 29 : 46

EVENT MCC-3 BURN (DPS-PGNS) FINISH 61 : 30 : 22

MCC-3 BURN (DPS-PGNS)

Channel	Parameter	Channel	Parameter
1	SERIAL DECIMAL TIME	2	ONE PULSE PER SECOND
3	PCM OSC 1 FAIL	4	LOW BIT RATE COMP
5	C & W PWR NOT FAIL	6	MASTER ALARM NOT ON
7	(UNASSIGNED)	8	BAT MAL NOT ON
9	LAND GEAR DEPLOYED	10	ED RLY A K1-K6 CLSD
11	ED RLY B K1-K6 CLSD	12	ED RLY A K7-K12 SAFE
13	ED RLY B K7-K12 SAFE	14	BAT 1 HIGH VOLT TAP
15	BAT 1 LOW VOLT TAP	16	BAT 1 MALFUNCTION
17	BAT 2 HIGH VOLT TAP	18	BAT 2 LOW VOLT TAP
19	BAT 2 MALFUNCTION	20	BAT 3 HIGH VOLT TAP
21	BAT 3 LOW VOLT TAP	22	BAT 3 MALFUNCTION
23	BAT 4 HIGH VOLT TAP	24	BAT 4 LOW VOLT TAP
25	BAT 4 MALFUNCTION	26	BAT 5 B/U CDR
27	BAT 5 NORM LMP	28	BAT 5 MALFUNCTION
29	BAT 6 NORM CDR	30	BAT 6 B/U LMP
31	BAT 6 MALFUNCTION	32	CDR SUIT DISC
33	LMP SUIT DISC	34	SUIT RLF CLSD
35	SUIT RLF OPEN	36	SUIT DIV EGRESS
37	CABIN RET CLSD	38	CAB RET OPEN
39	DEMAND A CLSD	40	UNASSIGNED
41	DEMAND B CLSD	42	UNASSIGNED
43	SEC COS SEL	44	SUIT FAN 1 MAL
45	SUIT FAN 2 MAL	46	REPRESS OPEN
47	SEL GLYCOL LOW	48	PUMP SW/O
49	IMU STANDBY	50	LGC OPERATE
51	LGC WARNING	52	ISS WARNING
53	PGNS AUTO	54	AUTO ENG "ON" CMD
55	AUTO ENG "OFF" CMD	56	APS ARM
57	APS ON	58	ABORT STAGE CMDED
59	ENG FIRE OVERRIDE	60	DPS ON
61	PITCH TRIM FAIL	62	ROLL TRIM FAIL
63	DPS ARM	64	ACA OUT OF DETENT
65	JET B4U DRIVER OUT VOLTS	66	JET B4U TCP
67	JET A4D DRIVER OUT VOLTS	68	JET A4D TCP
69	JET B4F DRIVER OUT VOLTS	70	JET B4F TCP
71	JET A4R DRIVER OUT VOLTS	72	JET A4R TCP
73	JET A3U DRIVER OUT VOLTS	74	JET A3U TCP
75	JET B3D DRIVER OUT VOLTS	76	JET B3D TCP
77	JET B3A DRIVER OUT VOLTS	78	JET B3A TCP
79	JET A3R DRIVER OUT VOLTS	80	JET A3R TCP
81	JET B2U DRIVER OUT VOLTS	82	JET B2U TCP
83	JET A2D DRIVER OUT VOLTS	84	JET A2D TCP
85	JET A2A DRIVER OUT VOLTS	86	JET A2A TCP
87	JET B2L DRIVER OUT VOLTS	88	JET B2L TCP
89	JET A1U DRIVER OUT VOLTS	90	JET A1U TCP
91	JET B1D DRIVER OUT VOLTS	92	JET B1D TCP
93	JET A1F DRIVER OUT VOLTS	94	JET A1F TCP
95	JET B1L DRIVER OUT VOLTS	96	JET B1L TCP
97	PGNS ATT HOLD	98	AGS MODE AUTO
99	AGS MODE ATT HOLD	100	GUID SEL SW AGS
101	ROLL PLS/DIR	102	PITCH PLS/DIR
103	YAW PLS/DIR	104	X TRANS OVERRIDE (WRITE WITH ZERO)
105	UNBALANCED COUPLES	106	AGS COND WARMUP
107	AGS COND STANDBY	108	CES AC PWR FAIL (WRITE WITH ZERO)
109	CWEA DC PWR FAIL (WRITE WITH ZERO)	110	AGS PWR FAIL (WRITE WITH ZERO)
111	MASTER ALARM NOT ON	112	APS HE 1 CLSD
113	APS HE 2 CLSD	114	APS FUEL LOW
115	APS OX LOW	116	APS VLVS A DELTA PSS
117	APS VLVS B DELTA PSS	118	DUA STATUS
119	MAP	120	DPS PROP LOW
121	(UNASSIGNED)	122	UNASSIGNED
123	RCS MAIN A CLSD	124	RCS MAIN B CLSD
125	ASC FEED A FUEL OPEN	126	ASC FEED B FUEL OPEN
127	A/B XFEED OPEN	128	A4 ISO CLSD
129	ASC FEED A OX OPEN	130	ASC FEED B OX OPEN
131	B4 ISO CLSD	132	A3 ISO CLSD
133	B3 ISO CLSD	134	A2 ISO CLSD
135	B2 ISO CLSD	136	A1 ISO CLSD
137	B1 ISO CLSD	138	ABORT CMD
139	ENG OFF	140	ENG ON
141	TURN ON COMPLETE	142	-R GIMBAL TRM
143	IDLSFLAG	144	+R GIMBAL TRM
145	-P GIMBAL TRM	146	+P GIMBAL TRM
147	IMU EC ON	148	ICDU ZRO
149	ONE PULSE PER SECOND	150	SERIAL DECIMAL TIME

MASTER ALARM NOT ON

BAT MAL NOT ON

BAT 2 HIGH VOLT TAP

BAT 3 HIGH VOLT TAP

IMU STANDBY

PGNS AUTO

AUTO ENG OFF CMD

AUTO ENG ON CMD

DPS ON

DPS ARM

ULLAGE: A4D, B3D, A2D, B1D

AGS MODE ATT HOLD

AGS COND WARMUP

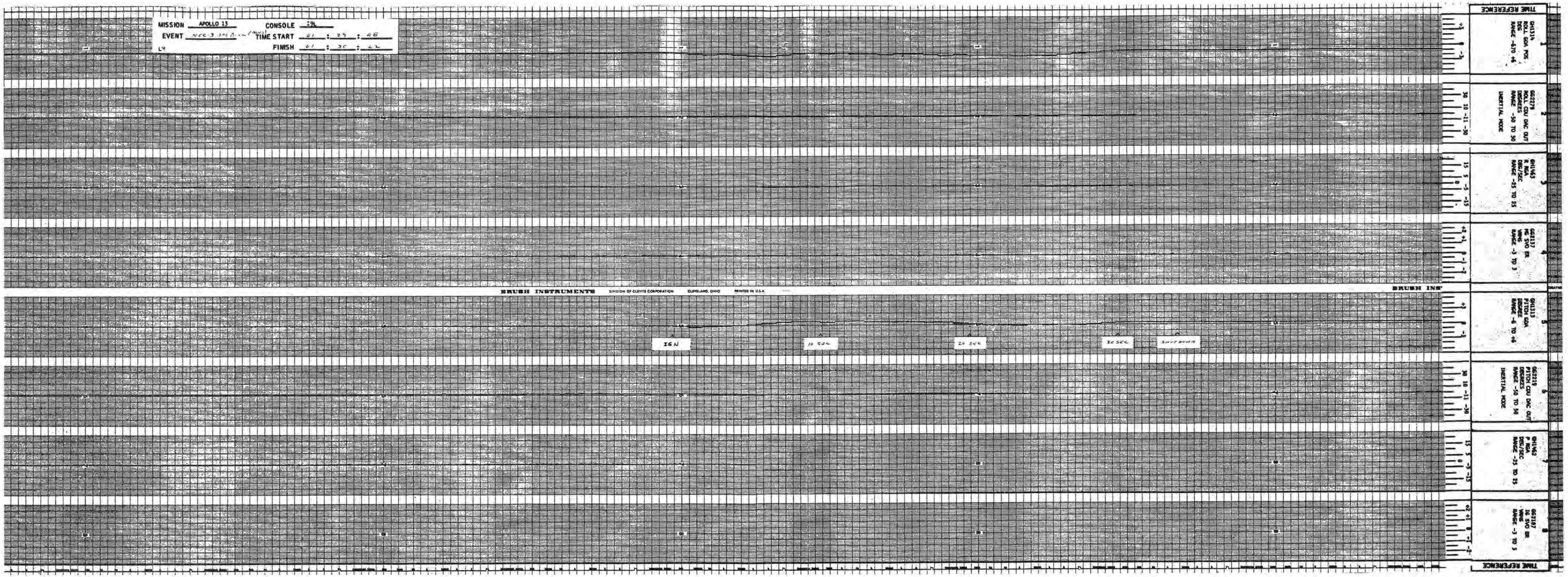
MASTER ALARM NOT ON

LGC ENG ON

LGC ENG OFF

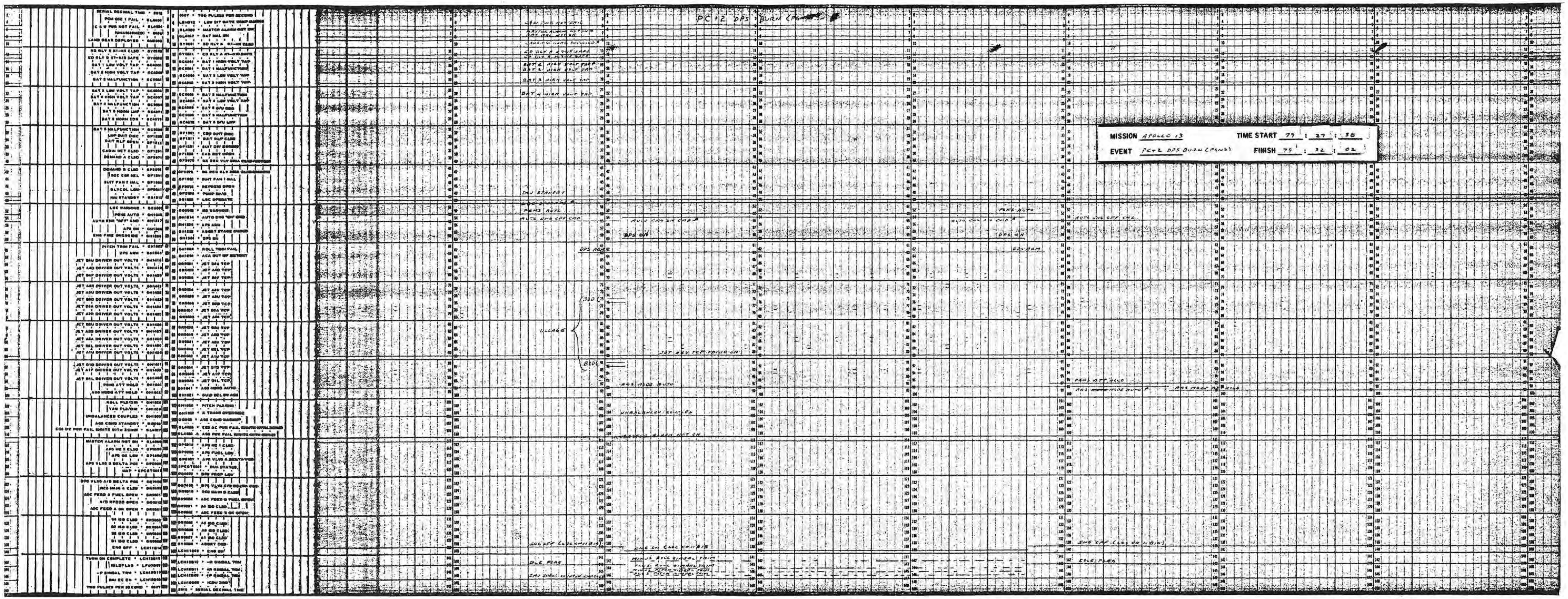
IDLEFLAG

IMU EC ON



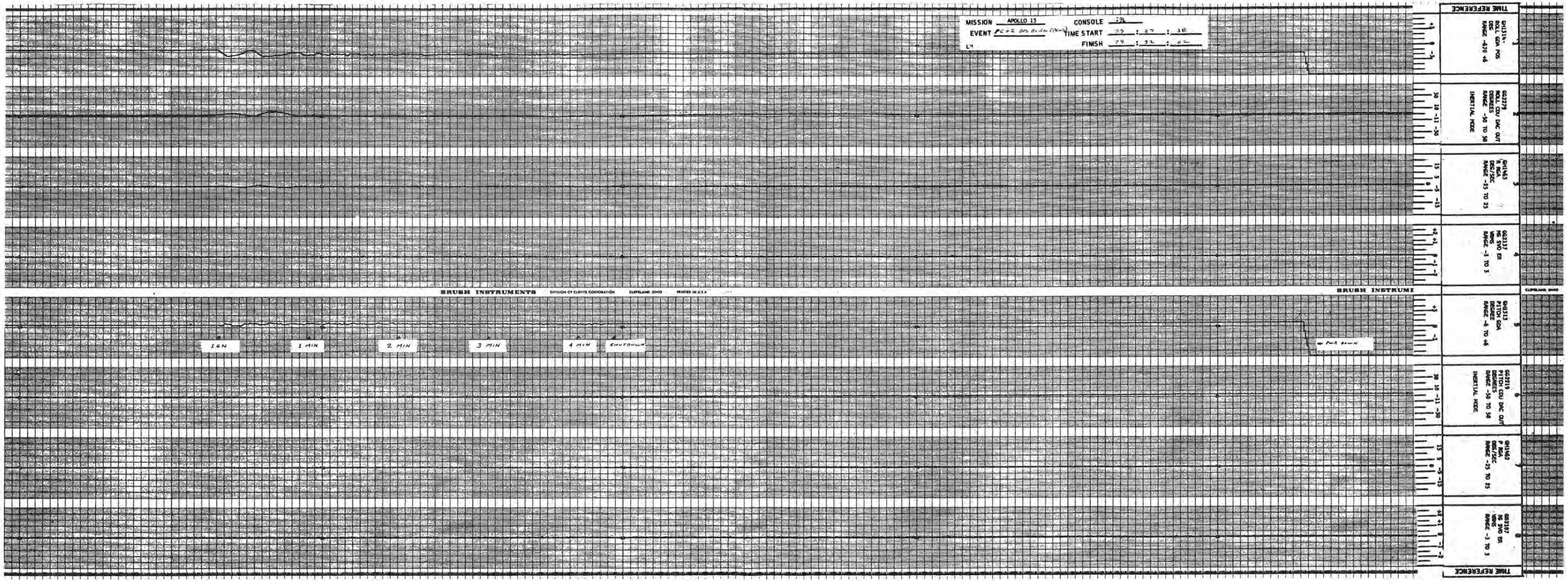
MISSION APOLLO 13
CONSOLE 29L
EVENT
TIME START 61 : 29 : 48
FINISH 61 : 30 : 22
BRUSH INSTRUMENTS
IGN
10 SEC
20 SEC
30 SEC
SHUTDOWN
TIME REFERENCE

PAGE 3

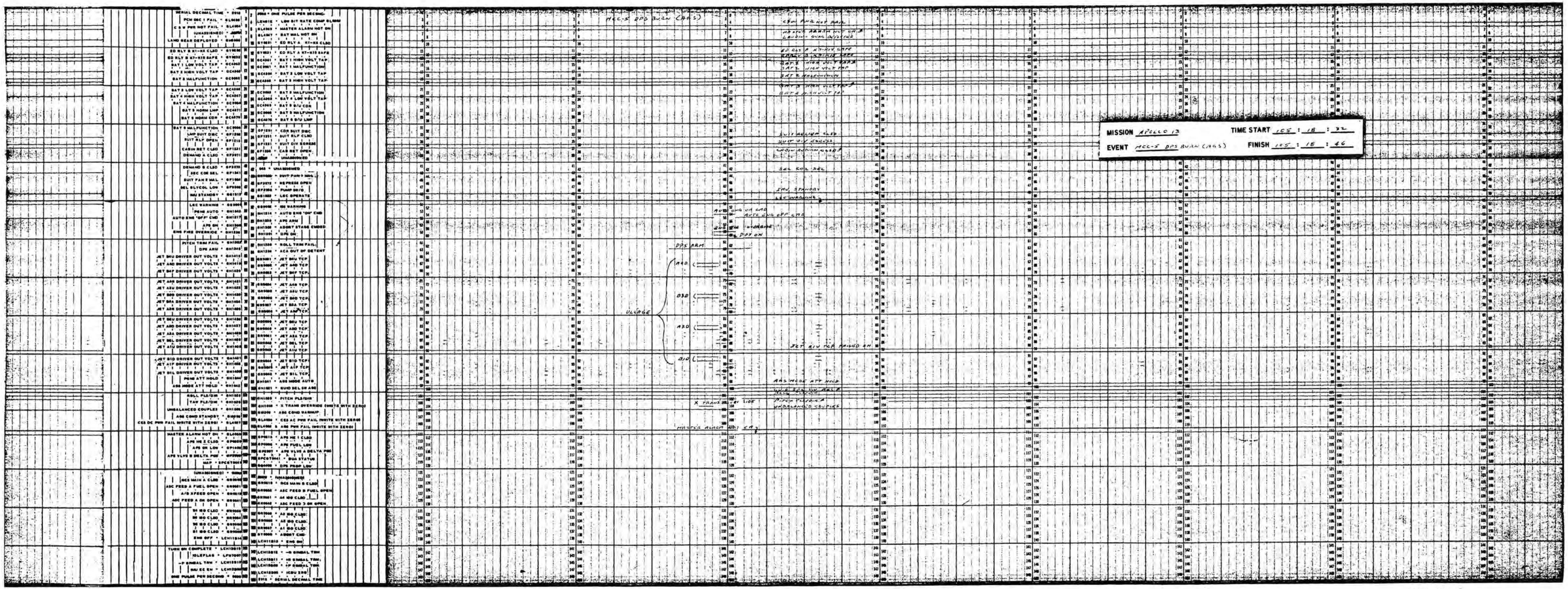


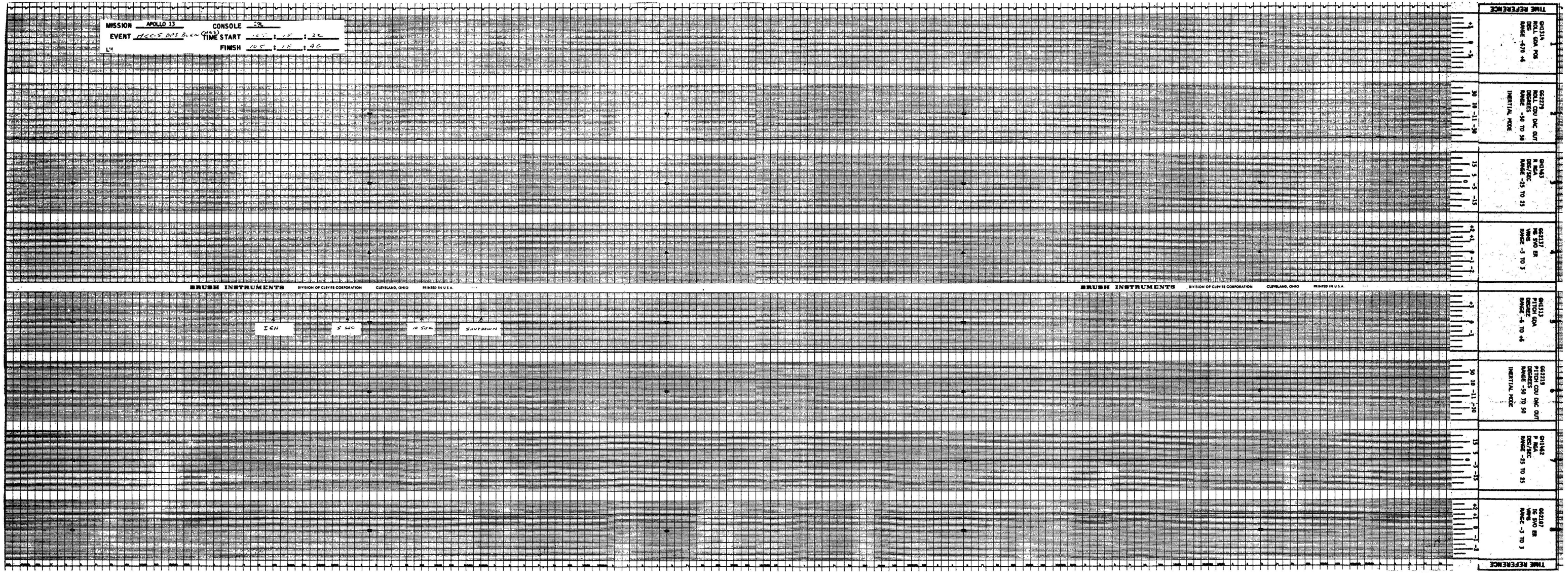
MISSION APOLLO 13 TIME START 75 : 27 : 38

EVENT PC+2 DPS BURN (PGNS) FINISH 75 : 32 : 02



MISSION APOLLO 13
CONSOLE 29L
EVENT PC+2 DPS BURN (PGNS)
TIME START 79 : 27 : 38
FINISH 79 : 32 : 02
LM
BRUSH INSTRUMENTS DIVISION OF CLEVITE CORPORATION CLEVELAND, OHIO PRINTED IN U.S.A.
IGN
1 MIN
2 MIN
3 MIN
4 MIN
SHUTDOWN
PWR DOWN
TIME REFERENCE
GH1314 ROLL GDA POS DEG RANGE -6 TO +6
GG2279 ROLL CDU DAC OUT DEGREES RANGE -50 TO 50 INERTIAL MODE
GH1463 R RGA DEG/SEC RANGE -25 TO 25
GG2137 RS SYD ER VRMS RANGE -3 TO 3
GH1313 PITCH GDA DEGREE RANGE -6 TO +6
GG2219 PITCH CDU DAC OUT DEGREES RANGE -50 TO 50 INERTIAL MODE
GH1462 P RGA DEG/SEC RANGE -25 TO 25
GG2107 IS SYD ER VRMS RANGE -3 TO 3


MISSION APOLLO 13
TIME START 105 : 18 : 32
EVENT MCC-5 DPS BURN (AGS)
FINISH 105 : 18 : 46
MCC-5 DPS BURN (AGS)
DPS ARM
ULLAGE


MISSION APOLLO 13
CONSOLE 29L
EVENT MCC-5 DPS BURN (HGS)
TIME START 105 : 18 : 32
FINISH 105 : 18 : 46
LM
BRUSH INSTRUMENTS DIVISION OF CLEVITE CORPORATION CLEVELAND, OHIO PRINTED IN U.S.A.
IGN
5 SEC
10 SEC
SHUTDOWN
TIME REFERENCE

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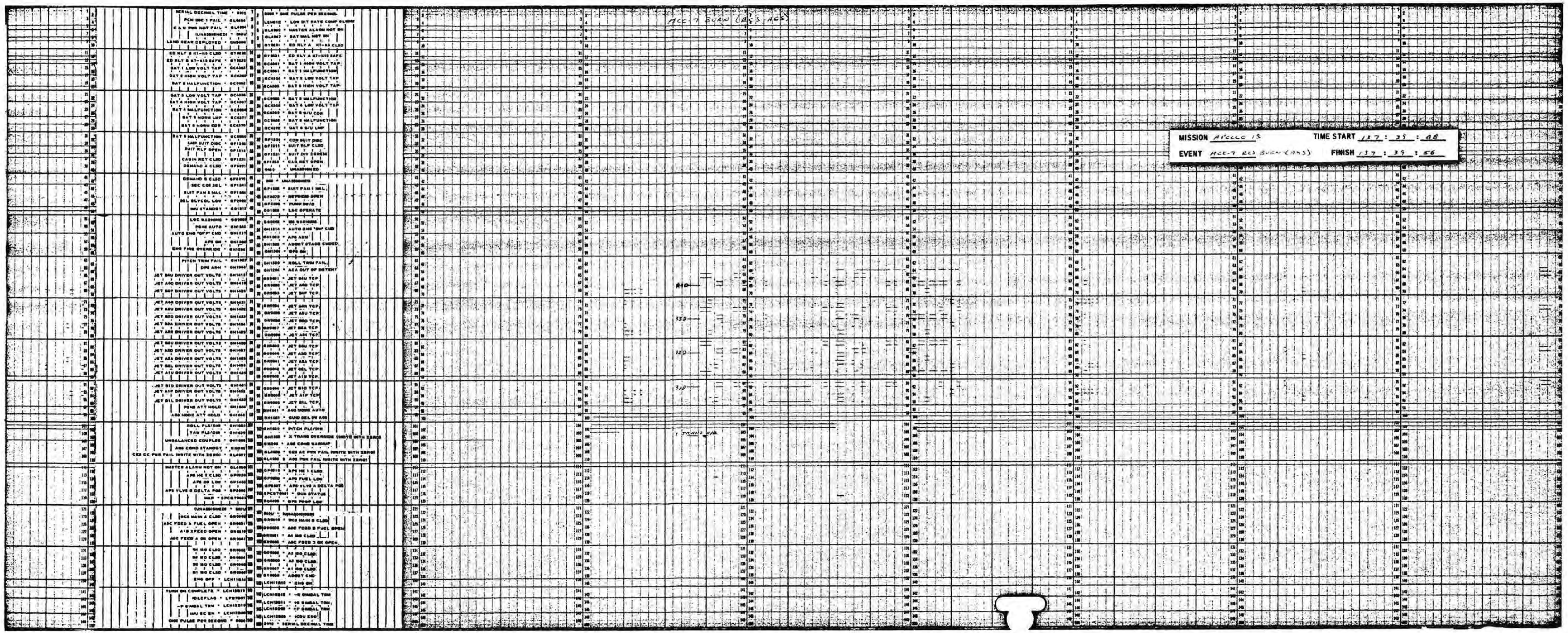
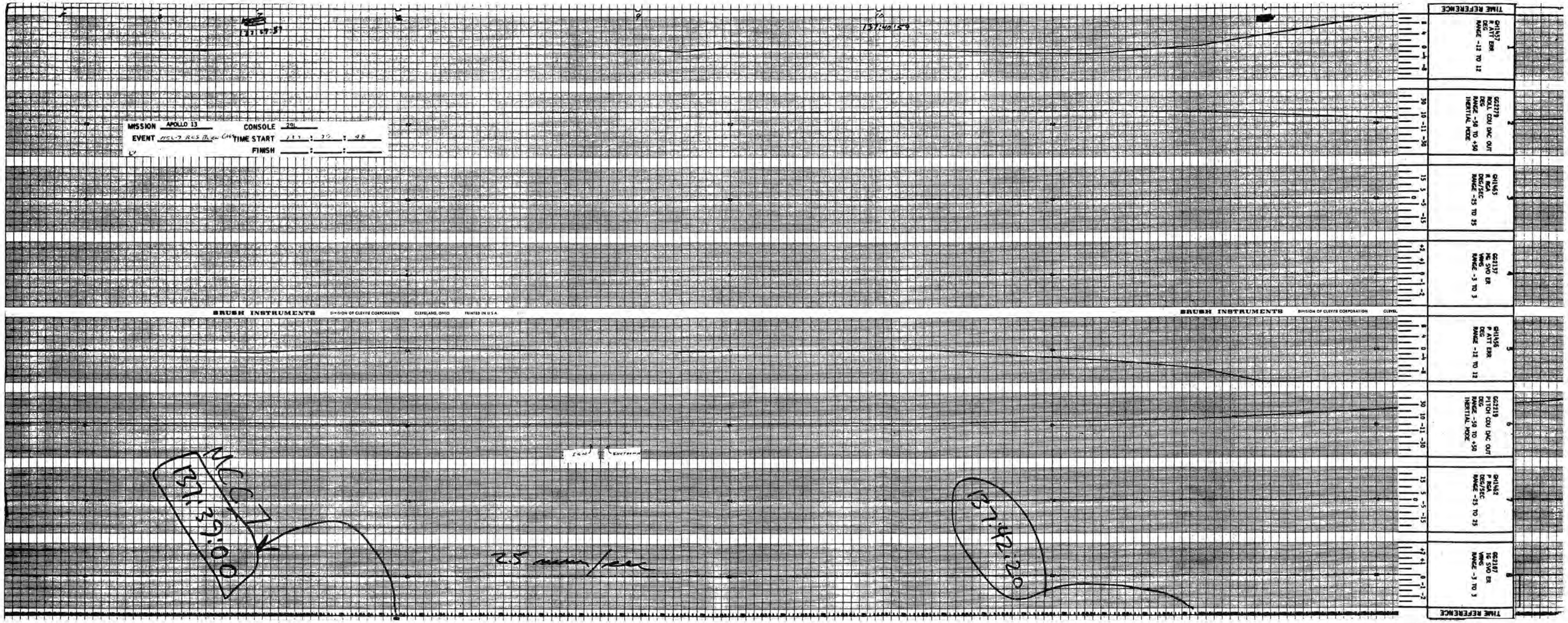

MCC-7 BURN (RCS AGS)
MISSION APOLLO 13
TIME START 137 : 35 : 48
EVENT MCC-7 RCS BURN (AGS)
FINISH 137 : 39 : 56


MISSION APOLLO 13
CONSOLE 29L
EVENT MCC-7 RCS Burn
TIME START 137 : 39 : 48
FINISH
137:40:59
BRUSH INSTRUMENTS DIVISION OF CLEVITE CORPORATION CLEVELAND, OHIO PRINTED IN U.S.A.
MCC 7
137:39:00
2.5 mm/sec
137:42:20
TIME REFERENCE
GH1457 R ATT ERR DEG RANGE -12 TO 12
GG2279 ROLL CDU DAC OUT DEG RANGE -50 TO +50 INERTIAL MODE
GH1465 R RGA DEG/SEC RANGE -25 TO 25
GG2137 MG SVO ER VRMS RANGE -3 TO 3
GH1456 P ATT ERR DEG RANGE -12 TO 12
GG2219 PITCH CDU DAC OUT DEG RANGE -50 TO +50 INERTIAL MODE
GH1462 P RGA DEG/SEC RANGE -25 TO 25
GG2107 IG SVO ER VRMS RANGE -3 TO 3

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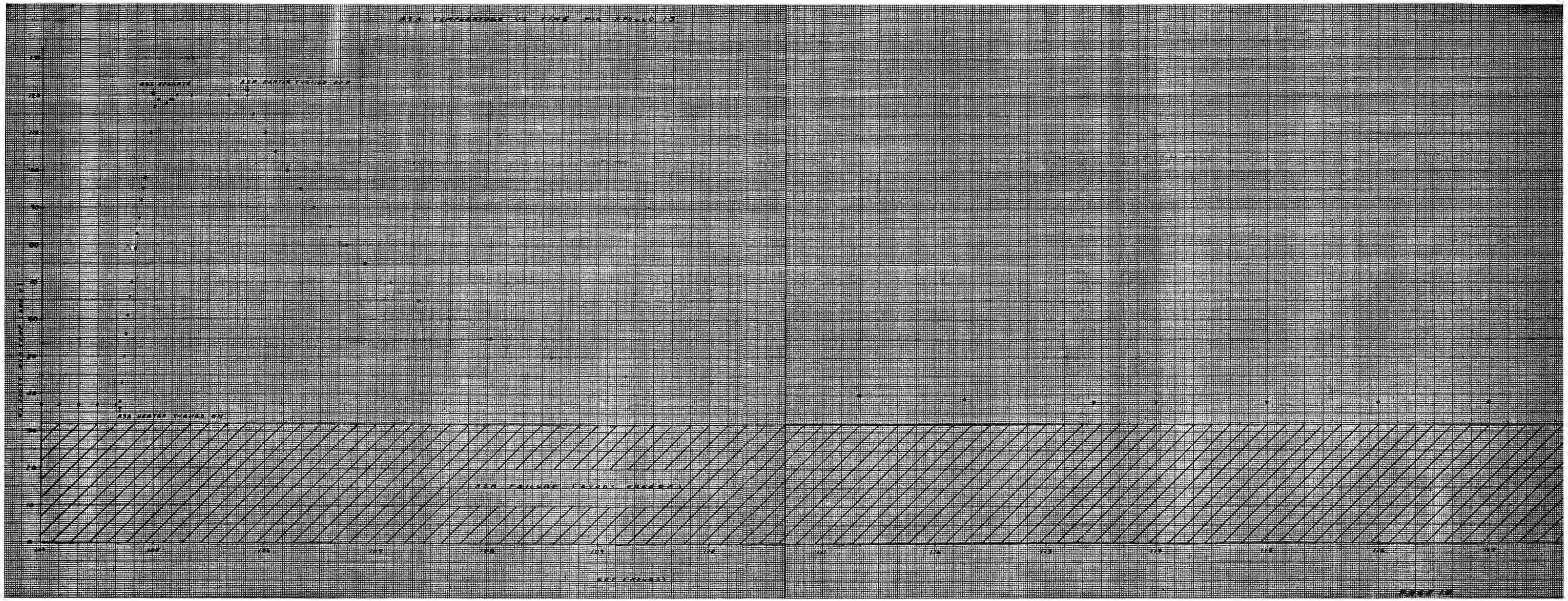
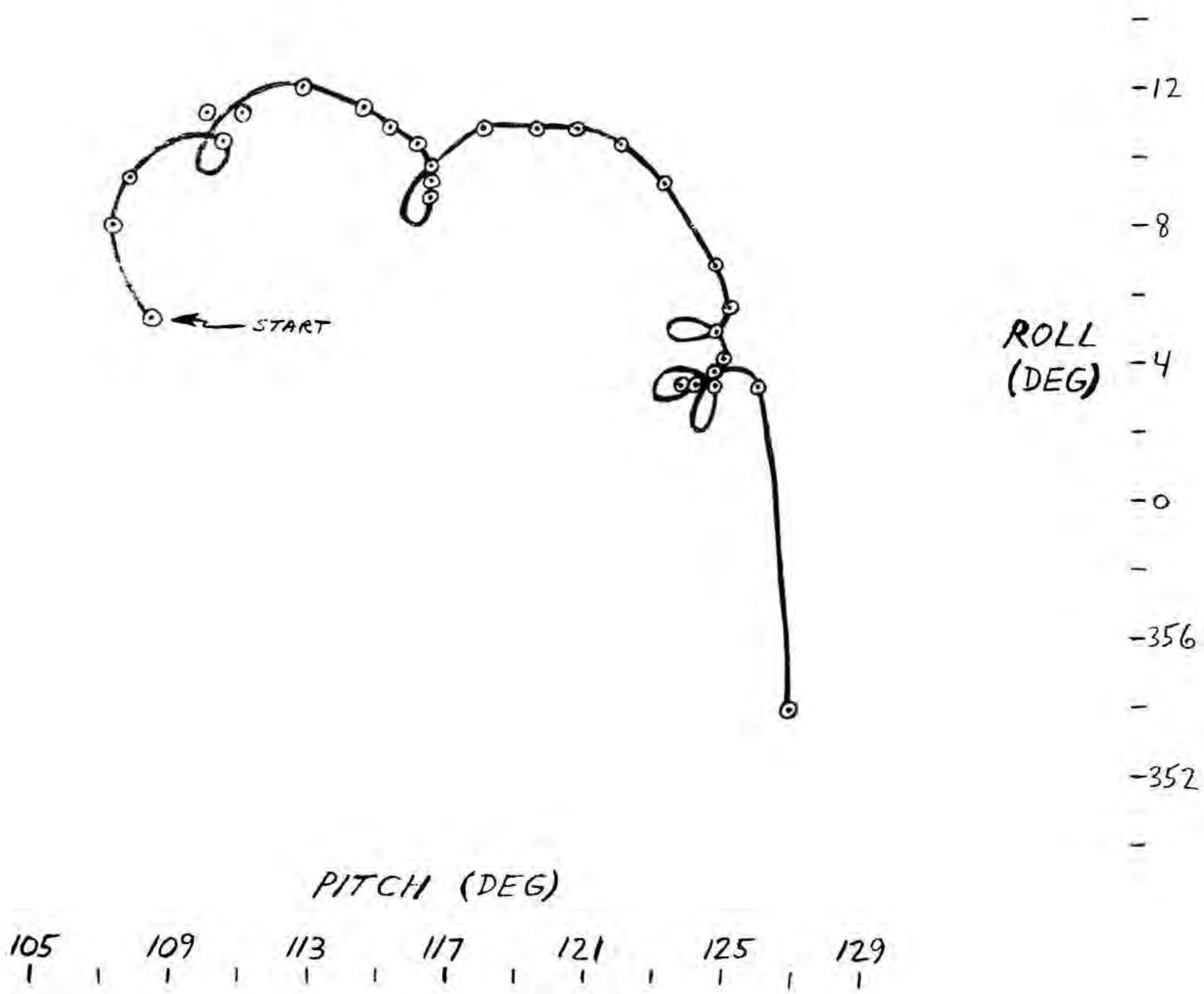


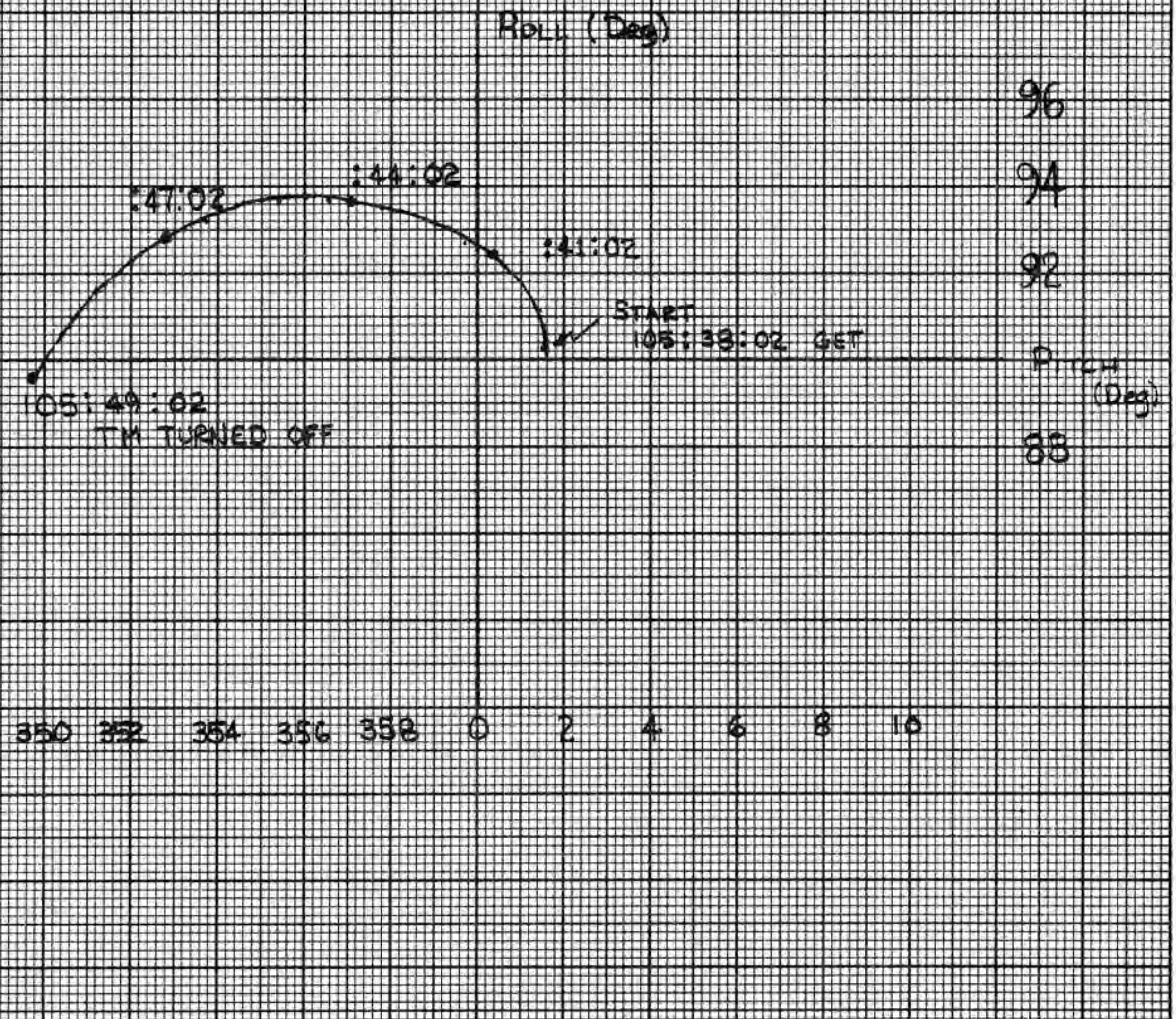
After MCC-4, an MIT recommended procedure was used to establish passive thermal control via the LM PGNS. The rates were nulled to less than 0.01 deg/sec by establishing a very slow minimum impulse limit cycle and then 30 clicks yaw right on the ACA to yield the slow plus vehicle yaw. 43 minutes of data indicated a 0.4 deg/sec yaw rate with the pitch and roll angles cycling about the starting point as shown in Figure ____. This PTC mode resembles closely the PTC modes established using the CM PGNS.

PGNS PTC PLOT



AGS PTC PLOT

PITCH AND ROLL ATTITUDE VS TIME



APOLLO 13 LM PROPULSION POST MISSION REPORT

PART III

TABLE OF CONTENTS

DPS

a. Engine Operation

The descent propulsion system performed three successful engine burns during Apollo 13 instead of the PDI expected. The purpose of the three burns was to establish a free-return trajectory and two mid-course corrections. The ablative and thermal characteristics for the three burn profile were found to be acceptable. The burns were performed nominally. Supercritical helium rise rates increased after the first two burns and is discussed in more detail later.

The first DPS burn was started at 61:29:48 GET. The purpose of this burn was to establish a free-return trajectory. The DPS was pressurized approximately 30 minutes prior to the burn. A four jet 10 second ullage preceded the burn. A ΔV of 40 FPS was achieved with the throttle at LTP for six seconds and 40 percent for 27 seconds.

The second DPS burn came at a GET of 79:27:28. A ΔV of 848 FPS was required to put the vehicles on a fast return trajectory. A two jet 10 second RCS firing was used to ullage the DPS. The burn was performed at LTP for four seconds, two second ramp from LTP to 40 percent, 18.5 seconds at 40 percent, and 238 seconds at FTP. To insure an operational DPS for a subsequent burn, descent REG 1 was closed approximately ten seconds prior to shutdown. This allowed the DPS to go in blowdown and prevented SHe flow if the regulator locked up at its maximum spec (253 psi) lockup after the burn. This extra SHe flow could possibly freeze or slush the Fu/Helium heat exchanger. The large ullage volume (almost 50 percent) made this necessary for this burn where it was not required for the first burn.

The third burn was a mid-course correction burn. At a GET of 105:18:32, the DPS performed the burn in blowdown ($\Delta V = 7.9$ FPS). The burn time was 13.8 seconds from engine on to engine off signal. The burn was a manual ON/OFF burn and the crew was instructed to terminate the burn one second early to prevent an overburn. An overburn would have required -X RCS trimming which would have impinged on the CSM. The burn was trimmed out with +X RCS.

b. Supercritical Helium

During the course of the pre-launch CDDT activities an anomaly was discovered in the DPS supercritical helium (SHe) system. An abnormally high SHe pressure rise rate was discovered at the conclusion of the liquid helium top-off during the chill down phase of the SHe landing operation. This rise rate decreased during the 24 hour chill down period to a nominal value, at final top-off. The average pressure rise rate after completion of loading to end of CDDT was a nominal 7.89 psi/hr. Analysis of the phenomena that had occurred lead to GAC's hypothesis that the vacuum annulus contained a small amount of gas or fluid. This loss of vacuum resulted in degraded thermal insulation properties as long as the gas remained a gas. During chill down, the fluid changes state from a gas to a solid, due to very low temperatures of the liquid helium. After the fluid in the annulus becomes a solid the thermal properties of the tank are restored to near nominal. The exact properties of the fluid was not known and as a result the temperature at which the fluid changes state was not known. Using data to predict worst case pressure development, GAC predicted that this anomaly would not impact the mission.

The pre-launch SHe loading was nominal, and was completed at 31 hours 16 minutes before launch. The average pressure rise rate from top-off to last data just prior to launch was 7.66 psi/hr. This produced a SHe tank pressure of 356 psia at launch.

Discussion of the SHe tank anomaly continued during the early hours of the flight. To insure that the SHe tank was performing nominally, it was decided that the crew would check the SHe tank pressure at initial LM entry at approximately 59 hours into the mission. Further discussion of the anomaly resulted in the development of a contingency procedure to cover the possibility of abnormal SHe system operation.

The contingency procedure consisted of three possibilities. At initial entry, the crew would check the onboard SHe pressure reading. If the pressure was between 710 and 770 psia, no further action would be taken. For a pressure of 780 to 800 psia, a second onboard reading would be taken approximately three hours later to ensure a high rise rate did not exist. A pressure of more than 800 psia would require that the TM system be brought up. The ground would monitor the pressure rise rate and predict a PDI pressure. If this predicted pressure was greater than 1800 psia some SHe would be vented after a 5 sec no ullage DPS burn. The burn would be required to open the SHe tank isolation squib valve.

First entry into the LM was made at 54:46 GET. The onboard SHe pressure of 720 psia was reported by the crew. The pressure rise rate from launch averaged to 6.53 psia/hr. This was slightly higher than the predicted value of 6.16 psia/hr.

At 61:31 GET, the first DPS burn occurred. This was a 40 fps ΔV burn to insure a free return trajectory. The SHe pressure at start of the burn was 791 psia and the end was 877 psia. Within three minutes the pressure increased to 941 psia. After this initial post burn pressure rise, the rise rate stabilized to an average of 10.29 psia/hr until the next burn.

The DPS-2 burn, TEI, was initiated at 79:27 GET. This was a 4 min 21 sec. burn to obtain a ΔV of 848 fps. The SHe pressure at the start of the burn was 1130 psia and was 949 psia at the end of the burn. The peak pressure experienced during the burn was 1194 psia, and occurred approximately 45 sec into the burn. The SHe rise rate immediately after the burn was 40 psia/hr. This rise rate continued to decrease during the following coast period. The average rise rate during this period was 33.29 psia/hr.

The SHe burst disk rupture occurred at 108:54:10 GET. The indicated SHe pressure at time of rupture was 1937 psia. Within three minutes, the SHe tank pressure had decreased to 158 psia. A total of approximately 10 minutes was required to vent the total of 27.5 of helium to a pressure of 8 psia.

The venting of the SHe was predicted to be non-propulsive. According to SPAN, the ΔV that could be imparted to the vehicles was 0.003 fps. The actual force imported to the vehicle was sufficient to stop the PTC of 0.3°/sec, reverse the direction and increase the rate. The crew reported a rate such that two revolutions of the spacecraft occurred in approximately 3 min 50 sec.

APS

The APS was never pressurized during this mission and the only anomaly occurred at RCS pressurization when both oxidizer and fuel inlet pressures rose approximately five (5) psi. This anominally will be discussed further in the section on RCS.

RCS

Following an electrical failure in the CSM at 55:58 GET, the crew activated the LM systems. The RCS systems were pressurized at 58:33 GET and the only anominally observed occurred shortly after pressurization when the APS inlet pressure rose approximately five (5) psi and system A dropped 3 percent. This data indicates that the system A ascent feed valves were momentarily opened. Since the ascent feed valves come down at one sample per second, it is difficult to determine if this actually occurred. After the first DPS burn, the redundant set of ascent feed valves were closed to insure RCS pressure integrity.

The first DPS burn which occurred at 61:30 GET was preceded by a 4 jet ullage of 10 seconds duration. Prior to the burn, the crew had been holding attitude with PGNS pulse using the TTCA. After the burn, the crew went to a PTC by holding attitude with PGNS pulse (TTCA) and doing a 90° yaw once every hour. It was calculated that this mode was using 1 percent per hour. This PTC was used until the next DPS burn at 79:30 GET.

The second DPS burn in so far as RCS was similar to the first burn except the UV jets were disabled during the burn and the ullage was 2 jet. Usage was slight during the burn due to yaw control. The vehicle was spun up (yaw) to give PTC and the RCS was deactivated to conserve power. The system stayed in this mode from approximately 80 to 104 hrs. GET.

At 105:30, a short DPS burn was performed and the RCS was reactivated at about 104:30 GET in support of this burn. This burn was a manual burn using the TTCA for attitude control and the DPS gimbal was off. Due to the short duration of the burn (13.8 seconds) only a few percent of propellant were used including burning out the residuals. From 106 to 133 hrs. GET, the vehicle was put in PTC and the RCS was again deactivated.

The RCS was activated for the last time at 133:30 GET. A RCS burn of 24 seconds was accomplished at 137:40 GET. The RCS usage for the maneuvers, attitude hold and other activities in support of the CSM P52, SM JET and SM photos were as expected. One PGNS auto maneuver was attempted but the 0.5°/sec. maneuver rate in the DAP was using too much RCS so the crew finished the maneuver in pulse. A maneuver rate of 0.2°/sec. would have prevented this difficulty.

The final amount of RCS remaining at LM jet was 26 percent (13 percent usable) compared to a predicted of 28 percent.

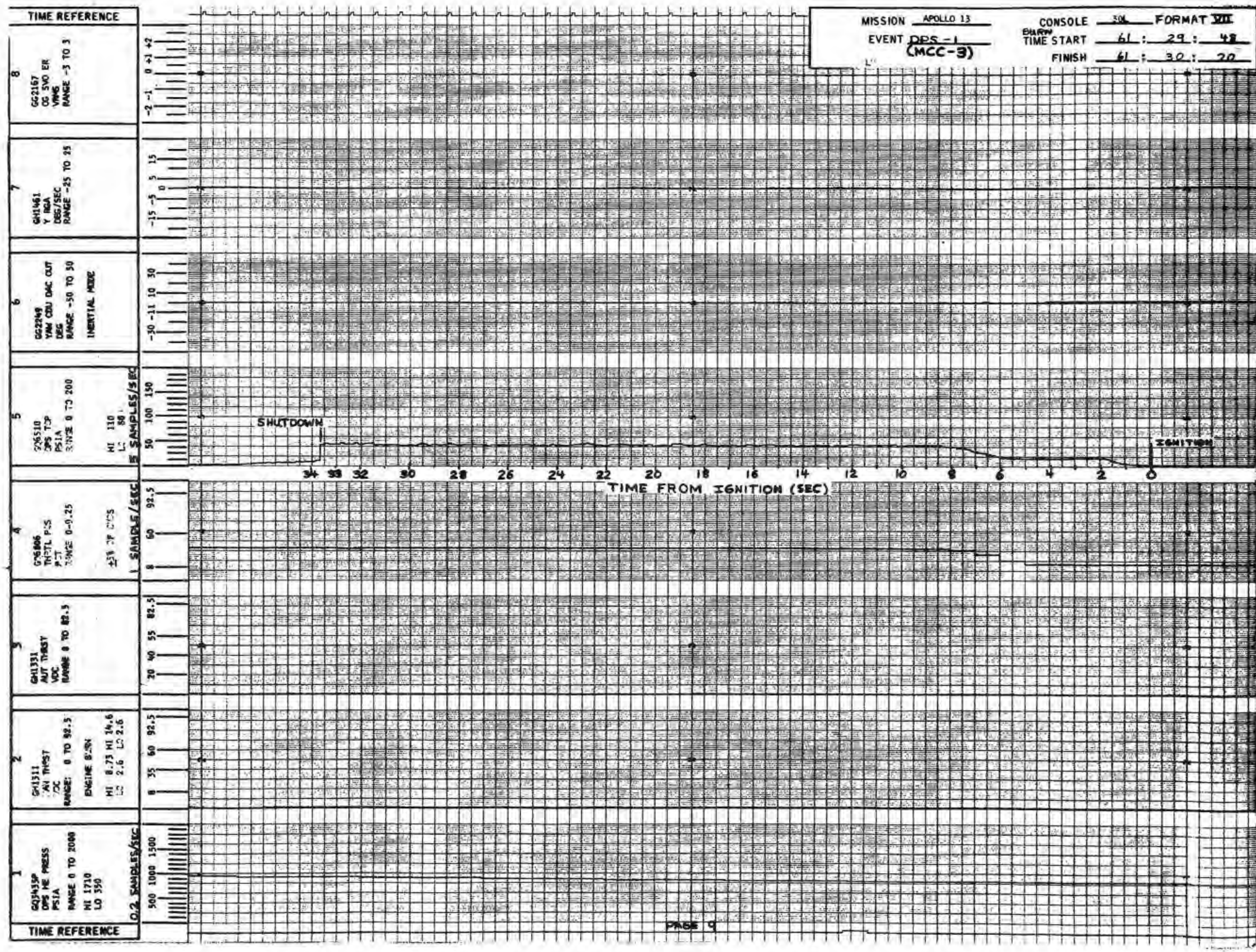
One important input that was received from SPAN during the mission was the data that the RCS could be operated in pulse mode with reasonable probability of success at quad temperatures of 70°F or greater.

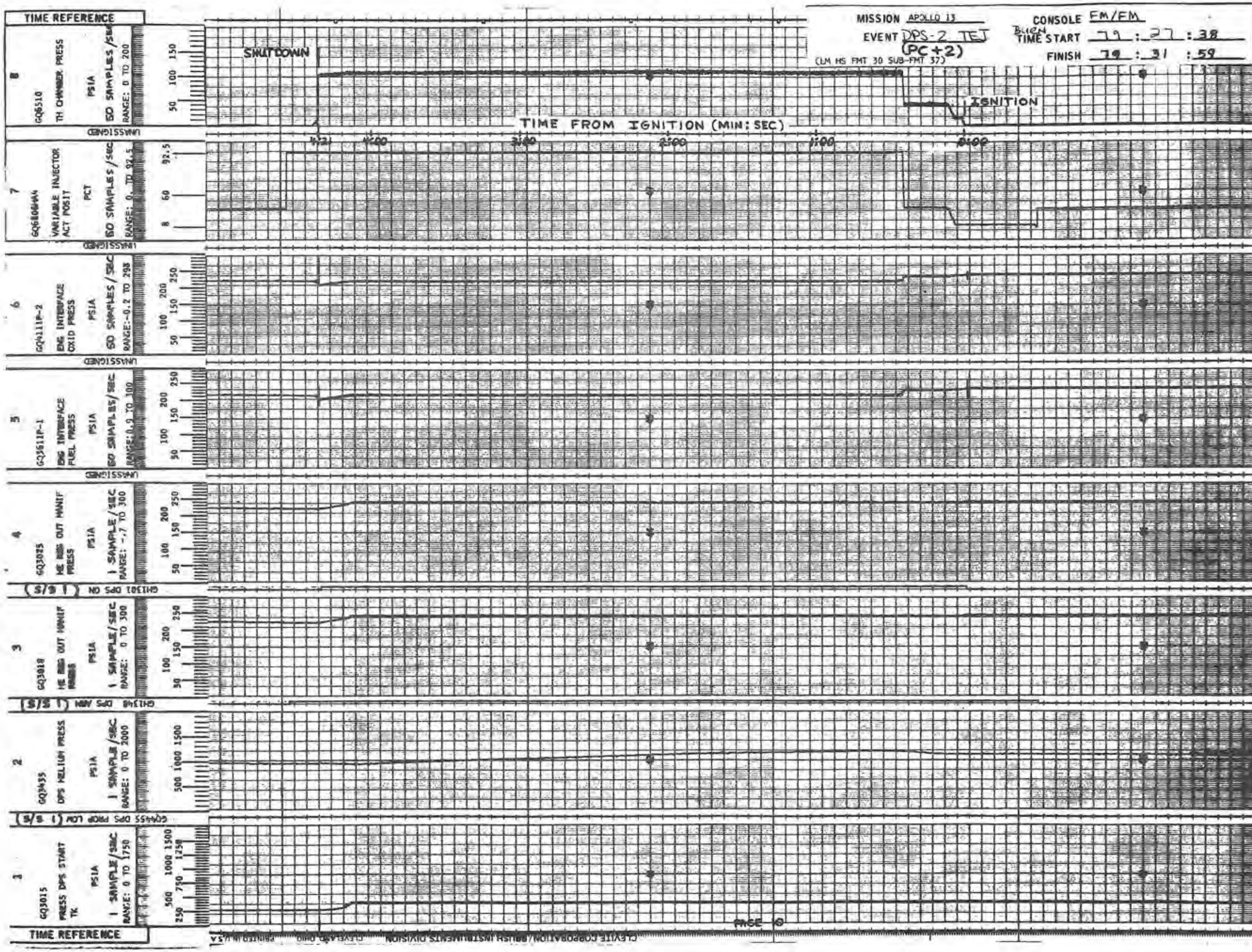
LM-7 BURN SUMMARY

BURN	START TIME (GET)	STOP TIME (GET)	ΔV OF BURN (FPS)	SYSTEM USED	PROPELLANT USED	
					APS/DPS (LBS)	RCS (%)
MCC-3	61:29:48	61:30:20	40.0	DPS*	408.6	5.5% **
PC + 2	79:27:38	79:31:59	851	DPS*	8032	5.7% **
MCC-5	105:18:32	105:18:46	7.9	DPS*	62.1	4.7% **
MCC-7	137:39:48	137:40:12	3.1	RCS	-	7.6% **

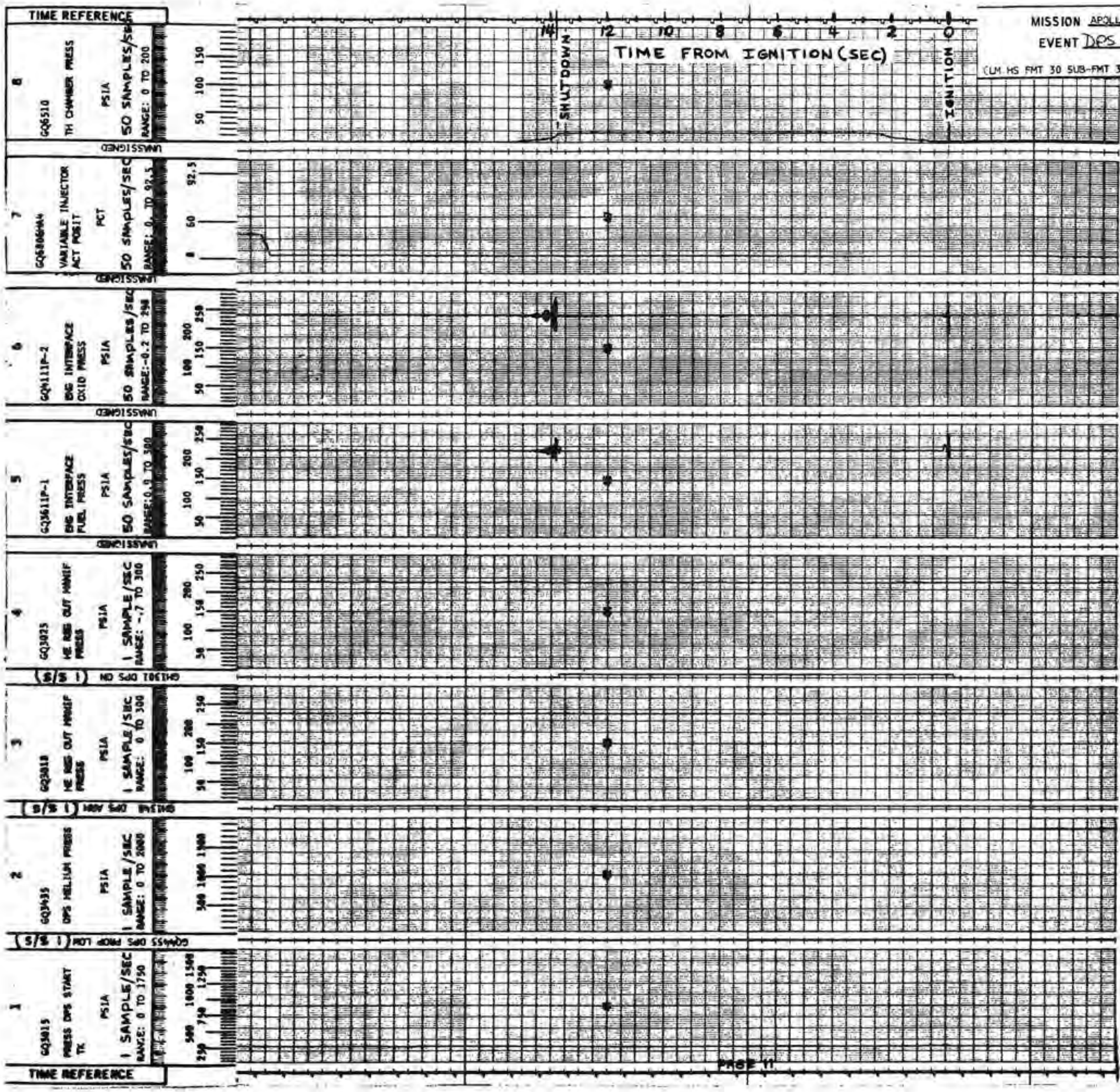
* 10 SEC RCS ULLAGE

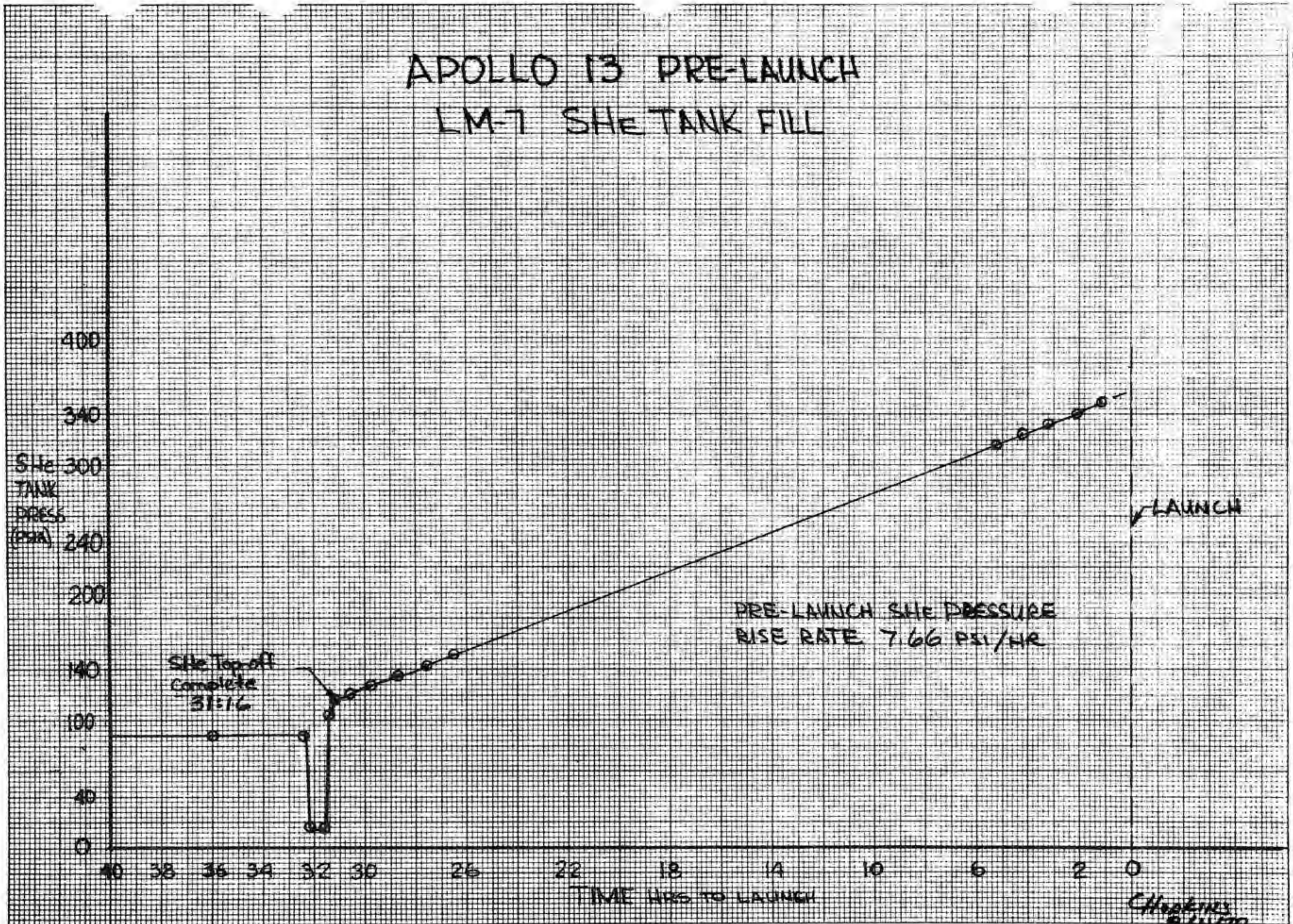
** INCLUDED MANEUVER TO ATTITUDE

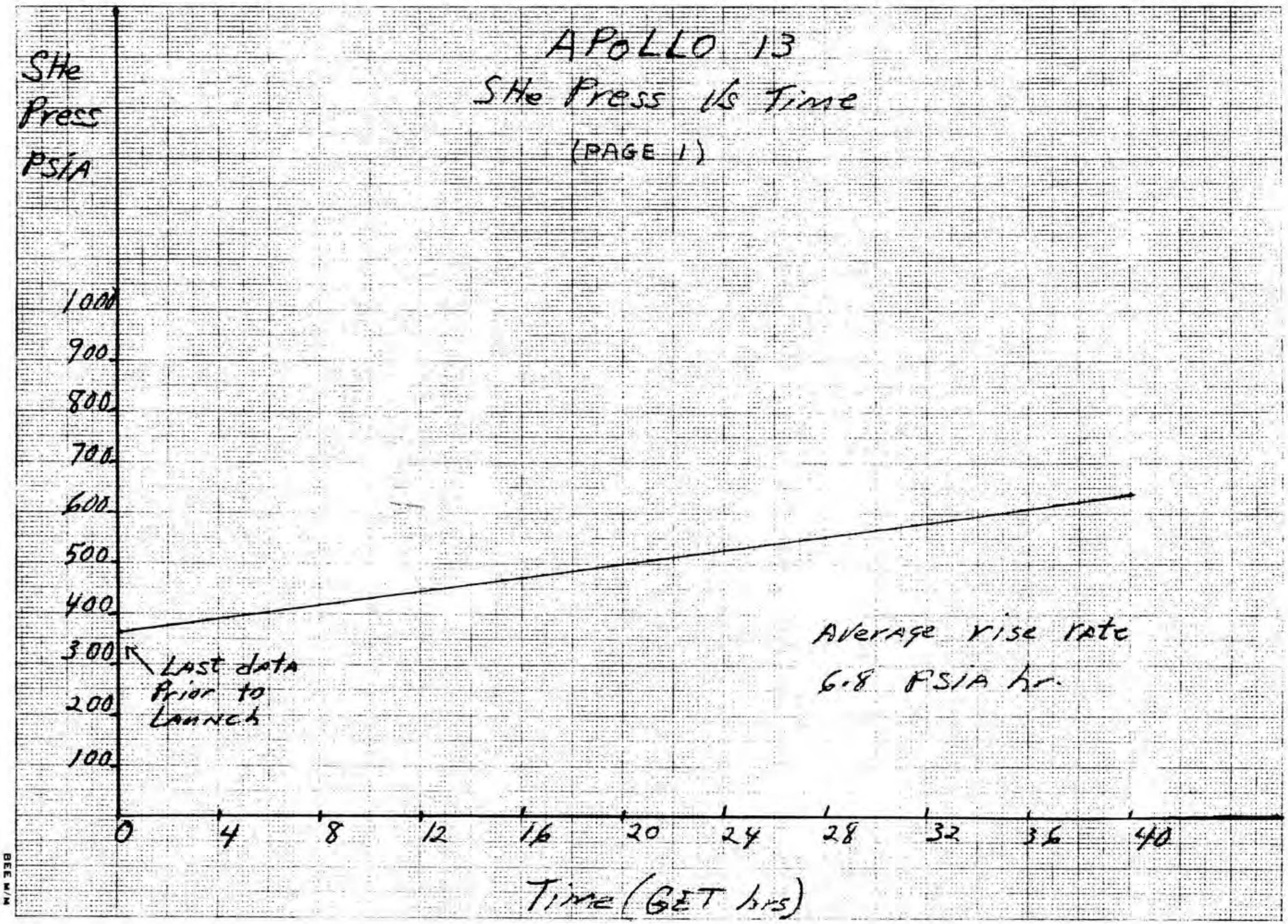

MISSION APOLLO 13
EVENT DPS-1 (MCC-3)
CONSOLE 306 FORMAT VII
BURN TIME START 61 : 29 : 48
FINISH 61 : 30 : 20
TIME REFERENCE
8 GG2167 GG SVO ER VMS RANGE -3 TO 3
7 GH1461 Y RGA DEG/SEC RANGE -25 TO 25
6 GG2249 YAW CDU DAC OUT DEG RANGE -50 TO 50 INERTIAL MODE
5 GQ6510 DPS TCP PSIA RANGE 0 TO 200 HI 110 LO 80
5 SAMPLES/SEC
4 GQ6806 THRTL POS PCT RANGE 0-0.25
1 SAMPLE/SEC
3 GH1331 AUT THRST VDC RANGE 0 TO 82.5
2 GH1311 AUT THRST VDC RANGE: 0 TO 92.5 ENGINE BURN HI 8.73 HI 14.6 LO 2.6 LO 2.6
1 GQ3435P DPS HE PRESS PSIA RANGE 0 TO 2000 HI 1710 LO 350
0.2 SAMPLES/SEC
TIME REFERENCE
SHUTDOWN
IGNITION
TIME FROM IGNITION (SEC)
PAGE 9

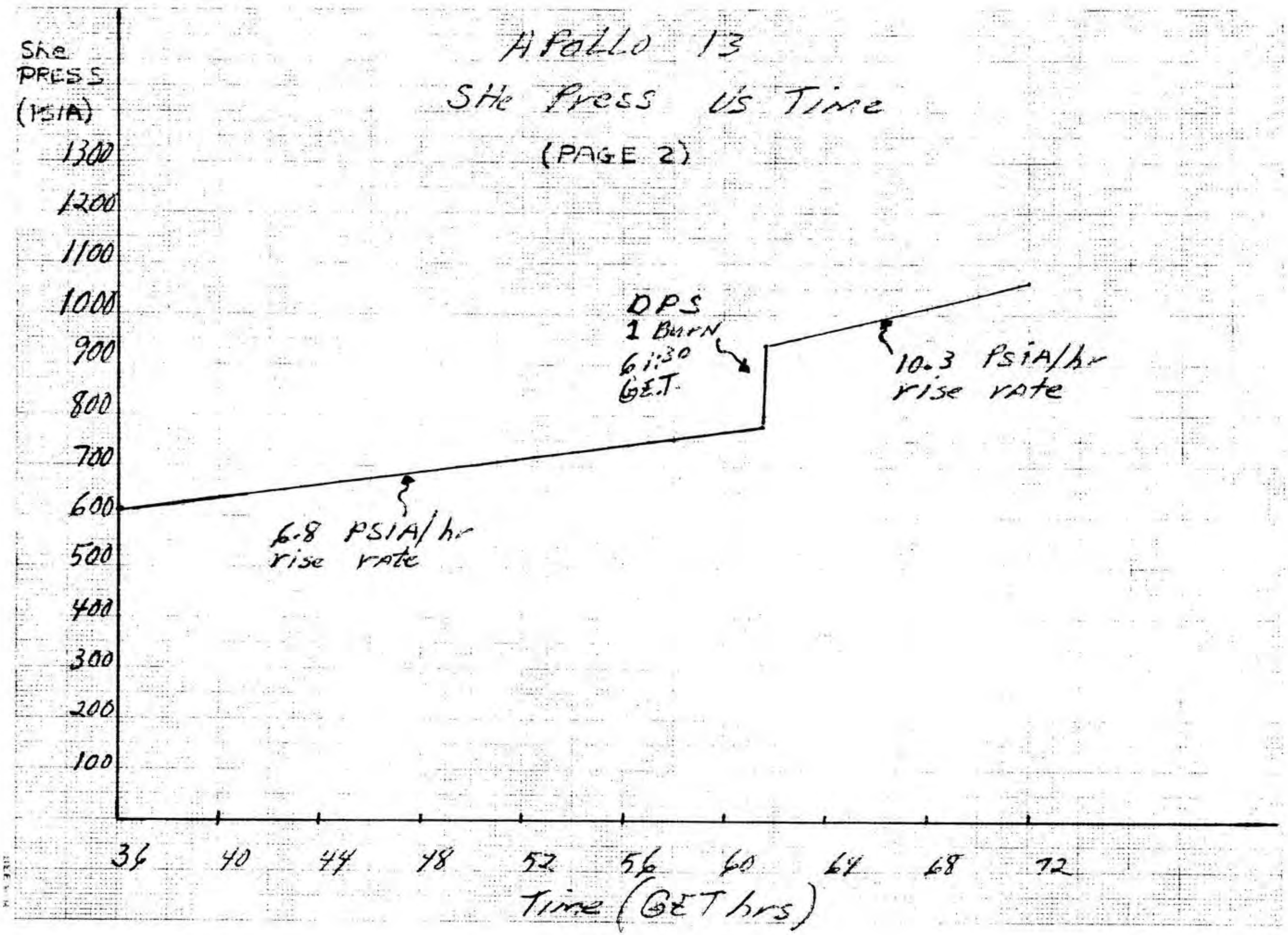

MISSION APOLLO 13
EVENT DPS-2 TEI (PC+2)
(LM HS FMT 30 SUB-FMT 37)
CONSOLE FM/FM
BURN TIME START 79 : 27 : 38
FINISH 79 : 31 : 59
TIME REFERENCE
SHUTDOWN
IGNITION
TIME FROM IGNITION (MIN: SEC)
4:21
4:00
3:00
2:00
1:00
0:00
8 GQ6510 TH CHAMBER PRESS PSIA 50 SAMPLES/SEC RANGE: 0 TO 200
UNASSIGNED
7 GQ6806HAH VARIABLE INJECTOR ACT POSIT PCT 50 SAMPLES/SEC RANGE: 0. TO 92.5
UNASSIGNED
6 GQ4111P-2 ENG INTERFACE OXID PRESS PSIA 50 SAMPLES/SEC RANGE:-0.2 TO 298
UNASSIGNED
5 GQ3611P-1 ENG INTERFACE FUEL PRESS PSIA 50 SAMPLES/SEC RANGE:0.9 TO 300
UNASSIGNED
4 GQ3025 HE REG OUT MANIF PRESS PSIA 1 SAMPLE/SEC RANGE: -.7 TO 300
(S/S 1) GH1301 DPS ON (1 S/S)
3 GQ3018 HE REG OUT MANIF PRESS PSIA 1 SAMPLE/SEC RANGE: 0 TO 300
(S/S 1) GH1348 DPS ARM
2 GQ3435 DPS HELIUM PRESS PSIA 1 SAMPLE/SEC RANGE: 0 TO 2000
(S/S 1) GQ4455 DPS PROP LOW (1 S/S)
1 GQ3015 PRESS DPS START TK PSIA 1 SAMPLE/SEC RANGE: 0 TO 1750
TIME REFERENCE
PAGE 0
CLEVITE CORPORATION/BRUSH INSTRUMENTS DIVISION CLEVELAND OHIO PRINTED IN U.S.A.

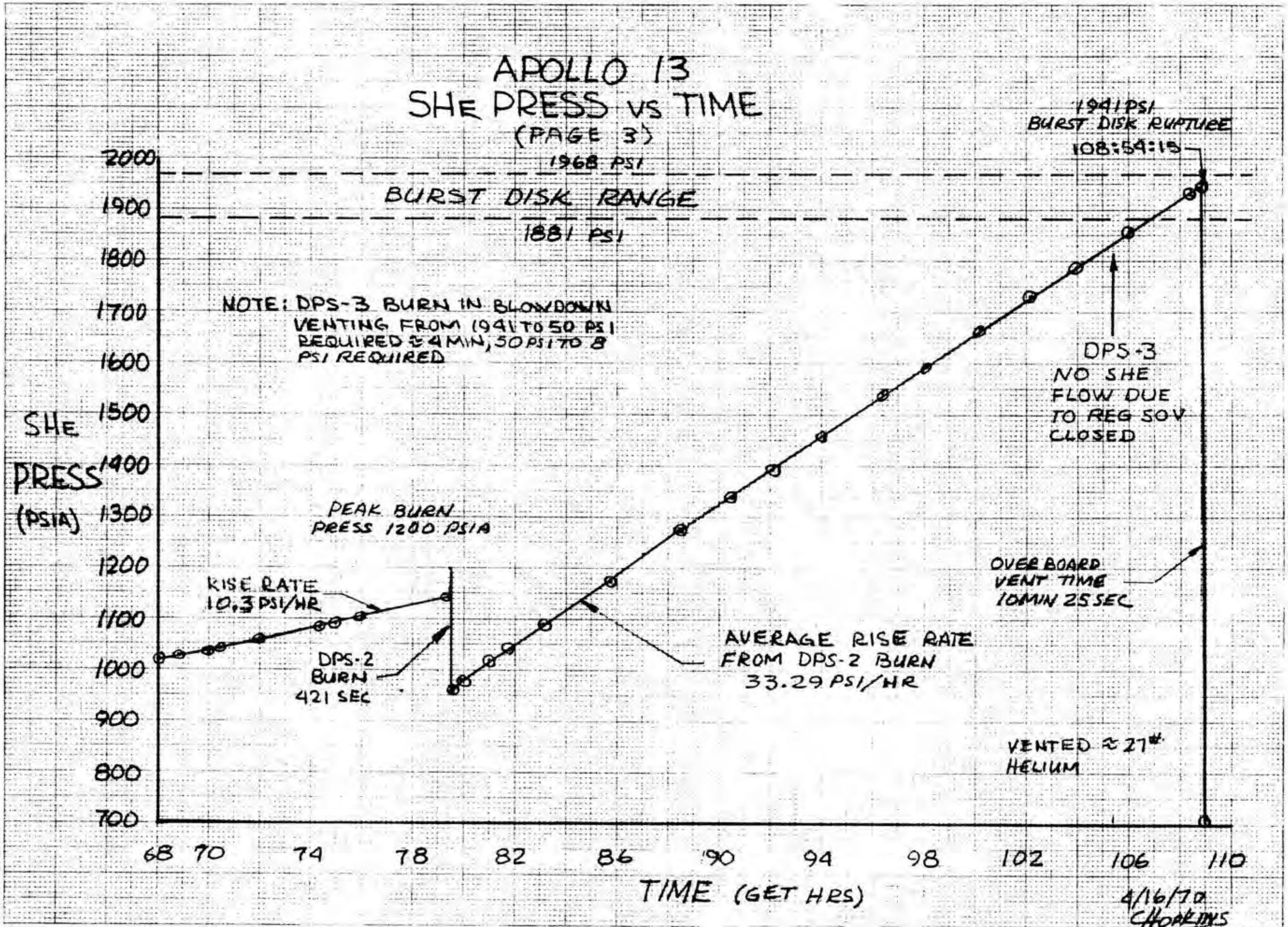
MISSION APOLLO 13 CONSOLE FM/FM
EVENT DPS-3 (MCC-5) BURN TIME START 105 : 18 : 32
(LM HS FMT 30 SUB-FMT 37) FINISH 105 : 18 : 46




APOLLO 13 PRE-LAUNCH
LM-7 SHe TANK FILL
SHe TANK PRESS (PSIA)
400
340
300
240
200
140
100
40
0
SHe Top-off Complete 31:16
PRE-LAUNCH SHe PRESSURE RISE RATE 7.66 PSI/HR
LAUNCH
40 38 36 34 32 30 26 22 18 14 10 6 2 0
TIME HRS TO LAUNCH

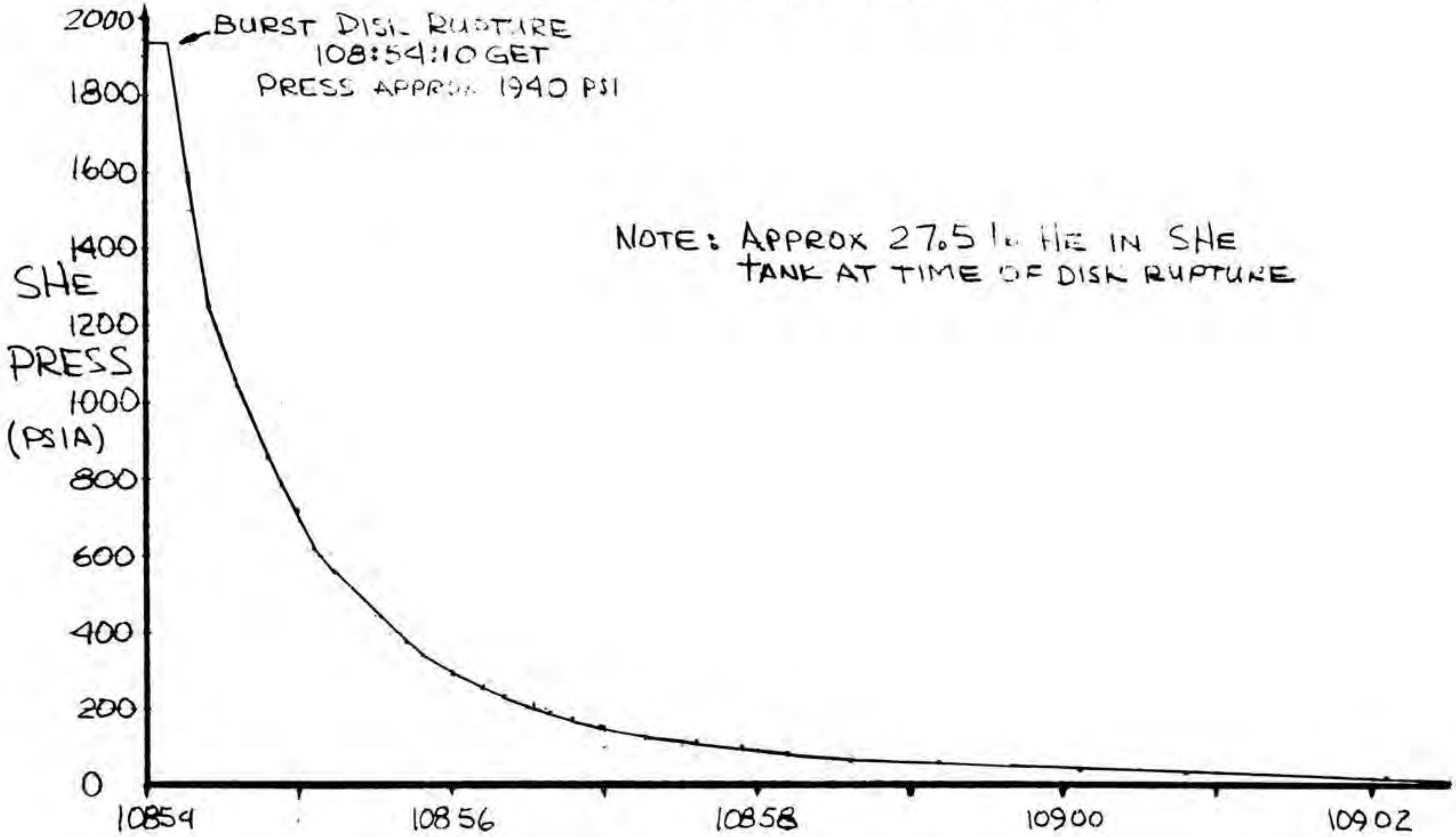

APOLLO 13
SHe Press Vs Time
(PAGE 1)
SHe Press PSIA
1000
900
800
700
600
500
400
300
200
100
Last data Prior to Launch
Average rise rate
6.8 PSIA hr.
0
4
8
12
16
20
24
28
32
36
40
Time (GET hrs)
BEE M/M


Apollo 13
SHe Press Vs Time
(PAGE 2)
SHe PRESS (PSIA)
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
DPS 1 Burn 61:30 GET
10.3 PSIA/hr rise rate
6.8 PSIA/hr rise rate
36
40
44
48
52
56
60
64
68
72
Time (GET hrs)



APOLLO 13
SHE PRESS VS TIME
(PAGE 3)
1968 PSI
BURST DISK RANGE
1881 PSI
1941 PSI
BURST DISK RUPTURE
108:54:15
NOTE: DPS-3 BURN IN BLOWDOWN
VENTING FROM 1941 TO 50 PSI
REQUIRED ≈ 4 MIN, 50 PSI TO 8
PSI REQUIRED
DPS-3
NO SHE
FLOW DUE
TO REG SOV
CLOSED
SHE
PRESS
(PSIA)
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
PEAK BURN
PRESS 1200 PSIA
RISE RATE
10.3 PSI/HR
DPS-2
BURN
421 SEC
AVERAGE RISE RATE
FROM DPS-2 BURN
33.29 PSI/HR
OVERBOARD
VENT TIME
10 MIN 25 SEC
VENTED ≈ 27#
HELIUM
68
70
74
78
82
86
90
94
98
102
106
110
TIME (GET HRS)
4/16/70
C HOPKINS

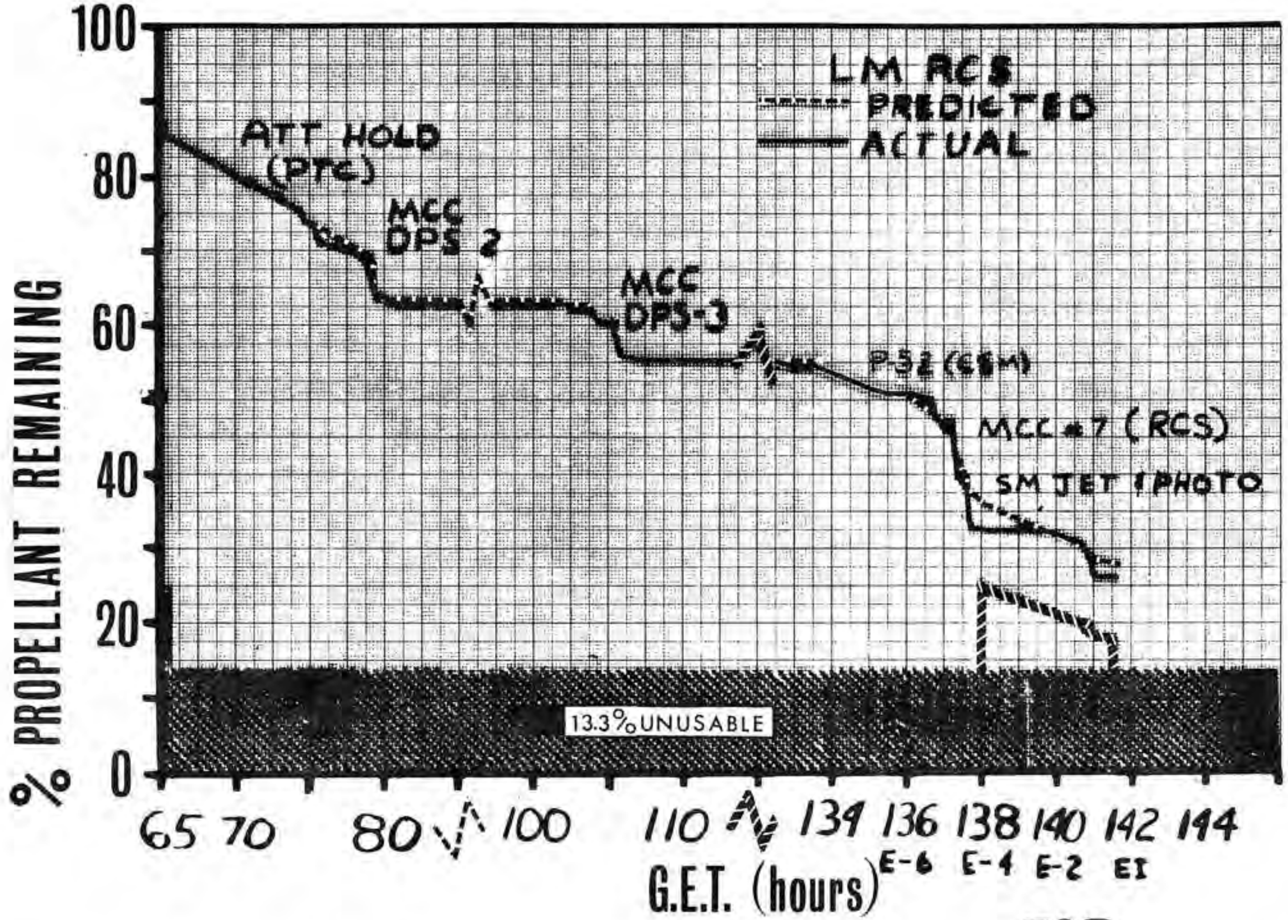
APOLLO 13 LM-7
SHE BURST DISK RUPTURE



C HOPKINS

LM RCS PROPELLANT PROFILE - MISSION

13 - A



SYSTEM A	SYSTEM B	AVERAGE	MARGIN	ESTIMATED at [redacted] JET	G.E.T. UPDATED
31 %	21 %	26.0%	- 2.0%	28.0%	141 : 30

NASA — MSC

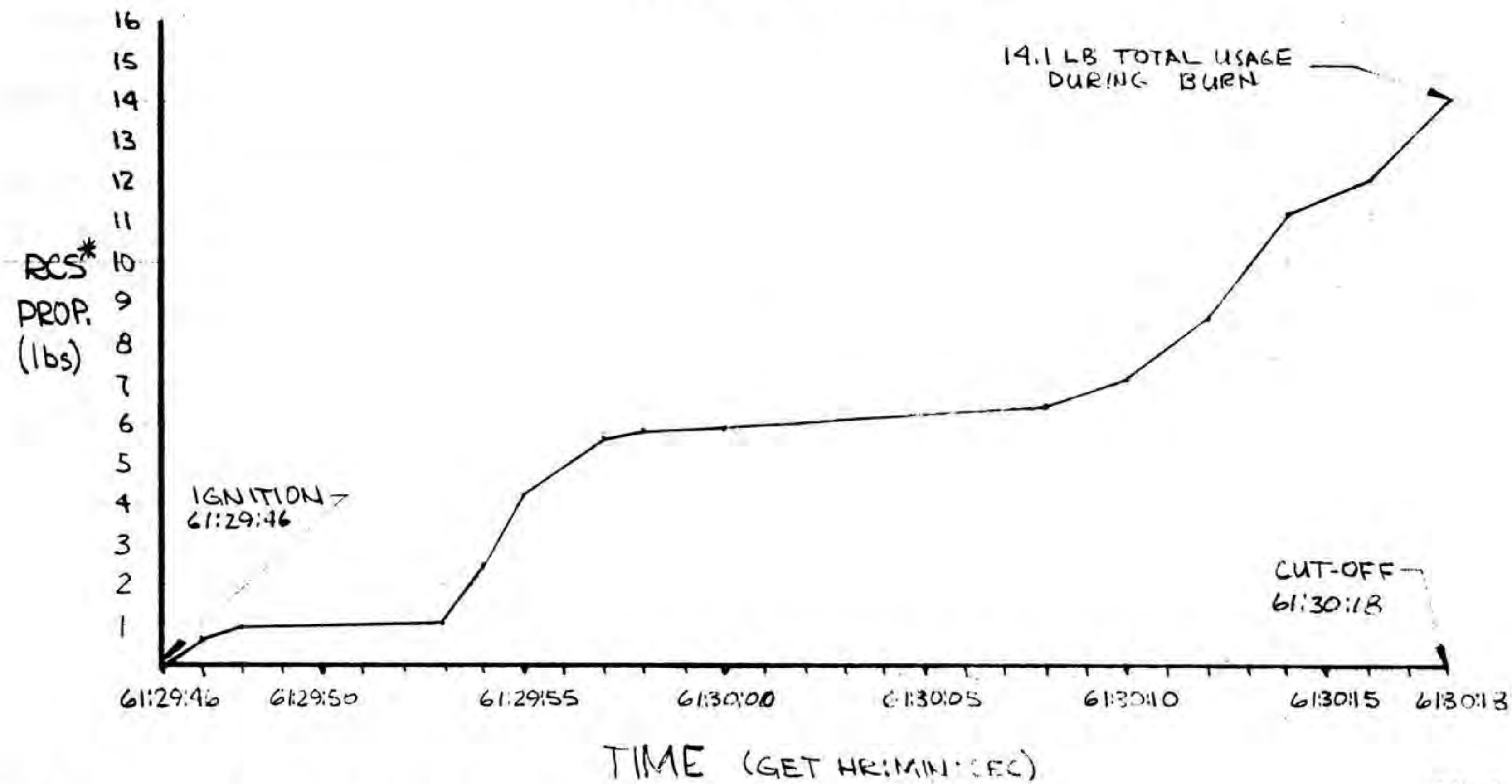
LM RCS USAGE RATES FOR VARIOUS MANEUVERS DURING APOLLO 13*

TIME OF ACTIVITY GET (HR:MIN)	S/C CONFIG.	DESCRIPTION OF ACTIVITY OR MODE	PREDICTED BY PROG.	ACTUAL AS OBSERVED
60:00	CSM+LM	AGS MANUAL MANEUVER USING TTCA	27.1#	26#
63:00 - 74:30	CSM+LM	MANUAL PTC WITH 90° YAW ONCE/HR.	--	6.3#/HR
74:30	CSM+LM	MANEUVER TO BURN ATT. (PGNS PULSE)	14.9#	15.7#
75:00 - 79:20	CSM+LM	MANUAL ATT. HOLD - APPROX. 1.4° DB (PGNS PULSE)	--	6.3#/HR
79:30	CSM+LM	DPS - 2 BURN		
		ULLAGE	7.3#	7.3#
		YAW CONTROL DURING BURN	7.4#	5.8#
80:00 - 100:00	CSM+LM	FREE DRIFT	0.0#	0.0#
104:00	CSM+LM	MANEUVER TO BURN ATT. (PGNS MANUAL)	13.1#	15.7#
105:30	CSM+LM	DPS - 3 BURN		
		ULLAGE	14.6#	14.6#
		AGS MANUAL CONTROL (TTCA)	--	14.1#
106:00 - 133:00	CSM+LM	FREE DRIFT	0.0#	0.0#
134:00	CSM+LM	CSM P52	26.2#	28.4#
136:30	CSM+LM	MANEUVER TO MCC7 BURN ATT. (COMBINATION OF MODES)	--	18.9#
137:10	CSM+LM	MCC 7 RCS 4 JET BURN (3.1 FPS)	30.8#	30.8#

* NOT ALL MANEUVERS OR ACTIVITIES ARE SHOWN DUE TO LACK OF DATA. THE ACTUAL PROPELLANT CONSUMED WAS SOMETIMES MASKED BY THE OVERSHOOT CHARACTERISTICS OF THE RCS GUAGING SYSTEMS.

RSN 4/28/70

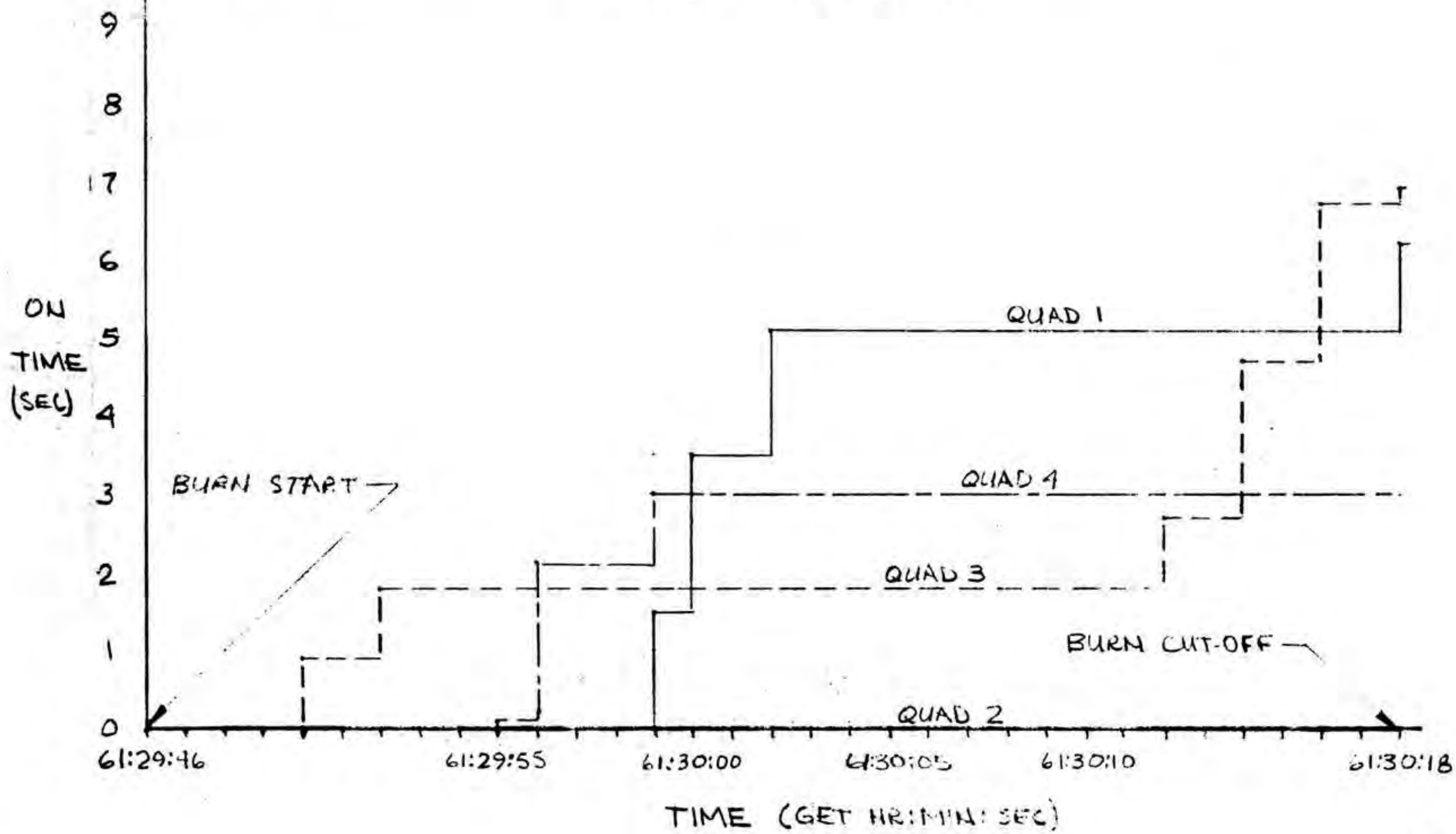
APOLLO 13
RCS PROPELLANT USAGE
DPS - 1 BURN



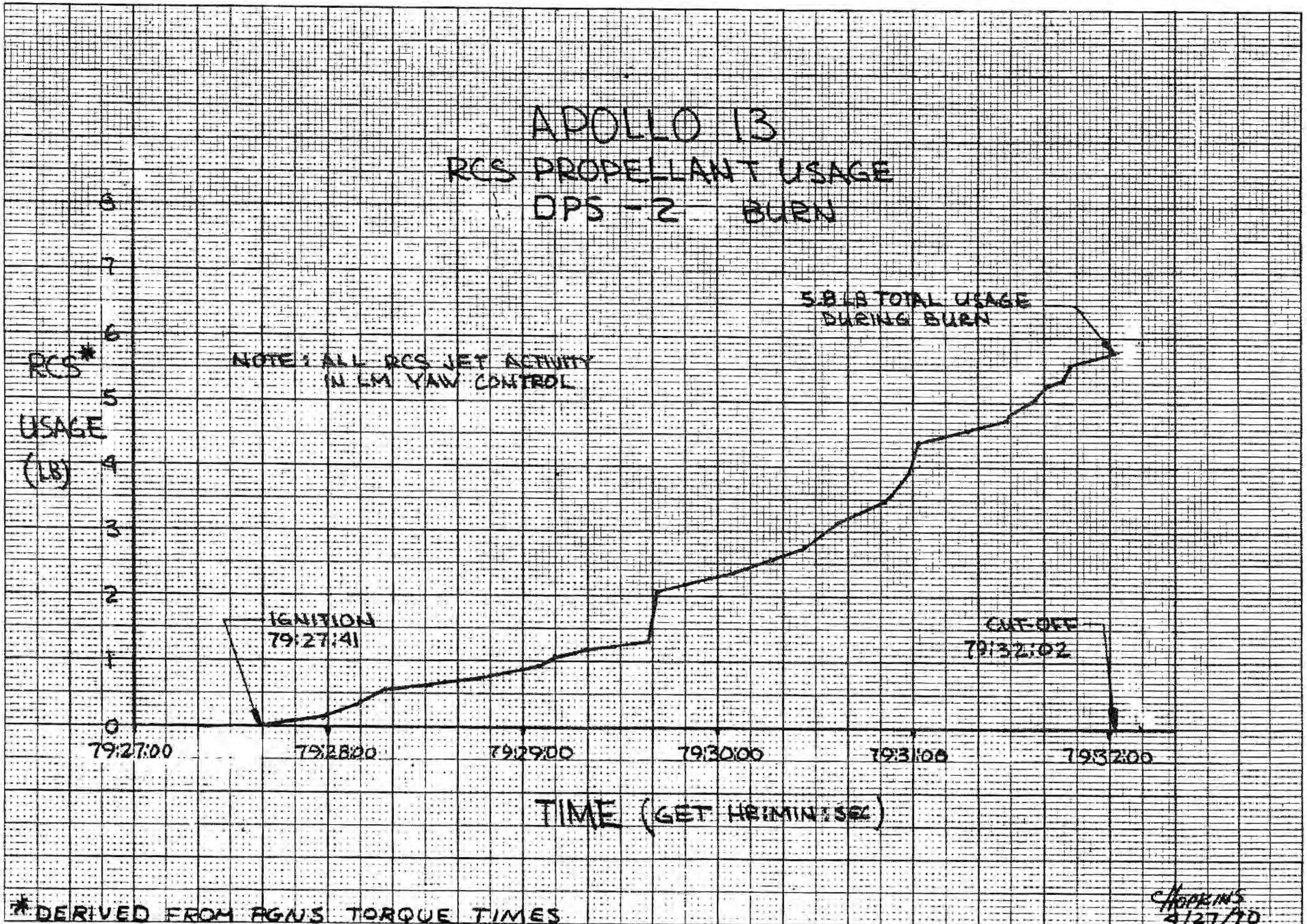
* DERIVED FROM PGNS TORQUE TIMES

CHopkins 4/24/70

APOLLO 13
RCS ON TIME PLOT
DPS - 1 BURN



GHOPKINS
4/27/70


APOLLO 13
RCS PROPELLANT USAGE
DPS-2 BURN
RCS* USAGE (LB)
0
1
2
3
4
5
6
7
8
NOTE: ALL RCS JET ACTIVITY IN LM YAW CONTROL
5.8 LB TOTAL USAGE DURING BURN
IGNITION 79:27:41
CUT-OFF 79:32:02
79:27:00
79:28:00
79:29:00
79:30:00
79:31:00
79:32:00
TIME (GET HR:MIN:SEC)
* DERIVED FROM AGNS TORQUE TIMES
Hopkins 4/27/70

APOLLO 13 ACTUAL WEIGHT HISTORY

ALL WEIGHT ARE IN POUNDS ASCENT STAGE	EARTH LAUNCH	TD AND E	INITIAL MANNING	PRE MCC-3 (DPS 1)	POST MCC-3 (DPS 1)	PRE PC+2 (DPS 2)	POST PC+2 (DPS 2)	PRE MCC-5 (DPS 3)	POST MCC-5 (DPS-3)	PRE MCC-7 (RCS 1)	POST MCC-7 (RCS 1)	POST JETTISON
DRY WT ASC	4551	4551	4551	4551	4551	4551	4551	4551	4551	4551	4551	4551
MISC WT ASC	0	7	493	493	493	493	493	493	493	493	493	288
APS FU REM	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009
APS OX REM	3220	3220	3220	3220	3220	3220	3220	3220	3220	3220	3220	3220
RCS A FU REM	107	107	107	87	81	74	69	66	61	53	43	32
RCS B FU REM	107	107	107	89	83	75	67	64	59	51	41	23
RCS A OX REM	209	209	209	170	158	145	135	129	119	106	87	63
RCS B OX REM	209	209	209	173	161	147	131	125	115	101	82	46
ASC 1 O_2Q	2.31	2.31	2.31	2.28	2.28	2.28	2.29	2.26	2.26	2.28	2.28	2.29
ASC 2 O_2Q	2.36	2.36	2.36	2.67	2.67	2.67	2.68	2.67	2.67	2.68	2.68	2.68
ASC 1 H_2O Q	42.1	42.1	42.1	42.3	42.3	42.3	42.3	42.1	42.1	24.5	24.0	12.7
ASC 2 H_2O Q	42.1	42.1	42.1	42.3	42.3	42.3	42.3	42.1	42.1	25.9	25.0	14.2
ASC TOT ST	10502	10509	10995	10882	10846	10805	10764	10746	10715	10639	10580	10264
DESCENT STAGE												
DRY WT DES	4359	4359	4359	4359	4359	4359	4359	4359	4359	4329	4329	4329
DPS 1 FU REM	3524	3524	3524	3524	3464	3464	1949	1949	1940	1940	1940	1940
DPS 2 FU REM	3524	3524	3524	3524	3464	3464	1949	1949	1940	1940	1940	1940
DES 1 OX REM	5645	5645	5645	5645	5549	5549	3123	3123	3107	3107	3107	3107
DES 2 OX REM	5645	5645	5645	5645	5549	5549	3123	3123	3107	3107	3107	3107
DES O_2 QTY	49.3	49.3	49.3	44.0	43.7	42.6	42.6	35.0	34.4	28.0	28.0	27.4
DES H_2O	253.6	253.6	253.6	177.5	176.9	159.1	153.8	62.5	61.4	16.2	16.2	16.2
DES TOT WT	23001	23001	23001	22919	22606	22587	14699	14601	14518	14467	14467	14466
LM TOT WT	33503	33510	33996	33801	33452	33392	25463	25347	25233	25106	25047	24730

FEC/TSG FORM 502 (JUNE 69)

NASA — MSC — Coml., Houston, Texas

APPENDIX I

Instrumentation and Communication Officer (INCO)

APPENDIX I

INSTRUMENTATION AND COMMUNICATIONS
OFFICER (INCO)

ALAN C. GLINES

GARY B. SCOTT

THOMAS L. HANCHETT

GRANVIL A. PENNINGTON

1. MILA TV During Rev 1

TV was planned during MILA's Rev 1 pass. At 1:35:39 GET the USB mode reset command was transmitted to terminate the DSE dump, and allow the TV to be received on the FM downlink. When the TV was not received at MCC MILA and Houston TV were queried about a possible MSFN problem. MILA subsequently reported that the FM downlink was not being downlinked from the CSM. The crew confirmed the S-band mode switch was in the TV position, and then selected transmit on the TV camera. The TV picture was received shortly after the TV camera transmit mode was selected.

The erroneous report from MILA indicated that the FM carrier was not on, when in fact, it was only the video portion of the FM modulation that was missing.

2. Madrid Uplink Anomaly

During the TLC phase, omni antenna switching is accomplished via INCO commands. To provide MCC the most telemetry data during each PTC revolution, the antenna switching command is executed just before MSFN uplink threshold is reached; i.e., just before two-way lock is lost. At a GET of 47:00:00 with MAD uplinking, the omni command was not received on the first command attempt. Before a second attempt could be executed, MAD had turned off the uplink command subcarrier (70 KHZ) to attempt reacquisition. It was necessary to change MAD to a Mode 3 (command only) uplink to gain enough uplink margin to accomplish the omni switch. This dropping of the uplink subcarrier occurred on three separate occasions. In previous missions during the PTC coast phase, the MSFN sites have always assisted INCO in his omni switching by leaving the command uplink subcarrier on after two-way lock is lost. If two-way lock is lost, this delay in turning off the command uplink has, in most cases, allowed INCO another try or two at getting his command into the spacecraft. INCO requested NETWORK to have MAD implement a short delay, but NETWORK declined. This delay in dropping the uplink is not a documented procedure.

It is recommended that a NOD procedure be written which advises the site to delay dropping the uplink subcarriers, if two-way lock is lost during PTC omni switching. INCO will follow-up this item with FSD.

3. High Gain Antenna Anomaly

The second activation of the CSM High Gain Antenna (HGA) for television at 55:03:00 GET was three hours earlier than scheduled in the Flight Plan. The CSM attitude was roll 290.0°, pitch 94.7°, and yaw 44.2°.

The crew attempted unsuccessfully to acquire on the HGA. The ground passed HGA angles of pitch $+5^\circ$ and yaw $+237^\circ$ for this attitude. On this attempt, the crew stated that the antenna would drive off in HGA yaw from $+270^\circ$ to 0°, and in HGA pitch from $+6^\circ$ to $+90^\circ$. The condition was true for both primary and secondary HGA servo electronics, and for both Auto and Reacq track modes. The crew confirmed all HGA circuit breakers were closed. The onboard HGA angle readout meters were checked for a possible readout error, but the readouts were correct. The antenna would not lock up; i.e., switch from wide to narrow beam width. A maneuver to the PTC attitude was prescribed, and as the maneuver was initiated, the HGA locked up in Reacq and Narrow beamwidth, and worked correctly until the CSM power problem occurred. No definite reason for the apparent failure has been concluded. Further investigation of this item will continue.

4. CSM/LM Low Power Communications Configuration

To comply with the need to conserve all possible electrical power on both vehicles after the power anomaly, the normal configuration of the communications system on the CSM and LM was changed in the following way and with the following ampere saving:

a. The following CSM communications systems were powered down as soon as possible after the oxygen anomaly. The CSM remained in this communication configuration until power was turned off at 58:00:00.

   (1) DSE off (1.6 amps).

   (2) HGA off (1.9 amps).

   (3) VHF-AM A and B off (.4 amps).

   (4) S-Band Power Amplifier to off when LM comm active (4.0 amps).

   (5) Operated CSM in LBR and Down Voice Backup after the Power Amplifier turned off in order to maintain voice and data under the reduced power situation.

b. The LM was operated in the following low power and high power modes during the remainder of the mission:

	Low Power Mode	High Power Mode
(1) Power Amplifiers (2.57 amps)	OFF	ON
(2) Voice (0 amps)	DOWN VOICE B/U	NORMAL VOICE

	Low Power Mode	High Power Mode
(3) Biomed (0 amps)	ON/OFF	ON
(4) Prim S-Band Transmitter/ Receiver (1.29 amps)	ON	ON
(5) PCM (0.39 amps)	LBR	HBR
(6) Ranging (0 amps)	OFF	ON
(7) DUA (.05 amps)	ON AS REQUIRED	ON AS REQUIRED
(8) PMP (.15 amps)	ON	ON

The following LM equipment was not powered up during the mission:

(1) S-Band Antenna Heaters

(2) CDR Audio Panel

(3) Onboard Communications Displays

(4) Steerable Antenna

(5) Secondary Transmitter Receiver

(6) Tape Recorder (and all AC)

(7) VHF

The high power mode was utilized only when HBR data was required, and when better voice was required for extended voice conversations. The high power mode was initiated for the remainder of LM lifetime commencing at 132:00:00 GET, because sufficient LM power and cooling remained.

c. Changes in the nominal Command Module communications system configuration for reentry were as follows:

(1) DSE Off (1.6 amps)

(2) VHF off (.21 amps)

(3) S-Band Primary Power Amplifier* (high 4.0 amps) (Low 1.5 amps)
*It was cycled between High, Low, and Off as required during the phase.

5. SIVB IU/LM Downlink Interference

The first procedure separated the IU and LM downlinks by offsetting the IU frequency a minus 144 KHZ from center carrier frequency, and the LM frequency a plus 144 KHZ from center frequency. This worked well, with the exception that RTCC "Data Select" reported that the LM tracking data was unusable because of the frequency offset.

The second procedure attempted to offset the IU downlink from its center frequency, and then maintain the LM at center frequency. This was accomplished by turning the LM transponder off (for 5 minutes) and readjusting the IU downlink to 57 KHZ off center frequency. After the IU frequency was offset, the LM transponder was turned back on and the MSFN locked up the LM downlink at center frequency. RTCC reported that the LM tracking data was usable at this time. It was later discovered that the RTCC personnel could have manually entered inputs to the computer to correct for the frequency offset.

Since the RTCC personnel have the capability to correct for the frequency offset, then the first procedure discussed above (item No. 5) can be utilized. However, it is recommended that the Booster personnel investigate the possibility of maintaining the capability to command off the IU transponder at any time prior to SIVB impact with the moon.

6. Entry Communications Anomaly

At 140:16:00 GET, the CSM communications system was activated. The power amplifier low power mode was commanded at 140:18:30 GET and HSK locked on the low bit rate telemetry and normal voice. At 140:20:10 GET, the varying of signal strength readings from -121 to -138 dbm at HSK initially led us to believe that the power amplifier was not on. Also, at this time the CSM current appeared low as compared to predicted loads with the power amplifier in the high power mode. The crew selected Power Amp Low and verified the "talk back" gray which was normal for the power amplifier operating in the high or low power modes. The LM antenna look angle display (LAD) indicated the HSK to LM look angle to be directly on the LM minus X axis. CSM antenna patterns in the LM/CSM docked configuration indicated antenna gains to be from -12 to -18 db below normal (reference 0 db omni) at this attitude. Power amplifier gains are +13 db and +19 db respectively for low and high power modes. Solid low bit rate telemetry and voice were maintained from 140:27:13 GET until 140:55:20 GET, at which time HBR telemetry was obtained with a -109 dbm downlink signal strength at HSK. This signal strength was normal for a 0 db omni and the power amplifier in the high power mode. Therefore, the communications problem discussed above was the result of LM being in a position between the CM and the ground station.

7. LM Look Angle Display Deficiency

The LM Look Angle Display (MSK 1475) did not operate according to requirements submitted prior to Apollo 11. The error is that the display does not operate when low bit rate telemetry is being received. Since the majority of the mission was LM active with LBR data, the communications operation was compromised. This error was discovered during simulations but rather than cause major RTCC reprogramming, the error was accepted for this mission.

However, the LM Look Angle Display must be programmed to operate in LBR data prior to the Apollo 14 mission.

8. RTCC Interface Deficiency

Manual (MED) inputs to the CLAD and LAD displays must be made by "Computer Dynamics" in the RTCC area. The Comm SSR personnel must coordinate these MED inputs with "Computer Dynamics" on the RTCC Dynamics loop. However, the FIDO Officer also coordinates with "Computer Dynamics" on this loop. There have been instances when it was very difficult to coordinate these inputs with "Computer Dynamics."

This problem will be investigated to determine if alternate personnel in the RTCC area can be utilized for communications display coordination, and if an alternate loop can be utilized for this coordination.

9. Simulations

Three areas for improvement in the simulations of communication systems and procedures are as follows:

a. A number of attempted communications failures have been incorrectly simulated such as an attempt to fail the entire USB downlink but failing to inhibit the crews downlink voice. These mistakes provide INCO negative training in resolving communications anomalies as well as causing the Flight Director to lose some confidence in INCO.

b. The wide spacing of simulations has apparently wasted more time than it has saved. So much time elapsed between each simulation that many hours were required to prepare for each one. Additional time was wasted in preparing for an April mission by simulating with data for a March mission.

c. INCO's commands, when executed, apparently require some real time monitoring via high speed printer to be properly received by the spacecraft; i.e., CMS, LMS, or math model. It has become necessary to execute commands an unreasonably large number of times to effect the proper spacecraft response.

10. Recommendations

a. MILA TV During Rev 1

Do not attempt TV until after TLI.

b. Madrid Uplink Anomaly

INCO will recommend a Network Operations Directive (NOD) procedure which advises the MSFN site to delay dropping the uplink subcarriers if two-way lock is lost during PTC omni switching.

c. High Gain Antenna Anomaly

No recommendation at this time.

d. CSM/LM Low Power Communications Configuration

No recommendation.

e. SIVB IU/LM Downlink Interface

Since the RTCC personnel have the capability to correct for the frequency offset, then the first procedure discussed above (Item No. 5) can be utilized. However, it is recommended that the Booster personnel investigate the possibility of maintaining the capability to command off the IU transponder at any time prior to SIVB impact with the moon.

f. Entry Communications Anomaly

No recommendations.

g. LM Look Angle Display Deficiency

It is recommended that the RTCC be programmed so that this display will operate when LM LBR data is being received.

h. RTCC Interface Deficiency

INCO will make an investigation to determine if alternate personnel in the RTCC area can be utilized for communications display coordination, and if an alternate loop can be utilized for this coordination.

i. Simulations

INCO will assist simulations in resolving errors in the proper simulation of communications systems anomalies. If a communications anomaly is incorrectly simulated, INCO recommends the anomaly be removed immediately, rather than continue throughout the simulation with unacceptable communications.

It is recommended that simulation commence with trajectory data for the mission to be flown, and continue with a frequency to provide and maintain a reasonable mission readiness posture.

It is recommended that simulations personnel better familiarize themselves with all command functions, and more closely monitor all commanding during simulations.

APPENDIX J

Procedures Officer (Procedures)

APPENDIX J

PROCEDURES OFFICER (PROCEDURES)

J. A. Lazzaro

E. W. Thompson

J. R. Fucci

1. FLIGHT CONTROLLERS OPERATIONS HANDBOOK

a. The current FCOH for Apollo 13 was the basic document dated September 10, 1969, through Revision C dated April 1, 1970. During Apollo 13, the FCOH procedurally worked very well.

b. Just prior to the mission, a request was made by the CSM Branch to use a presently existing capability of the PCM/GS DACS to suppress bits and increase the granularity of the strip chart recorder pen deflections.

Informal talks with PCM/GS personnel verified the capability of the DACS to perform the desired functions, and a memo was drafted from FCD to FSD formally requesting their support.

Procedures were not available to accomplish real-time requests for bit suppression and the following interim approach was taken.

(1.) The data user provided the Procedures Officer bit suppression information.

(2.) The Procedures Officer relayed the information to CCATS TM who had only the backup PCM/GS configured for bit suppression data processing. The prime PCM/GS remained in its original configuration.

(3.) The Procedures Officer verified the DACS were returned to the normal configuration subsequent to HSD sub-format changes.

2. SIMULATIONS

The following is an example of a communication failure which was simulated incorrectly. During an ascent simulation, the CSM 1.024 subcarrier was lost, resulting in the loss of all telemetry from the CSM. During this time MCC still had two-way voice with the CSM. The procedure for restoring data was exercised, and data was finally restored when the auxiliary PMP power supply was selected and the FM transmitter was activated. However, in checking with the MSFN site, it was reported that the data was being received on the PM downlink. This did not make any sense, and eventually "SIM NETWORK" called to report that an attempt had been made to simulate a failed antenna and although the CSM data was inhibited, the CSM voice was inadvertently let through.

3. ISP

Preliminary copies of the Instrumentation Support Plan (ISP) were distributed to Flight Controllers prior to the start of Apollo 13 simulations. Included was the Communications Plan for each phase of the mission from prelaunch to entry. Simulations provided the information necessary to update and correct station configurations, uplink and downlink communications modes, Data Storage Equipment (DSE) dump requirements, and TV support requirements. The final issue of the Instrument Support Plan was distributed approximately three weeks prior to flight.

The Instrumentation Support Plan was followed, until it became necessary to change site configurations based on the changes to the Flight Plan, due to the spacecraft oxygen anomaly. This occurred approximately 57:58:00 into the flight. Subsequent site configurations were handled in real time via SCM's and were coordinated by "PROCEDURES", "TRACK", and "TIC".

4. CHRONOLOGICAL LISTING OF SIGNIFICANT PROBLEMS

TIME: T -00:18:00

PROBLEM: Building 45 reported all video lines had been lost. The problem was reported to NETWORK and service was returned momentarily. The trouble was attributed to a blown circuit breaker. After a reset was accomplished, no further losses were experienced.

TIME: 00:20:00 GET

PROBLEM: The next station contact table, MSK1503, was noted to be displaying keyhole information, reflecting a 15° keyhole at 30 foot sites. Site modifications have reduced this figure to approximately $6\frac{1}{2}^{\circ}$.

TIME: 09:43:30 GET

PROBLEM: A query was made by the "NETWORK CONTROLLER" to "PROCEDURES", as to a requirement levied by "GUIDANCE", to recover TLI data by rerouting the ARIA aircraft to a nearby site for transfer and subsequent playback.

RESOLUTION: "FLIGHT" determined that the TLI data was not required on such a priority basis and the request was deleted.

TIME: 10:30:00 GET

PROBLEM: An on-site problem at HSK caused command computer faulting on several occasions prelaunch and during mission support.

RESOLUTION: Following a nominal handover from GDS to HSK at 11 hours GET, GDS was maintained as the backup site vice GWM until just prior to GDS's LOS at approximately 13:30:00 GET. This proved to be a sound decision, because a subsequent fault of the command computer at HSK, at 11:56:00, resulted in a timely and coordinated handover to GDS for command support.

TIME: 17:00:00 GET

PROBLEM: In preparing for an early site handover, it was noted that existing documentation did not define the necessary coordination efforts for determining the necessity of the handover.

TIME: 19:36:00 GET

PROBLEM: While analog chart recorders are being recalibrated, all PCM ground station data is inhibited for approximately 20 minutes. For Apollo 13 all chart recorders, events, and meters were affected during this calibration.

TIME: 29:00:00 GET

PROBLEM: It was necessary to run an additional delog request for the same data in order to provide a second copy to the Systems Engineers.

TIME: 35:20:00 GET

PROBLEM: An additional copy of a format 30 playback was requested by "GNC".

TIME: 48:12:00 GET

PROBLEM: The Procedures Officer could be heard on FD and/or GOSS CONF loops in Building 45.

RESOLUTION: The problem was relayed to the Communications Controller, his trouble shooting revealed that a lead on a relay card for the AFD Conf Loop was pinched under a mounting screw, and a grounded circuit was causing cross talk on the FD loop. The AFD conf loop was brought down for maintenance, for approximately an hour, while the card was replaced.

TIME: 51:39:00 GET

PROBLEM: Data recorded on magnetic tapes at the remote sites were being shipped back to MCC earlier than the Flight Controllers had anticipated. Prior to Apollo 12 and 13 missions, the Network Operations Directives and its supplements were circulated through the FCD branches for review and comment. For both missions, the documents reflected a 24-hour return time for most magnetic tape data with a few exceptions; e.g., 48-hour return of LM tapes from LOI through TEI. No comments were made to extend the period of time that data would be retained on site, and therefore, the documents were printed reflecting the 24 hour criteria.

TIME: 56:25:00 GET

PROBLEM: Spacecraft problems indicated a possible deviation from the normal Instrumentation Support Plan in order to provide support for both the CSM and LM in the area of voice, command, and telemetry.

RESOLUTION: "PROCEDURES" coordinated with "TRACK" and "NETWORK" to work on a site configuration if it became necessary for the crew to ingress the LM and power up the LM systems. "TIC" was contacted to coordinate the telemetry formats necessary to provide support for both vehicles. LM "power up" occurred at approximately 57:58:00 GET and the network provided the necessary support.

TIME: 56:30:00 GET

PROBLEM: Trends were indicating that it may be necessary to power down S/C systems in order to save power and consummables.

RESOLUTION: When it became evident that the crew would power down spacecraft systems, "PROCEDURES" provided to "NETWORK" the requirement to call up the Parks 210' antenna in order to provide the support necessary to maintain telemetry and communications in a "power down" configuration. The Parks 210' antenna provided full support within 24 hours and continued its support throughout the mission.

5. RECOMMENDATIONS

a. Flight Controllers Operations Handbook

Some of the FCOH procedures to be modified for Apollo 14 and subsequent missions are as follows:

1. Addition of a procedure for approval of the use of electrically powered equipment in the MCC, such as tape recorders, typewriters, etc.

2. Establish a procedure for submitting real-time call-ups or changes to the Universal Plots (rubber plots).

3. Change a procedure to request delogs from Computer Supervisor vice Computer TM. This will afford a more efficient control of the RTCC, and will expedite the return of data to the Flight Controllers. D/TV channels numbers for the delog are no longer needed and this requirement will be deleted.

4. Add an explanation of the numbers on the display request PBI's for inclusion into SOP 2.13 (channel attach or MSK display request failure).

5. Develop an SOP which will provide instructions and the method used to expand the appropriate wired DAC cards.

6. Add to an existing SOP, the procedures necessary to coordinate site handovers.

7. Addition of a procedure to perform analog strip chart recorder calibrations.

b. Simulations

It is understandable that a mistake can be made, but the mistake should be corrected as soon as possible so the simulation can continue without providing negative training. In the case sited in the above simulations section (section 2), the data should have been restored immediately, and the simulated failure attempted at a later time during the simulation.

Another point to be made is that malfunctions procedures are utilized according to what failure exist. In other words, a different procedure may be utilized for restoring data, as opposed to restoring of both voice and data. Therefore, the failures should be planned very carefully so the appropriate procedures can be exercised.

The INCO is still not able to exercise his command functions adequately during the simulations. The majority of the problems seem to be attributed to a lack of monitoring of the command sequences by the simulation personnel. The simulations personnel must become familiar with the spacecraft functions that are accomplished as a result of sending each command; i.e., Salvo II, USB Mode Reset, etc. This is the only way that commanding during simulations can be made similiar to real-time missions commanding, and therefore, provide positive training.

One of the major problems during simulations is the simulation of spacecraft loss of voice, and data, due to low signal strengths. It is understood at this time that the simulations personnel have no way of varying signal strength. Therefore, the data and voice must be cut off when a certain signal strength is reached. Under these circumstances, data and voice are very good at one instance, and completely gone the next. When this happens, there is very little the INCO and PROCEDURES OFFICER can do to solve the problem since MCC cannot talk to the crew at all, and usually has lost command capability to the spacecraft. Since this is not representative of the way things happen during a mission, the simulations personnel should at least simulate the varying signal strengths, and impending loss of voice, and data, by switching the data off and on several times, before cutting it off entirely. This at least gives the INCO and PROCEDURES OFFICER time to do such things as recommending of a new antenna, commanding of "LBR", commanding of "DN VOICE BU", etc.

c. <u>Chronological Listings Of Significant Problems</u>

Reference the above listing of problems

(1). TIME: 00:20:00 GET

RECOMMENDATION: Update the display to include the current keyhole data.

(2). TIME: 17:00:00 GET

RECOMMENDATION: A procedure will be written defining a single point of contact for all site handovers. This procedure will prevent "Data Select" from possibly losing continuity in tracking data, and interference with "INCO's" and "GUIDANCE's" commanding.

(3) TIME: 19:36:00 GET

RECOMMENDATION: It is understood that for Apollo 14 and subsequent missions, that the capability will exist to calibrate the chart recorders individually. This possible flexibility will have to be investigated. An FCOH procedure will be written defining how these calibrations will be accomplished.

(4) TIME: 29:00:00 GET

RECOMMENDATION: Delog requests forms were modified in real-time to include a query to the originator of the request as to the number of copies he needed.

(5) TIME: 35:20:00 GET

RECOMMENDATION: Through proper coordination with TIC and HOU TM, subsequent Format 30 requests provided to the Systems Engineers, an additional copy of the data, by utilizing the chart recorder in the Houston TM area.

(6) TIME: 51:39:00

RECOMMENDATION: It is recommended that for future missions the Flight Controllers review the NOD and its supplements to insure data is retained on site an adequate length of time to meet playback requirements. During Apollo 13 an ISI was transmitted to the remote sites instructing them to retain all data for 72 hours. As no playbacks were required from the sites post-mission, all data was shipped at splashdown.

APPENDIX K

Flight Activities Officer (FAO)

Appendix K

Apollo 13

Flight Activities Officer

Post-Flight Report

Signed: S. H. Gardner

S. H. Gardner

C. L. Stough

C. L. Stough

for S. H. Gardner

T. R. Lindsey

E. B. Pippert, Jr.

E. B. Pippert

Apollo 13
Flight Activities Officer
Post-Flight Report

0:00 - 6:00 (Gardner)

All activities through TLI followed the flight plan. Over CRO at 2:25 the crew reported an O_2 High Flow light and the O_2 Flow gage pegged at 2:20. This is a nominal occurrence with the Waste Stowage Vent valve open. A note will be added to future flight plans and checklists so the crew can expect the light.

While performing CM/LM Pressure Equilization, the crew did not reopen the Waste Stowage Vent valve. When asked, they replied that they preferred to wait until the completion of the SIVB Evasive Maneuver to open the valve. The FAO and EECOM rearranged the purge schedule to allow the nominal 8 hour purge.

After LM Ejection, the crew wanted to delay the SIVB yaw maneuver until they had maneuvered to see the SIVB. This was not as planned and the SIVB maneuvers were delayed. There was no real impact on the flight plan.

The P23 at 6:00 started on time. Flight Plan Support had checked each star and the attitudes in the flight plan were correct. G&C reported that the RCS was ≈23 lbs. above nominal so the crew was allowed to mark on all five stars.

During this shift, copies of the flight plan deletions were passed to the Flight Director, Mission Director, and CAPCOM.

06:00 - 14:00 (Lindsey)

The P23 was completed in 44 minutes as scheduled in the flight plan. Attitude deviations from the nominal were 0.5° or less. RCS consumption was nominal (≈23 lbs.).

Earth weather photography was started at 7:17:47, prior to establishing PTC. PTC was started at 7:30; however, immediate difficulties were encountered and PTC was stopped then reestablished at 8:32. The difficulties with the first PTC were partially a result of an apparent misunderstanding over an update furnished the crew. They were asked to disable quads A and B for PTC and to use .02999 in the DAP for rate during spin-up. In the future, the update should be clearly stated to disable quads "X" and "Y" for rate damping and the crew checklist should contain an entry to use .03750 in the DAP to establish at 0.3°/sec rate.

At 9:24 an update was furnished the crew to reset CMC bits which would prevent a CDU fail notification. The procedure was required as a result of doing a V37E 16 seconds after the optics switch was set to zero during P23.

The eleventh and last frame of Earth Weather photography was taken at 11:15.

14:00 - 22:00 (Stough)

Additional questions were generated by Marshall Space Flight Center for the launch vehicle debriefing at 25:00.

22:00 - 30:00 (Gardner)

The new launch vehicle debriefing questions were read to the crew with the flight plan update so the crew would have time to think about their answers. The crew was unable to provide a radiation reading per the post-sleep checklist. They had left their PRD's in their suits when they packed the suits away. The CMP wanted to perform a donning and fit check with his suit and agreed to remove his PRD and supply the reading then.

As the updated estimates of the SIVB impact were available, the FAO plotted them on a map to determine the trend and to try to obtain an early idea of where the photos might fit in the timeline. Also, S&AD and the MSE were asked to list the priorities of activities that might interfere with SIVB impact photos.

There were some discussions with the scientists on comet Bennett photos. Flight Plan Support obtained information on the comet's position and calculated a PTC roll angle and shaft and trunion angles for the photos.

During the shift, a meeting was held to discuss the list of flight plan deletions. The list came through the meeting unchanged. A CSM Solo Book and the flight plan bootstrap pages were marked with the changes. Work was also started on a flight plan to enter the LM at 55:00 GET to check the SHe pressure.

30:00 - 38:00 (Lindsey)

MCC-2 events were nominal with the TV transmission continued to 31:01. The P23 following the midcourse was accomplished without difficulty. Immediately following the P23, the spacecraft was maneuvered to PTC pitch and yaw and a roll angle compatible with pointing the optics at comet Bennett. The crew reported that sun shafting into the optics was so bad they could not see anything. Data previously generated by Flight Plan Support indicated there was no attitude, outside gimble lock, where the sun was not a potential problem. The decision was made to postpone further attempts to photograph the comet until TEC.

planned orbital activities. This type of activity ceased when the reactants were shut off to fuel cell 3 at 56:56 and fuel cell 1 at 57:17. At 57:37 the crew was instructed to proceed into the LM and power up per checklist ACT 1 (step 3), ACT II (omit step 1), ACT 12, ACT 13 (step 1), Demand Regs to cabin, ACT 25 (steps 1, 2, & 3), and ACT 37. By 58:40 the CSM was completely powered down and the LM was in control using PGNS pulse.

Contingency activation procedures for the 2-hour prep docked DPS burn were begun at 60:30. The burn was scheduled for and accomplished at 61:30 under PGNS control. At 62:49 the spacecraft was maneuvered to PTC attitude (LM + X axis pointed south) and a modified PTC procedure implemented (change LM pilot yaw 90° every hour). A proposed work/rest cycle through 102 hours was passed to the crew.

<u>62:00 - 73:00</u> (Stough)

A procedure for improving the O_2 circulation in the CSM using the CDR's LM hoses was passed to the crew.

The type of IMU alignment for the PC+2 burn was discussed. It was decided to perform a sun check to verify the present alignment and if the sun check failed then to perform an alignment using the earth and the sun. It was decided that regardless of how the sun check went to perform a star check when the spacecraft went into the moon's shadow.

<u>73:00 - 77:00</u> (Pippert)

The P52 sun check procedure was passed to the crew and performed successfully. The sun was about one diameter from the center of the AOT. The good alignment criteria was passed. A procedure to widen the LM deadband to 5° to reduce RCS consumption was read to the crew.

The DPS burn procedures using the PGNS was read to the crew at 75:00. The procedures were updated to include closing the DES HE REGS at 10 seconds prior to predicted engine cutoff.

<u>77:00 - 85:00</u> (Gardner)

Data were gathered from both the Cape and Houston simulators on LM PGNS PTC. The runs made were to verify MIT's procedure using an auto maneuver to PTC attitude, 20 to 25 pounds of RCS were required. The simulator instructors slightly revised the procedure to base the rate damping on rates, not time. Also, we found that on the simulator it was cheaper to set up PTC by using PGNS Pulse instead of an auto maneuver to attitude. The auto maneuver required a much longer time to dampen rates at PTC attitude, wasting time and fuel.

Because of the plans to enter the LM early, the TV was rescheduled. Discussions with NETWORK resulted in rescheduling the longlines for the earlier TV. At 32:48 a flight plan update was passed to the crew deleting the small segments of the solo phase and bootstrap phase to relieve the tight timeline.

At 33:20 PTC (established less than an hour earlier) became unstable and had to be reestablished. No one seemed to know any reason for the unstable condition.

<u>38:00 - 46:00</u> (Stough)

The predicted SIVB impact coordinates had stabilized at approximately $2^{o}10'$S, $28^{o}50'$W. After looking at the possible revolutions in which topo photographs of the impact area could be performed, the choices were narrowed to either Rev 27 or 28.

The MCC-3 burn was scrubbed and a final plan for entering the LM 3 hours early was completed. This plan allowed the crew to check the SHe pressure when they first entered the LM and also allowed additional time, if required, for later checks without affecting the crews rest period starting at 61:00.

<u>46:00 - 55:00</u> (Pippert)

The flight plan changes for entering the LM early were read to the crew at 47:45.

A procedure to determine the optimum roll angle for photographing the comet Bennett was read to the crew. The attempt failed because the PTC coning angle had become too large and the comet was always occulted by the LM. Several attempts were made to determine a time when the attitude would be close to 90^{o} pitch and 0^{o} yaw but with no success.

The detailed procedural changes to the checklist for the SHe checkout were read to the crew at 50:26. The crew asked if they could enter the LM earlier than planned so the checkout would be complete before the TV show. The crew entered the LM at 54:25. The SHe pressure was nominal and no further checks were required.

<u>55:00 - 62:00</u> (Lindsey)

TV was transmitted during LM familiarization from 55:17 to 55:47. At 55:55:04 the crew reported an AC Main B undervolt condition. They later reported hearing a loud bang about the time of the undervolt. At 56:09 the crew reported observing a venting condition visible out window one. By 56:23 the crew had been told to perform a partial emergency power down and open-circuit fuel cells 1 and 3. By this time we were already down 70 pounds on RCS and Flight Plan Support had begun looking at reducing

After the successful PC+2 burn, the procedures were coordinated with CONTROL and then read to the crew. It required much more time for the crew to set up PTC than it required in the simulator. Pulse mode did not work. We later guessed that pulse did not work because it could not overcome the CSM venting and the LM sublimator venting. Cross-coupling in all three axes made it very difficult for the crew to maneuver to attitude. After PTC was established, the crew powered down the LM. The FAO and INCO provided a procedure using visual and audible cues to aid the crew with omni switching.

PTC did not stay stable long. We requested that the crew call out the LPD angles when the earth and the moon passed through the CDR's window. This was done and it was possible to get a rough idea of how PTC was doing by plotting the LPD angles.

The FAO worked with the Guidance Officer, CONTROL and the Flight Dynamics Officer to provide a rough no comm procedure for a midcourse. The procedure was read to the crew. Work was also started on the detailed procedures for MCC-5.

<u>85:00 - 93:00</u> (Lindsey)

At 86:12, the FAO requested SPAN to coordinate stowage transfer lists for LM jettison. We continued to track PTC divergence by plotting the crew's report on the LPD angles of the earth and moon. Half-cone angles of up to 40° were reported to FLIGHT. At 90:00, the FAO set up a meeting between FCSD and FOD personnel to work out AGS PTC procedures.

At 91:00, a rough draft of the proposed LM alignment procedure for the next midcourse was passed to Mr. North for simulator development. At 91:40, the draft AGS PTC procedure was also given to Mr. North for simulator verification. Mr. O'Neill and Mr. Holloway of the Flight Planning Branch were requested to attend meetings to work out MCC and entry procedures.

93:00 - 102:00 (Stough)

The crew asked if it was possible to use the PLSS condensate bags for urine collection in zero-g since the bags were designed for 1/6-g water collection. Confirmation that the bag could be used was received from the subcontractor. A procedure was passed to the crew that avoided leakage from the bag.

A CO_2 C&W occurred and a procedure for using the CSM LiOH cannisters for CO_2 removal was read to the crew.

The crew was briefed on delaying MCC-5 to a time as close as possible to the predicted SHe vent. This was to allow PTC to be restarted as soon as the SHe had vented and to avoid possible PTC restarts due to the vent.

The crew received a procedure for checking Main Bus B. Approximately 10 minutes of CSM telemetry was downlinked while the CSM was powered up. Main Bus B was good.

At 99:50, there was a LM battery malfunction light. A procedure was read to the crew to check the malfunction. The battery was good; a sensor had failed and caused the malfunction light.

102:00 - 110:00 (Gardner)

A copy of the preliminary entry procedures was received and reviewed. With GUIDO, we verified that the sun would be at the top of the detent two field of view at the MCC-5.

A work/rest cycle was planned and read to the crew after MCC-5. After the O_2 incident, it was very hard to determine who was sleeping and who was not. Only one crewman generally was on the loop and CDR would always seem to be awake. The work/rest cycles were devised to put the crewman with the longest awake time to bed. We intended also to have the LMP or the CDR awake at all times. It is impossible to accurately determine who was awake when.

The FAO plotted the PTC after MCC-5 using the crew call-outs of the LPD angles for the earth and the moon. The AGS PTC procedure was used to establish PTC and the PTC appeared to be fairly stable until the SHe burst disk blew. The SHe vent caused the PTC to reverse in LM yaw and caused the rate to increase. The FAO requested SPAN to determine any restrictions on PTC rates. They replied that, structurally, we were constrained to 35°/second. There were no thermal constraints due to rate.

A meeting was held at 2 a.m. with SPAN, Bldg. 45 people, CONTROL, G&C, EECOM and backup crewmembers to discuss the proposed entry timeline. Mr. Lindsey attended the meeting.

110:00 - 116:00 (Lindsey)

As a result of the entry meeting and later discussions of this meeting with the Flight Director, MCC-7 was moved back 1 hour from EI-4 to EI-5 hours. GUIDO was requested to furnish state vectors, REFSMMAT's, etc., for the simulator entry runs scheduled that morning.

At 110:53, LM to CSM power transfer and CSM battery charge procedures were read to the crew. At 111:30, the FAO furnished the RETRO Officer preliminary entry stowage data.

116:00 - 124:00 (Stough)

The crew reported at 118:19 that the CSM was too cold to sleep in and that the CMP was resting in the LM.

The crew was briefed on the plan for entry. The ground recommended that the crew perform LM jettison unsuited to avoid consuming additional CM power. The entry stowage list for the CM and LM was updated.

The crew asked if it was possible to stow the black and white TV in B6 location rather than A7. The stowage people reported that this camera was too large for B6.

A procedure for powering the CM from the LM for another look at CM telemetry was read to the crew. The CM was powered from the LM for approximately 10 minutes and TM received. After the telemetry data were received, the Battery A recharge was restarted.

124:00 - 131:00 (Pippert)

Procedures for taking photos of the SM were read to the crew. The crew reported at 125:45 that both vehicles had been stowed according to the updated stowage list except for two Hasselblads, the probe and the drogue. They reported that the CM windows were coated with ice and they felt that they would be unable to use the windows for photography of the SM.

The CSM and LM entry procedures were read to the crew from approximately 126:15 to 129:30.

131:00 - 138:00 (Gardner)

Copies of the combined CSM entry procedures and LM procedures were passed out and the Flight Director reviewed them with the entire shift. Recovery requested that the S-Band Power Amplifier be on after blackout until the CM was on the mains. The FAO, EECOM and INCO wrote the change to the procedures and the change was read to the crew. Stars and shaft and trunion angles were checked for the SM separation attitude and the data given to FLIGHT and CAPCOM.

The crew was cold and could not sleep. Several ideas were discussed on how to heat up the LM cabin. Since there was a 100 percent margin on all consumables except RCS, the crew was told to power up the LM. At 134:30, a LM alignment was performed, using the moon and sun. MCC-7 was burned using AGS control with PGNS in P41 and follow-up. The SM separation occurred at 138:02 and the LM/CM was maneuvered to an attitude to photograph the SM.

138:00 - 143:00 (Lindsey)

CM powerup was begun at 140:09:55. Required uplinks were delayed to 140:40 because of difficulty maintaining lock with the spacecraft.

After starting P52, the crew reported they were unable to recognize the first star called because of many particles surrounding the spacecraft. CAPCOM recommended using the brightest stars in the field of view per information furnished by Flight Plan Support. The P52 was completed with no further problems.

At 141:09, the crew reported they were at LM jettison attitude and were closing out the LM. The spacecraft was not at the angles copied by the FAO during the air-ground update. By the time the angles were verified with CMS support and then with the Guidance Officer, the LM was already closed out. The trench decided that the actual angles (98° out in roll) were satisfactory. During future missions, the FAO should receive copies of all pads passed to the crew.

The remainder of LM jettison and entry went according to the updated procedures and those chutes sure were beautiful!

General Conclusions

Since this crew and several past crews have reported the O_2 High Flow light and the O_2 flow gauge pegged prior to TLI, the note will be made in the flight plan and the checklist.

With the confusion on the PTC quads resulting from how the quads to be disabled where called to the crew, the quads for PTC should be stated clearly to the crew. The PTC rate will be clearly indicated in the crew's checklist.

To avoid confusion for the FAO on pad data that, to date, the FAO had to copy while the data was read to the crew, the FAO should receive a copy of all pads to enable him to follow the crew procedures and respond quickly to errors the FAO observes.

FLIGHT PLAN

CSM CMP	GET	MSFN	LM CDR	LM LMP
	54:00	MSFN	CLEAR TUNNEL OF CM HATCH INSPECT TUNNEL & DOCKING LATCHES REMOVE PROBE & DROGUE	PTC P 90, Y 0
	:10			
TEMPORARILY STOW PROBE & DROGUE	:20		ACTIVATION CHECKLIST	OPEN LM HATCH RECORD AND REPORT DOCKING TUNNEL INDEX ANGLE (-2.0°) IVT TO LM PTC P 90, Y 0
	54:30		IVT TO LM	ASSIST CDR
	:40			
CM POWER TO LM-OFF	:50			LM POWER-ON PTC P 90, Y 0
	55:00		LM FAMILIARIZATION	LM FAMILIARIZATION

MCC-H

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE

FLIGHT PLANNING BRANCH

FLIGHT PLAN

CSM CMP		LM CDR	LM LMP	MCC-H
CM POWER TO LM-ON	55:00		LM POWER-OFF	
	:10			
QUADS C&D DISABLED		LM FAMILIARIZATION	LM FAMILIARIZATION	
	:20			
	55:30 (TV) (MSFN)			
			IVT TO CSM	
	:40	IVT TO CSM		

CSM

:50	QUADS C&D ENABLE CLOSE LM HATCH	FLIGHT PLAN MNVR TO R 60, P 90, Y 0	
	TERMINATE BATT B CHARGE CMC RESTART LT. MAIN B BUS UNDER VOLT (55:55:20) MAIN A BUS UNDER VOLT (55:58:25)		FIRST INDICATION OF SYSTEM MALFUNCTION
56:00			

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE

FLIGHT PLAN

MCC-H

Time	Station	Activity
56:00	MSFN	CMP: INSTALL CM HATCH LM TUNNEL VENT VALVE - LM/CM ΔP BUS TIE AC-ON OMNI C
:10		FUEL CELL 1 OFF LINE OMNI B
:20		EMERGENCY POWER DOWN TO DELTA OF 10 AMPS INVERTER 1 ON BOTH AC BUSES OMNI C
56:30		BMAG 2 OFF FUEL CELL 3 OFF LINE BATTERY A OFF OXYGEN SURGE TANK ISOLATED
:40		O_2 TANK 1 HEATER & FANS-ON
:50		BMAG 1 OFF OMNI B
57:00		

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FLIGHT PLAN

MCC-H

Time	Station	Activity
57:00	MSFN	FUEL CELL 3 REACTANTS OFF
		OMNI C
		RCS THRUSTER CONFIGURATION VERIFIED
:10		
		REPRESS PACKAGE ISOLATED
:20		FUEL CELL 1 REACTANTS OFF
		INITIALIZE ERASEABLE DUMP - V74
		CHARGE BATTERY A (57:26)
		WASTE WATER DUMP HEATER-OFF
57:30		QUADS A&C SM RCS PROP ISOL VALVES CLOSED
		LM POWER UP (57:36) CM POWER TO LM OFF (57:38)
:40		
:50		BATTERY A-OFF
58:00		

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FLIGHT PLAN

MCC-H

Time	Station	Activity	Notes
58:00	MSFN		
		DOCKED COARSE ALIGN (58:03)	
		V06N20E (CSM)	
:10		V06N20E	
		FINE ALIGN (58:12) POWER DOWN CMC & IMU (CSM) MISSION TIMER ACT	
:20		PRIMARY GLYCOL LOOP ACT	
		FDAI POWER-ON	
		RCS HTRS-ON	
58:30		RCS PRESS	
		DAP LOAD 30120	
		LM IN ATT HOLD	
:40		CSM POWERED DOWN	<u>UPDATE TO LM</u> GYRO TORQUING ⊁'s
		IMU FINE ALIGN	
:50			
59:00			

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FLIGHT PLANNING BRANCH

FLIGHT PLAN

MCC-H

Time	Station	Activity	MCC-H
59:00	MSFN	PQGS, HEATER & EPS DISPLAYS - ALL CIRCUIT BREAKERS OPEN	UPDATE PC+2 DPS ABORT PAD (59:02)
:10		LGC CLOCK ΔT - V55E	
		VERIFY ASCENT FEEDS - CLOSE	
:20			UPLINK TO LM PTC REFSMMAT T EPHEM
59:30			
:40			
:50			
60:00			

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE

FLIGHT PLANNING BRANCH

FLIGHT PLAN

GET	MSFN	CMP / CDR	LMP
60:00	MSFN	DESCENT O_2 (60:02)	
		P30 PAD UPDATE (60:53)	
61:00		DPS PRESS & C/O (61:12)	
		DPS MNVR GET: 61:30	
		POWERDOWN PGNCS	
62:00			
		FLIGHT PLAN UPDATE (62:34)	
		ATT HOLD	
63:00		LM POWER DOWN	REST PERIOD (6.0 HOURS)
		PC+2 P30 MNVR PAD UPDATE (63:05)	
64:00			
65:00		YAW 90° TO NEXT PTC ATT	
66:00			

GET	MSFN	CMP	CDR	LMP
66:00	MSFN	YAW 90° TO NEXT PTC ATT		REST PERIOD (6.0 HOURS)
67:00				
68:00		EAT PERIOD	YAW 90° TO NEXT PTC ATT EAT PERIOD	
69:00				CREW STATUS REPORT
				EAT PERIOD
70:00		REST PERIOD (6.0 HOURS)	REST PERIOD (6.0 HOURS)	
71:00				
		RENDZ RADAR PROCEDURE UPDATE		
72:00				

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FLIGHT PLANNING BRANCH

FLIGHT PLAN

Time		CMP	CDR	LMP
72:00	MSFN	P52 IMU ALIGN		
74:00				AOT SUN CHECK
75:00		2 HR ACT. CONT. CHECKLIST UPDATE		
		P30 PC+2 PAD UPDATE		
76:00		CREW STATUS REPORT		
		EAT PERIOD	EAT PERIOD	MISSION RULE UPDATE (LM BURN)
77:00				AOS/LOS, SR/SS UPDATE AOT STAR CHECK
78:00				

Time		CMP	CDR	LMP
78:00	MSFN	POWER UP LM SYSTEMS P30 EXTERNAL ΔV ALIGN AGS TO PGNCS CSM MNVR ENTRY UPDATE STATE VECTOR UPDATE		S-IVB LUNAR IMPACT
79:00		PC +2 — TIG: 79:27:38.30 BT: 4 MIN 24 SEC ΔV2: 861.5 FT/SEC ULLAGE: 2 JET 10 SEC		
		BURN STATUS REPORT		
80:00		UPDATE POWER DOWN & PTC PROCEDURE		
		CO_2 MASTER ALARM		
81:00		ESTABLISH PGNCS PTC		
		EAT PERIOD	EAT PERIOD	EAT PERIOD
82:00		PGNCS POWER DOWN CREW STATUS REPORT POWER DOWN LM SYSTEMS		
		REST PERIOD (8 HOURS)	REST PERIOD (3 1/2 HRS)	
83:00		PHOTO UPDATE	(TARGETS OF OPP. FOR SM JETTISON)	
84:00				

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FLIGHT PLANNING BRANCH

FLIGHT PLAN

Time	MSFN	CMP	CDR	LMP
84:00	MSFN			
85:00–85:30		REST PERIOD (8 HOURS)	REST PERIOD (3 1/2 HRS)	LM LiOH CANNISTER CHANGE (85:30)
86:00			LM BIOMED OFF COMM CK EAT PERIOD	EAT PERIOD
87:00		LM MCC BURN PROCEDURE UPDATE P30 NO COMM MCC-7 PAD		
89:00				REST PERIOD
90:00				

Time	MSFN	CMP	CDR	LMP
90:00	MSFN	PROCEDURE TO FAB LiOH HOOKUP		
90:30		EAT PERIOD		
91:00		CREW STATUS REPORT		
91:30				REST PERIOD (5 1/2 HRS)
92:00		PROCEDURE UPDATE CM CONFIG	EAT PERIOD	
93:00				EAT PERIOD
93:30		CO_2 MASTER ALARM		
94:00		LiOH CANNISTER CHANGE	REST PERIOD (6.0 HRS)	
95:00		PROCEDURE UPDATE LM POWER TO CM		
95:30		EAT PERIOD		EAT PERIOD
96:00				

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MSC Form 845D (Jan 69) FLIGHT PLANNING BRANCH

FLIGHT PLAN

Time	MSFN	CMP	CDR	LMP
96:00	MSFN		REST PERIOD (6.0 HOURS)	
98:00				BIOMED ON LMP
98:30			CREW STATUS REPORT	
99:00			EAT PERIOD	ADDITIONAL PROCEDURES FOR LM POWER XFER TO CM
99:30		PWR AMP ON FOR HBR LM BATTERY 2 ALARM		
100:00		PASSED UP PROCEDURES FOR LM MCC BURN		
101:30		CSM POWER PROCEDURES FOR TELEMETRY		
102:00		CSM POWER-UP FOR TELEMETRY		

Time	MSFN	CMP	CDR	LMP
102:00	MSFN	CM POWER DOWN EAT PERIOD	EAT PERIOD	EAT PERIOD
104:30		P30 MANEVUER PAD VOICED UP		
104:45		POWER UP LM SYSTEMS		
105:15		MCC-5 — TIG: 105:18:28, BT: 15.0 SEC, ΔV: 7.8 FPS — PGNCS DPS		
106:00		ESTABLISH PTC - AGS POWER DOWN LM SYSTEMS PA-OFF		BURN STATUS REPORT CREW STATUS REPORT
106:00–108:00		REST PERIOD		REST PERIOD

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MSC Form 8450 (Jan 00) FLIGHT PLANNING BRANCH

FLIGHT PLAN

108:00 – 114:00 (MSFN)

Time	CMP	CDR	LMP
109:00	SHe DISK BURST		
110:00	REST PERIOD		REST PERIOD
111:00	VOICE UP PROCEDURE FOR POWERING CM FROM LM		
	PROCEDURE VOICED UP FOR CHARGING BAT A PROCEDURE VOICED UP FOR REMOVING BAT A PROCEDURE VOICED UP FOR CM POWER REMOVAL SELECT HBR TRANSFER LM PWR TO CSM		
112:00	CHARGE BATT A LiOH CANNISTER CHANGE		
113:00	PROCEDURE VOICED UP FOR LiOH CANNISTER UTILIZATION	REST PERIOD (2 1/2 HRS)	LiOH CANNISTER ADDED LiOH CANNISTER ADDED
114:00			

114:00 – 120:00 (MSFN)

Time	CMP	CDR	LMP
115:00		REST PERIOD (2 1/2 HRS)	
116:00	REST PERIOD (IN LM)		REST PERIOD
117:00			
118:00			
119:00			
120:00			

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MSC Form 8450 (Jan 00) FLIGHT PLANNING BRANCH

FLIGHT PLAN

Time		CMP	CDR	LMP
120:00	MSFN	PA-ON		
		VOICED UP PROCEDURES FOR MCC-7, SM SEP, & LM JETTISON		
121:00		PA-OFF		
		VOICED UP TRANSFER AND STOWAGE LIST		
122:00		PCM-HBR; PA-ON		
		PCM-LBR	REVISED CM POWER UP PROCEDURES	
123:00		TERMINATE BATTERY CHARGE-BATT A		
		CSM POWER UP (TM) - CSM POWER DOWN		
		BATTERY CHARGE BATTERY A		
124:00			REST PERIOD	
		VOICED UP PHOTO DATA FOR POST SM SEP PHOTOGRAPHY		
125:00		REST PERIOD		
126:00		VOICED UP PROCEDURE FOR BAT B CHARGE		

Time		CMP	CDR	LMP
126:00	MSFN	TERMINATE BATT A CHG		
		START BATT B CHG		
		READOUT BATT B VOLTS & CHARGE AMPS		
		ENTRY PROCEDURES UPDATE TO CREW		
127:00				REST PERIOD
128:00		TERMINATE BATT B CHG		
		SW TO ASCENT H2O		
		DOCKING TUNNEL INDEX -2.1°		
129:00				ENTRY PROCEDURES UPDATE
		POWER AMPS-OFF		
130:00		REST PERIOD	REST PERIOD	
131:00				REST PERIOD
132:00				

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MSC Form 845D (Jan 69)   FLIGHT PLANNING BRANCH

FLIGHT PLAN

CMP | CDR | LMP

132:00

133:00

POWER UP LM SYSTEMS

START MISSION TIMER

134:00

AGS ACTIVATION & BODY ALIGN

MCC-H UPLINK LM S.V. & REFSMMATS, V66 (SUN-MOON)

P62 - LM IMU REALIGN, OPT 1

135:00

LM E-MEMORY DUMP

MSFN

136:00

MCC UPLINK: MCC-7 TARGET LOAD
MCC UPDATE: MCC-7 MNVR PAD
CM/SM SEP PAD
LM JETT PAD
P30 - TARGET MCC-7
P41-RCS THRUSTING
COMPLETE CM RCS PREHEAT

137:00

MNVR TO BURN ATT
AGS BODY AXIS ALIGN
MCC-7 (EI-5)

TIG: 137:39:48.39
ΔVR: 3.1 FT/SEC
BT: 23 SEC
(4 JET RCS, +X)

MNVR TO SEP ATT

138:00

CMP | CDR | LMP

138:00

CSM HOT FIRE
SM JETTISON 138:02

SM PHOTOGRAPHY & DESCRIPTION

MCC UPDATE: ENTRY PAD
RECOVERY WEATHER REPORT

139:00

140:00

MCC UPDATE: CM COARSE ALIGN θ's

POWER UP CM SYSTEMS
MCC UPLINK S.V., REFSMMATS, ENTRY TGT
CM COARSE ALIGN
CM P52 IMU ALIGN, OPT 1

141:00

LM MNVR TO JETT ATT — LM (FDAI): R 228, P 125, Y 12.4
LM CLOSEOUT
PRESSURIZE TUNNEL
HATCH INTEGRITY CHECK

LM JETTISON 141:29:56

MSFN

142:00

MNVR TO ENTRY ATT: R 0, P 91.3, Y 0
SXT STAR CHECK
MCC UPDATE ENTRY PAD & S.V.
MOON CHECK

EI - 142:40:39

143:00

SPLASHDOWN - 142:54:56

144:00

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MSC Form 845D (Jan 00)   FLIGHT PLANNING BRANCH

APPENDIX L

Aeromedical Officer (Surgeon)

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : FC/Apollo 13 Flight Director

DATE: APR 22 1970

FROM : DD/Chief, Medical Operations Division

In reply refer to:
DD-70-M-68

SUBJECT: Apollo 13 Anomalies

The attached comments on the Apollo 13 anomalies of medical concern are forwarded per your request.

Willard R. Hawkins, M.D.

Enclosure

DD:JFZieglschmid:rch 4-22-70

ANOMALIES OF MEDICAL CONCERN DURING THE APOLLO 13 FLIGHT

From the medical point of view, the first two days of the Apollo 13 flight were completely routine. The biomedical data were excellent in quality, and all physiological parameters were within the expected ranges. Daily crew status reports indicated that the crew was obtaining an adequate amount of sleep and they reported they had not taken any medications. The inflight radiation dosage of 46:44 hours GET was 260 mrads and was exactly as predicted preflight. In addition, the onboard television pictures suggested that the crewmen were healthy and were adapting successfully to the weightless condition.

On April 13, 1970, at 55:54:54 hours GET, a telemetry dropout, 1 second in duration, was observed on the strip chart recorder located in the Life Systems Staff Support Room. Prior to this event, the heart and respiration rates of the crewmen were the following: CDR - heart rate = 68 beats min and respiration rate = 18 breaths/min; CMP - heart rate = 65 beats/min and respiration rate = 15 breaths/min; LMP - heart rate = 72 beats/min and respiration rate = 12 breaths/min.

Immediately after the inflight emergency, each crewman's heart rate increased to well over 100 beats/min. In addition to the crew's verbal comments, this increase in crew heart rates is the only objective medical finding that indicated an inflight emergency. The heart rates were well within normal limits and may be interpreted to signify stress, excitement, increased workload, or any combination of these.

These biomedical strip chart records have proved useful to the accident investigation team in corroborating telemetry data from non-medical sources in establishing the exact time of the accident.

After declaration of the abort mode, there were several deviations from the established procedures and approved flight requirements that caused further anomalies. In some cases these anomalies degraded the level of medical support the Flight Surgeons were able to render the crew during the emergency abort profile. A detailed discussion of each anomaly of medical concern is presented below.

a. Increased concentration of carbon dioxide in the spacecraft atmosphere - The decision to live on the LM ECS raised immediate concern about increased CO_2 levels following the utilization of the two primary and three secondary lithium hydroxide canisters. It was apparent that some means of estimating the life-time of the CO_2 scrubber was necessary. Our immediate step was to increase the limits of CO_2 buildup from 7.6 mm to 15 mm. This was done using the first LM primary canister. The rationale for this decision was as follows: (1) an acute emergency state existed and a new procedure to utilize the CM canisters was needed- how long this would take was not known. (2) The physiological effects of increased carbon dioxide concentration are well-known and readily recognized with proper monitoring; (3) the biomedical data would reflect dangerous concentrations of carbon dioxide and serve as a backup to the onboard pCO_2 sensor which is subject to some error.

This decision to allow the carbon dioxide partial pressure to increase above 7.6 mm Hg under this emergency condition did not involve violation of any aeromedical mission rule. In actuality, the pCO_2 was above 7.6 mm Hg for only a 4-hour period (81:30—85:30 GET). Use of the CM lithium hydroxide canisters within the LM maintained the carbon dioxide partial pressure well below 1 mm Hg for the remainder of the flight.

b. Loss of biomedical data - The CM was completely powered down and this eliminated the simultaneous biomedical monitoring capability. We were limited to 1 ECG from one crewman at a time in the LM. This requires 1.2 watts of power; therefore, it was planned to retain biomedical data during the powered down mode in the LM. This was critical for assessment of the physical condition of the crew and the concentration of CO_2. Even these data were later sacrificed in an attempt to improve the air-to-ground communications. Communication was further compromised by the crew's decision to eliminate the hot microphone by switching the biomed switch to the "on" position. This would normally have given a biomedical parameter to monitor - but the CDR had completely removed his bioharness and sensors.

c. Deletion of Crew Status Reports - The crew status reports were very infrequent and it was difficult to adequately assess the true physiological effects of inadequate sleep, stress of the environment and the emergency situation. At best, we estimated the crew slept the following: CDR - 11 hrs; CMP - 13 hrs; and LMP - 18 hrs. This is very inadequate but certainly not unexpected under the emergency situation.and the extremely reduced cabin temperatures.

No personal radiation dosimeter readouts were transmitted after 46:44 GET. Major solar flare activity classified as a 2B (bright) flare was reported at 81:10 GET. Fortunately no particles impinged upon the LM during this event. Since the shielding properties of the LM are less than the CM, any particulate solar flare event is much more critical during LM occupancy.

On two occasions during the abort phase of the flight, inflight medications were taken by the crew without consultation. On one other occasion, medications were prescribed by the Flight Surgeon but were not taken as directed because the crew did not understand the message as relayed to them.

d. Potable Water Shortage - As soon as the criticality of the quantity of onboard water was established, the Flight Surgeon made a survey of all potentially potable water sources within the CM and LM. In addition to the 13 pounds of survival water in the CSM, there were 16 pounds of PLSS water that could be used by the crew if required. The PLSS water is chemically pure, but not sterile. Nonetheless, it was considered potable under emergency conditions.

On several occasions during the abort flight phase, the crew queried the MCC about the necessity for rationing potable water and using the "excess" for cooling of the spacecraft systems. It was recommended that the crew maintain adequate fluid intake, i.e. 6 pounds per man per day. These recommendations were transmitted to the crew but still they did not drink enough water. The CM potable water was used until depleted at about 125 GET. LM ascent water was then consumed for the remaining 17 hours of the mission.

e. Reduced Cabin Temperatures - After the CM was powered down and the LM was configured for minimum power usage, the cabin temperatures of both spacecraft decreased rapidly. The temperatures stabilized at approximately 38°F in the CM and 52°F in the LM. The crew reported that they were uncomfortable and that the extreme cold prevented adequate sleep. They donned the spare constant wear garments, but did not elect to wear their PGA's or use the blankets stowed in the CM survival kit.

A more complete evaluation of the medical anomalies during the Apollo 13 mission will be made following the medical debriefing of the crew.

APPENDIX M

Recovery Operations

APOLLO 13

MISSION OPERATIONS REPORT

APPENDIX M

RECOVERY OPERATIONS CONTROL ROOM

John E. Hoover

E. C. Bullock

S. J. Berthiaume

APOLLO 13

Mission Operations Report

Appendix M

Recovery Operations Control Room

Prelaunch through TLI phase

Prelaunch jimsphere balloon releases went as scheduled, and no CM land landings were predicted for any Mode I launch aborts. Weather in the Cape area was acceptable for recovery operations; however, at approximately L-8:30, it was brought to our attention that winds greater than 25 knots were forecast on the 72° launch azimuth groundtrack between 45°W and 60°W at launch time. Flight and Retro were alerted, and it was determined that aborts initiated between 6 + 30 and 8 + 10 would land in this area. At L-2:30, 16-foot swells were being predicted in portions of the launch abort area; and to our surprise, the Flight Director indicated he might consider delaying the launch to a greater azimuth to avoid the bad weather.

Recovery helicopters at the launch site reported receiving a signal (possibly an LVTM frequency) on their electronic search equipment at approximately T - 30 mins. The bearings were to the launch pad, and during launch the bearings pointed to the launch vehicle/spacecraft until LOS. Had an abort occurred, it is possible and likely that some confusion and delay would have resulted in locating the CM if we had to rely strictly on an electronic search.

Launch was on time, and shortly after insertion, target points 2-1, 3-1, 3-4, and 4-4 were verified using the LM ephemeris. There was no significant change from premission, and Retro and the DOD recovery forces were notified. After TLI, recovery ships and aircraft not required for subsequent support were released.

TLI through CSM anomaly

The Translunar Abort Summary messages for aborts between T + 8 to T + 60 were prepared and sent to recovery forces at 12/0400Z. Fixed time of abort TP's through T + 60 hours were prepared and furnished recovery forces at 12/0715Z.

At 12/1400Z, we were advised of a possible storm in the South Pacific that might be passing through the T + 25 and T + 35 landing area at time of scheduled landing. This was confirmed about an hour later, and by 12/1830Z the T + 35 hour abort landing point was moved from 165°W to 155°W. The T + 25 hour abort was not changed, since it was already 24-hour GET, and the crew was in a sleep period.

Network reported at 12/2151Z that transmissions from the LRD electronics lab were causing interference with the video and was making it unreadable. We confirmed that transmissions were being made and requested that they be terminated. Similar problems had been encountered during Apollo 12, but discussions with FSD/LRD personnel were supposed to have resolved the problem.

At 13/0730Z, target points for the LOI-5 and PC+2 aborts were approved and furnished the recovery forces. We were advised at 13/1130Z that the tropical storm "Helen" was moving slower than previously predicted and might make the T + 45 and T + 60 landing points unacceptable. A subsequent satellite picture confirmed this, and the T + 60 TP was moved to 153°W from 165°W at 13/1551Z--too late to change the T + 45 abort TP.

CSM anomaly through entry

After the problem with the CSM, Retro asked us to look at moving the T + 60 hour abort TP back to its original point. Since we had no information to indicate the weather might improve there, we recommended against doing so.

Retro, at 14/0536Z, passed us four target points to evaluate for possible use. They were located on or near the MPL, the AOL, the EPL, and the IOL, with landings at 142 hours, 133 hours, 137 hours, and 152 hours, respectively. These were passed to Weather for evaluation and to the DOD to determine if merchant or other ships were in these areas to be called upon for possible assistance. Shortly thereafter (at 14/0555Z), three or four additional points were brought in by the Flight Dynamics SSR. These were also passed to Weather, and the DOD was asked to provide shipping information for a band of latitudes around the world and centered at 22°S. The State Department was also passed all the above points, should their assistance be required in working with foreign governments. By 14/0810Z, a burn had been scheduled for 14/0843Z to put the spacecraft on a free-return trajectory with a TP at 60-01E, 20-37S. NASA Recovery representatives assigned as advisors to recovery forces in Hawaii, Germany, and Virginia, as well as on the PRS, were alerted to the problems and kept advised of the situations.

By 14/1327Z, Retro informed us that they were considering three options to return to the South Pacific in range of the PRS. Two were quick returns at 118 GET, and the third was a landing at 142 + hours. The PRS was sent to a position to be in range of all three points. By 14/1402Z, we were informed by Flight that the landing at 142 + GET to 165°W was the most likely.

At approximately 14/1500Z, CSM EPS informed us he was working on postlanding power usage and would get back with us later. About 1 hour later, he proposed to us a preliminary plan based on 12 hours postlanding power being available after splash.

DUTY CYCLE

VHF receiver	50%
VHF beacon	Off (use survival radio)
Audio center 1, 2, 3	Off
Cabin lights	Off
PLV (low mode)	50%
Flashing light	25% (only if landing in darkness)
One uprighting	

We evaluated his proposal and stated that we would prefer the VHF beacon remain "on" for 3 hours before plugging in the survival radio, since we wanted to insure the beacon was "on" immediately after main chute deployment and would remain "on" without interruption until the rescue aircraft had a reasonable time to electronically search the recovery area.

Offers of assistance came from many foreign governments. The offers included the use of aircraft, airfields, ships, and assistance in contacting any merchant vessel flying their flag. The resources of the U. S. were of course available to us, and the USS America, an aircraft carrier, left Puerto Rico earlier than scheduled enroute to Rio de Jamerio, should an Atlantic landing occur, although the possibility at this time was low. Near the Indian Ocean TP, the USS Bordelon happened to be in Port Louis, Mauritius. A C-141 aircraft was put on standby to fly a NASA recovery crane and a NASA Advisor to Mauritius should they be required. If a landing had occurred, the Bordelon could have been there at time of landing to retrieve the crew and CM.

Some offers from other governments listed specific ships and aircraft and their locations. In general, most of these were classified and will not be discussed here. Other data received, indicated there were twelve freeworld merchant vessels within 500 n. mi. of the IOL TP and two within 600 n. mi. of the AOL TP.

Once it was fairly certain we were going to the MPL, most of our activities were directed to this area. Logistics plans for return of the crew and data were being developed. Although the weather for the EOM TP looked good at this time, the tropical storm "Helen" was still in that vicinity, and its speed and direction were uncertain. Daily weather reconnaisance flights were then scheduled to keep track of it. By recovery day, it had virtually dissipated and presented no problem.

Although we would normally support the EOM TP with two HC-130 rescue aircraft and a primary recovery ship, two additional aircraft and one additional ship were made available. The extra ship was an experimental minesweeper and would cover the "Constant G" TP. The PRS Iwo Jima would cover the G&N and EMS TP. The aircraft were placed along the reentry groundtrack both up and downrange.

Information concerning the LM and SM IP's and dispersion area was passed to NASA Headquarters to alert ships and aircraft that might be in the area-of-debris reentry

Since we had had so many offers of assistance from around the world, we began working with the Flight Dynamics SSR to come up with a schedule based on available ΔV when a landing could no longer occur east of certain longitudes. This was extremely useful in allowing us to relax our support posture when the capability to land in a particular area no longer existed. This information was passed to the State Department and DOD for dissemination.

At 16/0825Z, the RFO stated they might prefer not to do MCC-7 if they were within $1/4^{\circ}$ of the desired flight path angle, due to the crowded crew timeline. This meant that the TP may move as much as 50 miles at EI-5 hours. This was acceptable to us from a ship standpoint.

EECOM informed us (at 16/1630Z) that due to low power available, they desired to turn off S-band at EI. Since the recovery aircraft are equipped with S-band tracking equipment which can determine if the spacecraft has passed by, we felt it advisable to have the spacecraft transmit S-band to narrow down the search area should there be an undershoot or overshoot in case a visual or electronic search should be required. He concurred and informed us that S-band would be "on" until main chutes in high power voice downlink mode.

At 17/0900, the subject of S-band in high or low power mode during entry was discussed with EECOM and Flight. It cost about 3/4 amp-hour to have it in high power during reentry. At the time, this was about 30 minutes of postlanding power. They were predicting 12 amp-hours after one uprighting, which calculated to about 6 hours of postlanding power. There apparently was some discrepancy between the power usage of various systems and also what amount of power was available, since later calculations provided for approximately 12 hours of postlanding power after one uprighting. We were later informed that approximately 32 amp-hours were available. This would approximate 22 hours after one uprighting. We requested EECOM to confirm that the crew should go to the low power checklist should voltage drop below 27.5 volts. EECOM confirmed the crew was aware. The final postlanding configuration agreed upon was to have VHF receive, recovery beacon, audio centers, and PLV (low) "on."

At 17/1139Z, the Constant G point was changed from 22-28S, 169-08W to 22-10S, 169-35W. At 17/1722Z, we were informed it changed to 21-10S, 167-45W. The ship covering the "Constant G" TP was directed to proceed to the new TP, and aircraft #3 was relocated.

Entry through postrecovery

The first reported electronic contact with the recovery forces was an S-band contact received by Samoa Rescue 4 at 1801Z. There is now some doubt about the validity of this report, however. Signals from the VHF recovery beacon were first received by the Recovery, Photo, and Swim I helicopters at 1803Z. Splashdown occurred at 18:07:41Z, as determined by the recovery forces.

At the time of landing, Iwo Jima was located 5 n. mi. north of the predicted target point, having arrived on station several hours prior to that time. All ship-based aircraft were on station 20 minutes prior to landing.

A visual sighting report by Recovery was received at 1803Z prior to acquisition of recovery beacon signals. Fuel dump and voice contact with Apollo 13 was noted during descent. No readout of latitude and longitude was received from the spacecraft. The CM remained in Stable I after landing, with flashing light operating and inflation of the uprighting systems occurring some 10 minutes subsequent to splash.

After confirming the integrity of the spacecraft and assurring that the crew was in good condition, Recovery attempted to snag the main parachutes with grappling hooks and flotation prior to their sinking.

Swimmer-equipped helicopters arrived on scene at 1816Z and immediately proceeded with retrieval efforts. Swim 2 deployed swimmers to provide flotation to the spacecraft, while Swim 1 deployed swimmers to the apex cover located up-wind.

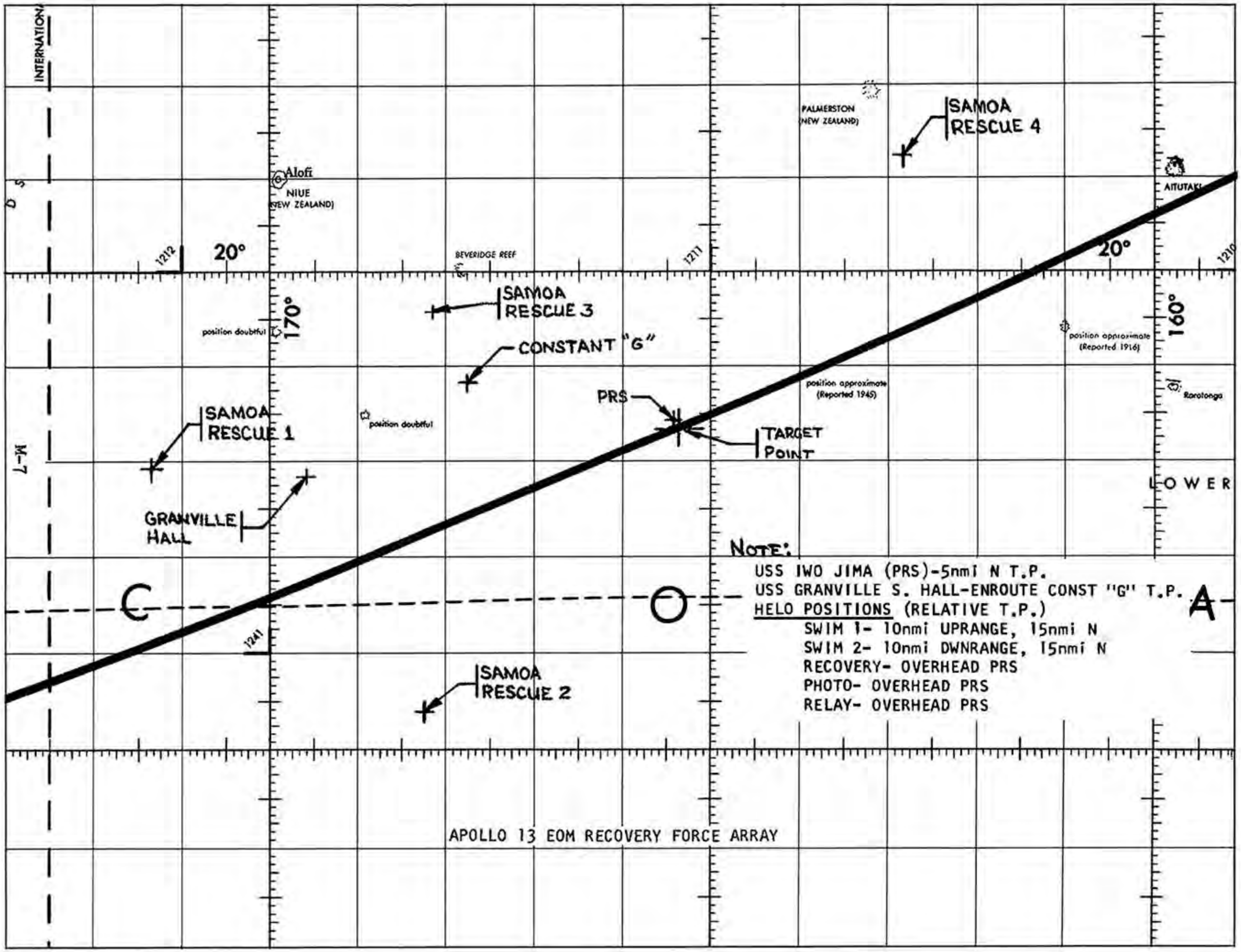
Crew egress occurred at 1835Z, followed by a rescue net retrieval of each crew member. The crew were onboard the recovery helicopter by 1842Z. The CM landed at 21°-38.4'S, 165°-21.7'W, approximately .5 n. mi. from the TP. The crew was on the Iwo Jima at 1853Z.

Command module retrieval took place at 1936Z at coordinates 21-39.1S, 165-20.9W, without incident. One main parachute and the apex cover were retrieved by small boat and brought aboard.

The flight crew departed Iwo Jima at 18/1820Z for American Samoa and subsequently by C-141 aircraft to Hawaii, arriving at 19/0235Z. The spacecraft and associated equipment arrived Hawaii aboard the Iwo Jima at 24/1800Z, to be followed by deactivation at Hawaii and subsequent shipment to NAR, Downey, California, on April 27.

GMT - GET CONVERSION TABLE

GMT	GET (HR:MIN)
11/1913Z	0:00
12/0715Z	12:02
12/1400Z	18:47
12/1830Z	23:17
12/2151Z	26:38
13/0730Z	36:17
13/1130Z	40:17
13/1551Z	44:38
14/0536Z	58:26
14/0555Z	58:45
14/0810Z	60:57
14/0843Z	61:30
14/1327Z	66:14
14/1402Z	66:49
14/1500Z	67:47
16/0825Z	109:12
16/1630Z	117:17
17/0900Z	133:47
17/1139Z	136:26
17/1722Z	142:09
17/1807Z	142:54



APOLLO 13 EOM RECOVERY FORCE ARRAY

Recommendations

No recommendations are made. Several minor problems that did occur are identified in the report, and these areas will be reviewed and the procedures possibly redefined.

APPENDIX N

Network Operations

F O R E W O R D

The Apollo 13 Network Controller's Mission Report was compiled by personnel of the Operations Support Branch. The purpose of this report is to provide a summary of those MCC and MSFN problems that had an impact on support of the Apollo 13 Mission. Because of time restrictions, no attempt has been made to provide a detailed analysis of each problem encountered during the mission. However, an attempt had been made to identify major problem areas which require investigation and corrective action prior to Apollo 14.

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CONTENTS

ILLUSTRATIONS

TABLE I

APOLLO 13 TIMELINE

GMT LO WAS 11/19:13:00.65

LAUNCH TO TRANSLUNAR INJECTION

EVENT	GET
L.O	00
SIC/SII SEP	00:02:44.3
SII IGNITION	00:02:46.0
SII CUTOFF	00:09:52.6
SII/SIV SEP	00:09:56.9
SIVB IGNITION	00:12:29.8
SIVB CUTOFF	00:12:39.8
INSERTION	00:12:39.8

TRANSLUNAR INJECTION TO LUNAR ORBIT

TLI IGNITION	02:35:46.4
TLI CUTOFF	02:41:37.1
TRANSLUNAR INJECTION	02:41:47.1
SIVB/CSM SEP	03:06:00.0
CSM/LM EJECT	04:01:10.0
SIVB EVASIVE MANEUVER	04:18:00.5
MCC 1	Not required
MCC 2	30:40:49.0
MCC 3	Not required
MCC 4	61:29:42.8

TRANSEARTH COAST TO SPLASH

PC+2	79:27:38.3
MCC 5	105:18:31
MCC 6	Not required
MCC 7	137:39:48
CM/SM SEP	138:02:06
LM/LM SEP	141:30:02
ENTRY INTERFACE	142:40:47
SPLASH	142:54:45

1.0 GENERAL

The Mission Control Center (MCC) and the Manned Space Flight Network (MSFN) were placed on mission status for Apollo 13 on March 31, 1970. Launch occurred on April 11, 1970, at 19:13:00.65 GMT. Splash occurred on April 17, 1970, at 18:07:00 GMT.

Overall the support provided by the MCC/MSFN was excellent. In the face of a near catastrophic failure onboard the CSM, the MSFN personnel responded very quickly and professionally and deserve a great deal of credit for the successful completion of this Apollo mission.

Due to the CSM anomaly, there were many real time configuration changes and some real time procedure changes in order to support this non-nominal mission.

Following the accident through SIVB impact on the moon, the procedure developed premission to track two vehicles with the same uplink and downlink frequencies was implemented. However, deviations were required due to the manner in which the IU/CCS transponder responded; these deviations worked and valid LM tracking data was provided.

Air-to-ground voice communications were considered good to excellent even though a considerable portion of the mission was flown on LM omni antennas and on low power. The MSFN support of LM backup voice was very good. Tracking data at these low signal levels was excellent and was even received from uncooled 30' sites which was totally unexpected. The quality of the support provided made it possible for the MCC flight controllers to operate in the LM low power mode throughout the majority of the mission and thus to conserve critical electrical power on the spacecraft.

In addition to the excellent support provided by those stations of the MSFN planned for support of Apollo 13, special mention and a word of appreciation should be given to those personnel involved in configuring the Parkes 210' antenna for support of Apollo. During the two Parkes view periods, approximately 20% more valid telemetry data was received and good air-to-ground voice was provided.

1.1 Major System Problems/Considerations

1.1.1 MCC

A. RTCC

The RTCC provided continuous support for Apollo 13 with out a single major failure.

F. GSFC Communications

In general network communications was the best we have experienced. The only significant problem was an unusual number of failures at the communication satellite station in Buitrago, Spain.

1.2 Procedures

1.2.1 After TLI, INCO expressed a desire to maintain the retransmit counter at 3. On future missions INCO's desires should become known early enough to be included in Network's TLI message. The NOD should reflect the fact that the post-TLI retransmit setting is not absolute.

1.2.2 Based on comments received during the mission as well as in the MMR's it is necessary to review the ground rules that the "Handover" procedures are based upon. There are several significant questions unanswered regarding "countdown," announcements," "absence of communications" etc.

1.2.3 It is recommended that the low speed data rate of one sample per ten seconds become the standard rate for the lunar phases (TLC, lunar orbit and TEC) of the missions. It was noted that no significant delays or queue buildup resulted in the handling of the one sample per ten second data rate by the GSFC CP. The appropriate areas of the NOD should be changed to reflect the above recommendation along with a schedule of when the data rate will change from one sample per six seconds to one sample per ten seconds.

1.2.4 It was noted that the procedure for coordination of site release messages should be reviewed. Track was involved in many time consuming discussions concerning site release messages during the mission.

2.0 CONFIGURATION

The MCC and MSFN configuration at launch was as specified in the following paragraphs:

2.1 MCC Hardware

The configuration of the MCC hardware and equipment was in accordance with AS-508 "H_2" Mission Data Packs, plus AS-508 MRR's 001 through 58.

2.2 RTCC

2.2.1 Hardware

The RTCC configuration was "A" 360/75 MOC (on line) with "D" 360/75 as DSC (off line) and "F" 360/75 as static standby.

2.2.2 Software

Mission program version 508-45 with RTOS 11.0.27

2.3 CCATS

2.3.1 Hardware

The CCATS CP configuration was "A" system on line with "B" system as standby.

2.3.2 Software

CCATS 508 version IV, Release 16 program.

2.4 GSFC CP

2.4.1 Hardware

The "A" system was on line with "B" as standby; wideband data line GW 58526 was the prime data path between MCC and GSFC with GW 58527 as the alternate data path.

2.4.2 Software

Systems tape 4 and errata tape 04-2 plus change requests 1 through 6.

2.5 RSDP

2.5.1 Data core decom programs were as follows:

SIC AS-508	LI001.0	7/25/69
SII	LII001.1	8/15/69
SIV	LIV001.0	7/25/69
IU	LIU001.0	7/25/69
CSM	CSM001.0	9/10/69
LM	LM002.0	2/02/70

2.5.2 Data Core/ALDS

2.5.2.1 Hardware

Data Core module #3 was the online system with module #4 as backup.

System "B" was the online system with output on both prime (GW 58245) and alternate (GW 58246) wide band circuits.

System "A" was the standby system with the CIF antenna field selected as the prime USB and VHF data source for LV data.

2.5.2.2 Software

ALDS program 508.3.2 Rev 4 was utilized.

2.5.3 642B

The Remoted Telemetry Program, NCG 738-2 with errata T1 through T9; command program with errata C1; EMOD program 738-2; and OUCH program 738-2 were used at all remote sites which provided high speed command/telemetry support.

3.0 SYSTEMS PERFORMANCE

3.1 RTCC

3.1.1 Summary

RTCC system performance for this mission was excellent with only minor discrepancies observed in the mission program. A single episode of computer faults occurred but these had no impact on mission support. The performance of the RTCC computer controller teams was exceptional throughout the mission.

3.2.2 Software

Only minor software discrepancies were observed in the mission program. The RTCC ability to provide full mission support was not affected by the discrepancies since work-around procedures were developed for the problems and all required data was provided.

3.1.3 Hardware Anomalies

The single episode of computer faults during this mission occurred during the period of two computer, i.e., MOC/DSC operation, and there was no interruption to mission support. Machine checks occurred in the MOC which was 75D. A selectover to 75A which was the DSC was performed immediately and was followed by a channel to channel high speed restart from 75A to 75F so that two computer support was restored. This incident occurred at a GMT of 06:37:00 on April 15. Operations on 75A as the MOC and 75F as the DSC were continued through the recovery of Apollo 13 flight crew, and without interruption.

3.2 CCATS

3.2.1 CCATS Processor Hardware

A. During the AS-508 Terminal Count and Mission Support, four hardware problems were encountered. Support was not affected by these problems:

1) "C" CP System Instruction faulted at 0200Z (4/13/70). At the time this problem occurred, the "C" CP was being used as a Standby CP; however, it was not required for mission support. This problem was isolated to a bad cable between the "OLD SCU" and the FH-880 Drum on the "C" CP. The "OLD SCU" was by-passed by installing a spare I/O cable between the Drum and the Computer Mainframe.

B. CCATS CP

The CCATS CP supported Apollo 13 without any major problems. The most significant problem in this area that resulted in a loss of data was the recycling of the CCATS CP. Each recycle resulted in a 2 to 5 minute loss of low speed data.

1.1.2 Manned Space Flight Network

A. RSDP

The support of Apollo 13 was the best provided by the RSDP systems. HSK's command computer problem was the only significant problem and this problem was only significant because of the length of time it took to resolve the problem. There was no mission impact, however, due to the intermittent nature of the problem some rearrangement of premission site assignments was necessary. HSK finally solved the command fault problem by cleaning all contacts and connectors and reseating the logic cards in chassis 7.

B. Command

There were no major problems encountered in this area. Several sites did lose portions of command histories and this problem is under investigation.

C. Telemetry

There were no major problems which impacted mission support.

D. Tracking

There were no significant anomalies which impacted mission support.

E. Air/Ground Communications

Air/Ground Communications were excellent despite the fact that most of the mission was conducted with out benefit of the power amplifier on the LM and that backup voice was the primary mode of operation following the accident.

2) "B" CP System had an FH-880 Drum parity error while the system was being recycled "IN-SYNCH" with the "A" CP (0738Z - 4/13/70). The "B" CP was being used as a Standby CP; however, it was not required for mission support at that time. "B" CP was released for maintenance testing by UNIVAC Customer Engineers. No problem was found and the system was reloaded from tape with the CCATS Mission Program with no further occurrence of this problem during mission support.

3) "A" CP System indicated receipt of "Blanks" on the Lowspeed Radar "H" Teletype input; however, this condition did not exist on the "B" CP (Standby) (0910Z 4/14/70). The problem was determined to be a bad relay on the input CLT 1-14 of the "A" CP. The relay was replaced. The "A" CP was "On-Line" at the time; however, no data were lost.

4) "C" CP System would not load from tape (1810Z - 4/15/70). This problem was found to be a bad Printed Circuit (PC) card in the D/O (Arithmetic) Register which was replaced.

B. Total 494 down time during AS-508 from commencement of terminal count to splash was 4 hours and 53 minutes. However no impact to mission support resulted.

3.2.2 System Configuration Unit (SCU)

A. Three problems were encountered with the SCU during mission support:

1) Cross Point MAP's taken at various times during mission support indicated cross points were Closed when they should have been Open. An attempt was made to correct this problem; however, it was unsuccessful. There was no impact to mission support.

2) Unable to input "MITE" timing into the "C" CP System via the SCU. An alternate path was selected through the SCU for the "C" System "MITE" timing interface (1545Z - 4/11/70). There was no impact to mission support.

3) "C" CP System Mission Support configuration (PCC 1C01) was entered into the SCU (0939Z - 4/14/70). A "MAP" indicated one I/O pair and many Cross Points were closed that should have been Open in Matrix 2. It was determined that Matrix 1 had loaded properly; however, Matrix 2 had not loaded properly. An atempt was made to reload PCC 1C01 manually with the same results. This problem did not affect the On-Line ("A") or the Standby ("B") CP's. Due to this problem, the "C" CP had a minimal configuration capability via the SCU and the "C" CP could provide mission support.

B. All SCU problems remained unresolved at mission termination.

3.2.3 Software

A. Software support was provided for the AS-508 Terminal Count and Mission Support with Release 16 of the CCATS Operational Program (5084.16).

B. Processor recycles were required as a result of (1) the On-Line and Standby CP's were outputting "old" (previously received/transmitted) teletype messages (2323Z - 4/11/70, 2017Z - 4/12/70 and 1410Z - 4/14/70) and (2) Executive Buffer depletions (2336Z - 4/13/70 and 0553Z - 4/14/70). These problems were isolated by investigation of system fault dumps. Procedures were established to prevent their recurrence.

3.3 Command

3.3.1 The amount of command activity during Apollo 13 was considerably reduced because of the CSM's power loss. The only significant anomalies that affected command were as follows:

A. The HSK 642B #1 was either "red" or "red can support" from 11/1643Z through 15/1449Z. Because of the intermittent nature of the problem, the planned pre-mission site assignments had to be rearranged.

B. Twice CRO's command histories were missing most of the commands uplinked. Post mission they found a Magnetic Tape Unit (MTU) roller problem.

C. During one GDS pass, there was no transfer of CAP words from the command computer to the telemetry computer. The problem was caused by a bad Inhibit Driver card.

D. There were 123 spacecraft rejects, 18 ground rejects, 10 lost executes and 33 Remote Site invals. These anomalies were caused by the following conditions.

1) The spacecraft rejects were due to executes attempted during periods of low signal strength; however, an undetermined number of these executes were functionally verified.

2) The ground rejects were due to executes attempted when a site was "unable to command," thus, the command subcarrier was off.

3) The Remote Site Invals were due to executes attempted while another execute uplink was already in progress.

4) Nine of the Lost Executes were due to communication outages at the time of the execute request. The other lost execute was due to a HSK command computer fault.

3.3.2 A chronological list of command anomalies follows:

A. April 11, 1970 (F-0 day)

Time: 2033Z

Problem: CRO command history did not show the first 10 of 12 uplinked commands.

Impact/Resolution: No impact as CRO provided the essential information by an OPN message. Post mission CRO identified the cause as a worn pinch roller on 1540 magnetic tape unit #2.

Time: 2311Z

Problem: GDS could not access the command computer to change the Map Wait Period. CAP words were not received for twenty uplinked commands at 12/0010.

Impact/Resolution: The IU was handed over to MIL after the scheduled CSM handover to HAW to permit GDS to work on the command computer. All uplinks were verified by voice. A bad Inhibit Driver card in chassis 13 slot 46B was replaced, and GDS was green at 12/0026.

B. April 12, 1970 (F+1 day)

Time: 0244Z

Problem: HSK reported command computer red, cannot support.

Impact/Resolution: None, HSK was not in acquisition. Replaced three cards in the command computer, and successfully passed an interface test at 0604Z.

Time: 0327Z

Problem: GDS no go for command because of PA #1 fault.

Impact/Resolution: Loss of command capability. GDS switched to USB system number 2. GDS had an arcing problem. The problem was resolved by replacing the arc detection chassis.

Time: 0708Z

Problem: HSK command computer faulted, unable to recover.

Impact/Resolution: One command was lost during the fault. The CSM was handed over to GDS. Diagnostics indicated the problem was in Chassis 7. Later, all contacts and connectors on Chassis 7 were cleaned and the computer was declared green at 15/1449Z. HSK did successfully uplink two loads to the LM at approximately 14/1100Z.

Time: 1730Z

Problem: TEX magnetic tape unit inoperative.

Impact/Resolution: The H-70 command interface was delayed for six minutes. At 1800Z the MTU lost control and allowed the tape to run away. A defective "Start Seq" logic card was replaced.

Time: 2041

Problem: MAD telemetry computer faulted, would not recover.

Impact/Resolution: The CAP's for three uplinked commands were lost, but the verification was relayed by voice. The telemetry computer was reloaded. The cause of the fault has not been identified.

C. April 13, 1970 (F+2 days)

Time: 0244Z

Problem: GYM command computer had an intermittent "GMT Disabled" printout.

Impact/Resolution: None, as GYM was not the active or backup site. The memory chassis, A-11 was replaced at 0400Z.

Time: 0958Z

Problem: 16 of 18 commands were missing from CRO's TTY command history.

Impact/Resolution: No impact as the essential data was received by an OPN message.

Time: 2335Z

Problem: Both CP's faulted with Executive Buffer depletion.

Impact/Resolution: No significant command impact. However, INCO had to uplink a command, and theCP's were recycled before GDS could be configured to computer Mode 1. Both CP's were core dumped and recycled in sync.

D. April 14, 1970 (F+3 days)

Time: 2213Z

Problem: MAD telemetry computer faulted, could not clear upper register.

Impact/Resolution: Two loads were uplinked to the LM, using GDS telemetry for verification. No problem was discovered. The computer was up and cycling at 2309Z.

E. April 15, 1970 (F+4 days)

No command problems.

F. April 16, 1970 (F+5 days)

No command problems.

G. April 17, 1970 (F+6 days)

No command problems.

3.3.3 Command Tables

A. Table II

Command load transfer by date and site.

B. Table III

All uplink executes (excluding load initiates) by site and date. These uplink requests were executed from MCC from liftoff to splashdown.

C. Table IV

Total loads uplinked. These uplinks are not included in Table III. In addition, the total number of telemetry rejects (TMR) or data rejects (DRJ) received furing the uplink of these loads are noted. The only two TMR's occurred during the time the CSM was in low bit rate which is correct response, there were no data rejects received during this mission.

D. Table V

Total spacecraft rejects (SCR) and ground rejects (GDR). These uplink requests are included in the total of Table III.

E. Table VI

Total lost executes (LST) and RSCC invalid requests (RSI) for command uplink requests. These LST and RSI executes are included in Table III.

3.3.4 Command Load Operation

3.3.4.1 A total of 326 SLV prelaunch loads, 25 loads per site plus one additional load required by MIL for launch vehicle pad interface, were transmitted low speed prior to the terminal count. These loads were loaded by each site during the terminal count after site interface.

3.3.4.2 A total of 102 loads were transferred from T-30 minutes to splashdown. This total included GMTLO to all sites plus an extra GMTLO to MIL at T-30 minutes.

3.3.4.3 No problem was encountered in any load transfer during plus time activity.

TABLE II

LOADS TRANSFERRED

The following loads were transferred to all sites premission:

4001	4002	4501	4601	4602	4603
4701	4702	4703	4704	4705	4706
5001	5002	5003	5802	5803	5804
5805	5806	5807	5809	5810	5811
5812					

5801 was transferred to MIL.
6050 was transferred to MIL at T-30.

The following were transferred post lift-off:

April 11, 1970

ALL - 6001
BDA - 0002
CYI - 0002
VAN - 0002
HAW - 1201
GDS - 1201

April 15, 1970

GDS -	2008	2205
MAD -	2008	2205

April 16, 1970

NONE

April 17, 1970

CRO -	0017	0018	0701	0702	1212	1213	1402
	1801	1802	1806	1807	1808	1809	1810
	1901	2017	2206	2305	2306	2402	
GWM -	0017	0018	0701	0702	1801	1802	1806
	1807	1808	1809	1810	1213	1402	1901
HSK -	0702	0018	1402	2017	2206	2305	2306
	2402						

April 12, 1970

GDS -	0004	0005	1001	5808
MAD -	0005	1001		
GWM -	0004			
HAW -	5808			

April 13, 1970

GDS -	0006	1201
HAW -	0006	0007
ACN -	0007	
MAD -	1201	

April 14 - 1970

GDS -	0008	2002	2006	2007	2101
	2202	2203	2204	2301	2401
HAW -	0008	2002	2003	2101	2202
	2401				
MAD -	2006	2007	2203	2204	2301
HSK -	2003				

TABLE III- RTC EXECUTES

DATE	ACN	BDA	CRO	CYI	GDS	GWM	GYM	HAW	HSK	MAD	MIL	TEX	VAN	TOTAL
4/11		4	28	5	19			7	7		3	4	13	90
4/12					136	65		3	10	161				375
4/13			71		195					210				476
4/14					119				21	16				156
4/15					16									16
4/16														-
4/17			103						45					148
TOTAL		4	202	5	485	65	-	10	83	387	3	4	13	1261

TABLE IV -- LOADS UPLINKED

	ACN	BDA	CRO	CYI	GDS	GWM	GYM	HAW	HSK	MAD	MIL	TEX	VAN	TOTALS
LOADS UPLINKED			7		13				6	3			1	30
TIM REJ			2											2
DATA REJ														0

TABLE V - S/C/GND REJECTS

	ACN	BDA	CRO	CYI	GDS	GWM	GYM	HAW	HSK	MAD	MIL	TEX	VAN	TOTALS
S/C REJECTS			28		31	22		3	4	35				123
GROUND REJECTS			7		2	3				6				18

TABLE VI- LOST EXECUTES/RSCC INVALS

	ACN	BDA	CRO	CYI	GDS	GWM	GYM	HAW	HSK	MAD	MIL	TEX	VAN	TOTALS
LOST EXECUTES		2			3				1	4				10
RSCC INVALS			5		17				1	10				33

3.4 Telemetry

3.4.I The telemetry support provided by the MSFN and ALDS/ Data Core was excellent. Special mention should be made of Parkes support. Approximately 20% more valid telemetry data was received during the two Parkes view periods, than was possible from HSK during those same periods. Parkes was not called up for support until 84:20:00 GET, after the spacecraft contingency.

3.4.2 The following anomalies were noted during the mission and listed by GMT day:

A. April 11, 1970 (F-0 day)

Time: 1932Z

Problem: Marginal CSM data was received by CYI resulting in intermittent CSM and CMC data at MCC.

Impact/Resolution: The trouble was attributed by CYI to the spacecraft auxiliary Oscillator which was causing some extraneous modulation on the PM downlink, causing receivers to lose lock. CYI was one-way on the CSM during this pass. On the next pass, CYI was two-way, and the situation did not reoccur. No other site saw this problem (CYI pass #1 was the only one-way site during the mission).

B. April 12, 1970 (F+1 day)

Time: 0421Z

Problem: MILA telemetry computer faulted during a CSM playback.

Impact/Resolution: 10 seconds of playback data were lost. Immediate auto recovery was performed and continuation of data processing was resumed. MILA reported no symptoms and this item is still open.

Time: 0840Z

Problem: HSK telemetry computer had an input GMT failure indication.

Impact/Resolution: Negligable impact because the internal clock took over the GMT update. A printout of "real GMT not established" was received on-site. No resolution at this time and the telemetry computer continued to operate on the internal clock. FC was queried as to the effect of running on the internal clock, and they stated that they did not notice any difference.

Time: 2041Z

Problem: Loss of sync indication from MAD due to telemetry computer fault.

Impact/Resolution: 12 seconds of data were lost. TIC handed over to GDS for telemetry data processing. Auto recovery at MAD did not work and a manual recovery was performed to restore the telemetry computer processing.

Time: 2103Z

Problem: Loss of sync indication from MAD due to a Telemetry Computer fault.

Impact/Resolution: 10 seconds of data were lost. TIC handed over to GDS for telemetry data processing. A auto recovery, a manual recovery, and a reload from tape failed to restore operation and the telemetry computer was declared red at 2106Z. Troubleshooting on site revealed a defective P.C. Card that would not allow the U upper register to clear. Replacement of the defective part corrected the problem and proper operation was restored.

C. April 13, 1970 (F+2 days)

Time: 0351Z

Problem: GDS Telemetry computer was unable to locate FMT 512 on mag tape.

Impact/Resolution: There was no data loss; the only impact was delay of a tape playback. The tape handler heads were cleaned and the ability to select Format 512 was restored.

Time: 0540Z

Problem: While reconfiguring GDS from Playback configuration 6 RT, TIC was unable to replace high speed format 512 with Format 007 via computer execute function.

Impact/Resolution: There was no data loss. TIC handed over to HSK for real time telemetry data processing. A computer restart was performed at GDS and proper operation was restored. This was the result of the telemetry computer selecting the wrong tape handler.

D. April 14, 1970 (F+4 days)

Time: 1958Z

Problem: Loss of sync indication from MAD due to a Telemetry computer fault.

Impact/Resolution: Lost approximately 1 minutes of telemetry data. Handed over to ACN, but theACN data was intermittent due to the LM comm configuration. After an auto recovery was not successful, a manual recovery was performed and proper telemetry computer operation was restored.

Time: 2139Z

Problem: Loss of sync indication from MAD due to a Telemetry computer fault.

Impact/Resolution: No impact, since GDS data was being processed. Auto recovery was performed and operation of telemetry computer was restored; no explanation was given.

Time: 2211Z

Problem: Loss of sync indication from MAD due to a Telemetry computer fault.

Impact/Resolution: No impact since GDS data was being processed by MCC. The telemetry computer could not be recovered and the computer was declared red at 2212Z. At 2310Z the telemetry computer was returned to mission support after troubleshooting efforts failed to find any problems. Subsequent investigation of this problem on April 15 found a defective printed circuit card; and after this card was replaced, no further telemetry computer faults were experienced during the mission.

E. April 15, 1970 (F+4 days)

No telemetry problems occurred on this day.

F. April 16, 1970 (F+5 days)

Time: 0350Z

Problem: GYM TLM computer faulted.

Impact/Resolution: This did not cause any impact, as data was being processed from GDS. The computer faulted and auto recovered after three attempts. No symptoms were observed. See (0359Z) entry.

Time: 0359Z (104:46 GET)

Problem: GYM TLM computer went down and could not recover.

Impact/Resolution: No impact as GDS was the prime site. GYM reported the computer red, and at 0406Z it was reported that bit 2^{25} was being set in the lower memory bank, causing the computer to address the wrong instruction. At 0605Z GYM reported that the computer could support, but was red because of the intermittent problem.

Time: 1503Z

Problem: Unable to turn on telemetry data from ACN via computer execute function.

Impact/Resolution: There was no impact since telemetry data was being processed from MAD at this time. The problem was caused by a configuration error which was made when the station replaced a failed Data Transmission Unit (DTU) on Net 6. At 1518Z proper site configuration was restored and telemetry data was turned on via CEF.

G. April 17, 1970 (F+6 days)

No significant problems were experienced on this day.

TABLE VII

DATE/TIME	STATION	PLAYBACK TYPE	LENGTH	DATA QUALITY	REMARKS
12/1850Z	VAN	Voice DSE	5 minutes	Weak with background noise.	Playback was made on H.F. lines.
12/1850Z	CYI	Voice DSE	3 minutes	Good with background noise.	None
12/1920Z	GDS	Voice DSE	6 minutes	Good with background noise.	None
13/0201Z	MAD	CSM PM FMT's 518, 519, and 522	7 minutes	Good	MCC-2 burn data.
13/0326Z	GDS	CSM PM FMT 512	80 minutes	Good	None
13/0559Z	HAW	CSM PM FMT's 109, 512, and 513	44 minutes	Good	None
13/0651Z	GDS	CSM PM FMT's 108 & 519	24 minutes	Good	None
13/0817Z	HSK	EMOD CSM	3 minutes	Good	Pass 1 - Banks 1-2-5-7-8 valid. Pass 2 - All banks valid

DATE/TIME	STATION	PLAYBACK TYPE	LENGTH	DATA QUALITY	REMARKS
13/0828Z	HAW	CSM PM FMT's 511 & 515	15 minutes	Good	None
13/1332Z	MAD	CSM PM FM/FM FMT 9	11 minutes	Good	Playback had to be repeated due to GNC's recorders not on at start of playback. (MCC-2 PB)
13/1427Z	MAD	CSM PM FMT 110	6 minutes	Good	MCC-2 burn
13/1542Z	MAD	CSM PM FMT 521	2 minutes	Good	MCC-2 burn (DAC's normal)
13/1558Z	MAD	CSM PM FMT 521	2 minutes	Good	MCC-2 burn (DAC's expanded 4 through 11)
14/0005Z	MAD	CSM PM FMT 109	8 minutes	Good	None
14/0631Z	HSK	EMOD CSM	3 minutes	Good	Pass 1 & 2 - all banks valid.
14/0634Z	GDS	CSM PM FMT 501	20 minutes	Good	None

DATE/TIME	STATION	PLAYBACK TYPE	LENGTH	DATA QUALITY	REMARKS
14/0940Z	GDS	CSM PM FMT 510	20 minutes	Good	None
14/1004Z	GDS	CSM PM FMT 512	20 minutes	Good	None
14/1032Z	GDS	CSM PM FMT 514	20 minutes	Good	None
14/1055Z	GDS	CSM PM FMT 515	20 minutes	Good	None
14/1118Z	GDS	CSM PM FMT 515	13 minutes	Good	Last 6 minutes of data were static due to weak signal strength.
14/2110Z	GDS	CSM PM FMT 514	20 minutes	Good	None
14/2303Z	GDS	CSM PM FMT 308	10 minutes	Good	None
14/2315Z	GDS	CSM PM FMT's 519, 520, 521, 523, 524, and 525	98 minutes	Good	None

DATE/TIME	STATION	PLAYBACK TYPE	LENGTH	DATA QUALITY	REMARKS
15/0145Z	GDS	CSM PM FMT 108	10 minutes	Good	None
16/0137Z	MAD	CSM-PM FMT 109	3 minutes	Good	None
16/0544Z	GDS	CSM-PM FMT 514	10 minutes	Good	None
16/2258Z	GDS	CSM PM FMT 109	8 minutes	Dropouts due to weak signal strength during the R.T. recording.	None
17/1015Z	HAW	EMOD	3 minutes	Usable	Pass 1 bank 8 invalid. Pass 2 Banks 1-5-7, and 8 invalid.
17/1606Z	CRO	EMOD CSM-LBR	3 minutes	Good	Pass 1 - banks 4 through 8 valid Pass 2 - all banks valid.

3.5 Tracking

3.5.1 The entire Apollo Network performance was outstanding. With the many real time reconfiguration changes, operating at near threshold signal strengths, and having to comply with real time procedure changes, all sites responded exceptionally well.

HSK 642B computer was red from prelaunch to 15/1500Z. This caused a perturbation in planning for Apollo/ALSEP coverage during times when only three or four sites were in view. There were very few other on site equipment failures, all of which had little or no impact on the mission.

The one problem that caused the greatest loss of Tracking Data was once again MCC/CP recycles. The majority of CP recycles were accomplished to prevent the CP from outputting old teletype messages. Total loss of low speed tracking data was 2 to 5 minutes for each recycle.

3.5.2 A chronological list of tracking anomalies follows:

A. April 11, 1970 (F-0 day)

Time: 11/1913Z - Liftoff

Problem: VAN CDP declared red.

Impact/Resolution: Just prior to launch, the VAN loaded the 507 program in the CDP. GSFC CADFISS had made several attempts to pass the VAN high speed tracking data using the 508 program all of which failed. After loading the 507 program, GSFC was unable to CADFISS the VAN as the GSFC computers were configured for launch. GSFC and VAN felt more confident using the 507 program, but still declared the CDP red for launch. Actual data obtained during powered flight was noisy but did give C and S-Band a "go" for orbit solution. FIDO did not elect, however, to use this VAN C and S-Band solution for orbit determination. The low speed data after insertion received at MCC was processed but the data did not fit the orbit. Other sources orbit determination indicated an apogee of 102.5 nm and perigee of 100.3 nm whereas VAN data indicated 300 nm and 150 nm respectively.

The problem is unresolved at this time.

Time: 11/2028Z

Problem: CRO Mark I ranging unit red.

Impact/Resolution: For the entire revolution 1 pass, CRO ranging data had a very large bias, and was unusable. The doppler data, however, was used. At 2100Z, prior to rev 2, support, CRO replaced a bad card in the transmitter coder unit and went green.

B. April 12, 1970 (F+1 day)

Time: 12/0145Z

Problem: HAW doppler data appeared noisy.

Impact/Resolution: No impact as data was still usable. However, a bias or fluctuation of $\pm$ 1 cycle appeared on all doppler data from system 1. After switching receivers and synthesizers, running CADFISS, and conducting on site tests, the problem was traced to a wiring error in the system 1 range rate gate. The wiring error prohibited the octal numbers 1, 3, 4, and 6 from being output.

Time: 12/0326Z

Problem: GDS System 1, P.A. Fault.

Impact/Resolution: No significant impact. When P.A. #1 faulted, System 2 was brought up 2-way. System 1 was only down momentarily. System I was not declared Red. After site LOS, GDS discovered the ARC detector chassis that was in use when the PA fault occurred did not have an EI installed that made the detector less sensitive to arcing. A new chassis with the EI modification was installed. No further P.A. faults were experienced.

Time: 12/0903Z

Problem: MAD System 2 analog/digital converter Red.

Impact/Resolution: No impact as ranging data from system 2 was not required. A reference amplifier card in the MKI A/D converter was replaced. The item was declared green after site LOS at 13/0645Z.

Time: 12/2357

Problem: HAW Doppler Bias

Impact/Resolution: Impact was a loss of doppler data for approximately one minute. The synthesizer setting was off by one cycle which caused a doppler bias of 104 cycles. This problem was corrected by adjusting the synthesizer.

C. April 13, 1970 (F+2 days)

Time: 13/0542Z

Problem: Lost HSK-X low speed tracking data after H/O of IU/SIVB. At the time of the loss of data, an unidentified TTY indicator was received.

Impact/Resolution: No major impact. Low speed was lost for four minutes until HSK-X put on a new start of message header on data.

Time: 13/1037Z

Problem: Insufficient sites to support required data sources (Apollo, ALSEP, SIVB).

Impact/Resolution: Impact was a 21 minutes loss of ALSEP data. The requirements for support during this period were: (1) a two-way carrier with full system capability to the CSM, (2) a backup three-way site to the CSM with the same capability, (3) a two-way site with carrier only to the SIVB, and (4) a separate site for ALSEP receive and record, since ALSEP and theCSM/SIVB were not within the beamwidth of a single antenna.
Since the HSK command computer was red, CMD capability was lost from both 85 ft dishes at HSK and HSK-X. The only other sites in view after HAW LOS at 40:50 GET, were CRO which was assigned to CSM two way and GWM which was previously assigned to ALSEP and had to be used as backup to CSM. HSK had early LOS due to masking, which left a gap in ALSEP support until CYI AOS at 41:11 GET. HSK-X could have covered the ALSEP support without any masking problems until CYI AOS, but was not modified for ALSEP support.

Time: 13/1059Z

Problem: MAD range system 1 Red cannot support.

Impact/Resolution: There was no impact since System 2 was used at handover. MAD replaced two open R. F. cables to support R. F. doppler updates.

Time: 13/2143Z

Problem: GDS-X was red for servo amplifier.

Impact/Resolution: GDS-X lost valid auto track data for 10 minutes while changing servo amplifier units. The CSM was handed over to GDS-Prime putting both vehicles on prime antenna with dual TDP operations. After the servo amplifiers were changed, the CSM was handed back to GDS-X.

Time: 13/2302Z

Problem: Site doppler biases were observed.

Impact/Resolution: Select support while looking at doppler residuals noted that while GDS was in dual TDP on separate vehicles (see above problem) the IU doppler residuals were about .5HZ. When any site, 85 or 30 ft, was tracking in a single TDP mode the IU doppler residuals were 4HZ. There is no explanations for this condition.

D. April 14, 1970 (F+3 days)

Time: 14/0257Z

Problem: HSK-X reported PA #4 red for fan motor in heat exchanger.

Impact/Resolution: No impact, problem was corrected prior to AOS. The fan motor was changed and the site went green at 0415Z.

Time: 14/0604Z

Problem: Not saving GDS-X low speed data.

Impact/Resolution: Two way site data was not available for trajectory processing. PIR had the IU frequency pulled off and had failed to lock the synthesizer to VCO. Problem was resolved by locking the synthesizer to the VCO.

Time: 14/0651Z

Problem: GWM USB was Red for Y-axis failure.

Impact/Resolution: GWM was the backup site to the LM and site assignments had to be changed from GWM to HAW. GWM went green at 0720Z, after replacing a servo amplifier.

E. April 15, 1970 (F+4 days)

Time: 15/0034Z

Problem: No IU acquisition data was available for HAW, and ACN from GSFC computers.

Impact/Resolution: Sites were currently tracking but if an LOS had occurred, there would have been no acquisition data available to aid in reacquiring. The problem was in a program limitation at GRTS. They could not output acquisition data within ± one hour of impact.

Time: 15/1723Z

Problem: MAD doppler contained sporadic noise.

Impact/Resolution: No impact; the points were several minutes apart and could be edited. Two way carrier was handed over from system 1 to system 2, to isolate the problem. Sporadic noise was still present on system two. No resolution.

Time: 15/1828Z

Problem: ACN 1218 computer was red.

Impact/Resolution: No impact, The 1218 was green at 1837Z after reloading the computer.

F. April 16, 1970 (F+5 days)

Time: 16/0907Z

Problem: GDS Apollo Timing Equipment was red.

Impact/Resolution: No impact. The problem affected TDP high speed data only.

Time: 17/0135Z

Problem: Lost HAW Low Speed data and received an S-Band unidentified TTY indicator on the Track Console. GDS-X low speed data was also lost at about the same time. This apparently caused a C-band unidentified L/S indicator to light. HAW and GDS-X data was reestablished and the console indicators returned to normal with exception of UN-ID being lit along with 8 sources.

Impact/Resolution: No major impact (lost a few frames of data.) A check with GCC and with Track support on the CP L/S handling resulted in no reason identified for the problem.

G. April 17, 1970 (F+6 days)

No tracking problems.

3.6 Communications

3.6.1 Communications support from the Communication Managers and Voice Controllers at GSFC and the MSFN personnel was considered excellent. All positions were quick to respond in resolving communications problems with the MSFN and adherence to the established Communications Interface Procedures was excellent. As indicated in the daily chronologies the communication links to Madrid were plagued with problems. Communications to the rest of the Network were excellent.

3.6.2 The following is a chronological resume of those communications problems which had mission impact.

A. April 11, 1970 (F-0 day)

Time: 11/2215Z

Problem: Non-receipt of BIOMED upon GDS handover.

Impact/Resolution: Normally, no significant impact would be felt because of immediate availability of BIOMED from an alternate source. In this instance, BIOMED via HAW was attempted without success. At 2217Z, GSFC Voice Control received GDS BIOMED and transferred it to MCC. It is believed that the problem was due to a misinterpretation of procedures which stipulate remoting on Net 5 at TLI plus 3 hours vice 3 hours Ground Elapsed Time. This will be reviewed and clarification will be provided.

B. April 12, 1970 (F+1 day)

There were no significant anomalies with mission impact during the course of this GMT day.

C. April 13, 1970 (F+2 days)

Time: 0928Z

Problem: Non-sequential segments on all Telemetry Data were received at MCC.

Impact/Resolution: The impact was loss of useable telemetry data for a period of 12 seconds. The problem was an occurence of momentary line hits on the Primary Wideband circuit (GW58526), and was of such short duration that tracing a cause within the commercial carrier system was impossible. Communications Control placed error counters under surveillance to detect any possible recurrence, however, no further errors appeared.

Time: 1242Z

Problem: Momentary loss of Net 4 (High Speed Command) capability to MAD.

Impact/Resolution: MAD's Net 4 was restored on a make-good facility (the satellite wideband system) at 1244Z. The problem with the basic Net 4 facility was determined to be a noisy carrier between Paris and Madrid, which was repaired and returned as operational at 1315Z.

Time: 1258Z

Problem: GSFC "A-System" Communications Processor Fault.

Impact/Resolution: The Telemetry Instrumentation Controller reported a 2-second dropout of all data sources. Further, four low speed teletype sources were lost by Track and required "re-starts; these stations were MAD, MAD-X, CRO, and GWM. The cause of the fault was a buffer control register parity on a low speed ESI (Communications Line Terminal). The CLT was replaced and the faulty CLT was not utilized again pending post-mission repair. The effect of the problem was minimal since GSFC was able to effect an immediate swap to the "B-System" (Standby system). The Telemetry Instrumentation Controller reported a good interface at 1259Z.

Time: 1455Z

Problem: Loss of all GSFC-MAD Nets (except Net 1)

Impact/Resolution: Command, telemetry, biomed and voice coordinated was lost to MAD. At 1502Z, GSFC completed a restoral of Net 2 (Network Voice Coordination) via London. Nets 2 and 4 were declared good at 1502Z. The trouble was attributed to a failure of a radiation hazard protection switch at the Buitrago (Spain) Earth Station. Nets 2, 3, 5 and 6 were placed back on their normal routes at 1509Z.

Time: 1456Z

Problem: Loss of GSFC-MCC GOSS Conference Circuit.

Impact/Resolution: Air-to-ground capability was lost briefly until this function was shifted to a backup circuit. The normal GOSS Conference circuit was returned to service at 1510Z; the trouble was due to a faulty jack at AT&T Washington, D.C.

Time: 1512Z

Problem: Loss of Low Speed Tracking Data.

Impact/Resolution: Approximately 1 minutes of tracking data was lost at MCC. At 1512Z the GSFC CP (On-Line System B) experienced a drum parity error. A check indicated that GSFC did not lose output; however, the interruption necessitated "re-starts" on the tracking data.

Time: 1521Z

Problem: Loss of MAD Net 6.

Impact/Resolution: Approximately 15 to 20 seconds of telemetry data was lost and a switch was made to the backup format. By 1524Z, Net 6 was restored to normal and the Telemetry Instrumentation Controller reported good data. The reason for the problem was a mispatch at MAD which had been effected during the process of setting up a backup route via CYI.

Time: 1612Z

Problem: Loss of CRO Net 4.

Impact/Resolution: There was no data impact at MCC, since MAD data was being processed. The circuit was restored to operation at 1620Z; the trouble was reported as a faulty message unit (MUR) between Faulkner, Maryland and Oklahoma City, Oklahoma.

Time: 1716Z

Problem: MAD Net 4 (High Speed Commands) impaired.

Impact/Resolution: The impact was loss of high speed commands to MAD. Since GSFC Communications Manager was dualing Nets 4 and 6 to MAD, MAD was advised to switch to the receive side of Net 6 as a restoration action. The problem with the basic Net 4 circuit was reported as low levels.

Time: 1739Z

Problem: Loss of MAD Net 2 (Network Voice Coordination) Net 3 (BIOMED), and Net 5 (High Speed Track)

Impact/Resolution: These three nets were on the MAD wideband system (satellite) which had been experiencing dropouts caused by the antenna elevation switch ("Radiation Hazard Protection Switch") cutting out at low elevation. Net 2 (Network Voice Coordiation circuit) was shifted to cable facilities via London. Attempts were made to shift Net 3 via ACN (backup site); however, ACN could not provide BIOMED (30 ft antenna). By 1742Z, the MAD wideband was restored and BIOMED was being received via MAD Net 5. The total impact was loss of BIOMED for approximately 2 minutes. Because of recurring problems experienced with the Buitrago (Spain) Earth Station auto track at low elevation, GSFC decided to retain all circuits (except Net 5 BIOMED) in their present configuration. At 2051Z the tracking station at Buitrago lost auto track capability and had to track manually. Since all MSFN support nets except BIOMED, were on other facilities, the only service in jeopardy was BIOMED, which was quickly shifted to a make-good facility via CYI.

Time: 2044Z

Problem: Non-receipt of BIOMED at MCC.

Impact/Resolution: BIOMED was lost for approximately 3 minutes due to a mispatch at GSFC.

D. April 14, 1970 (F+3 days)

Time: 0926Z

Problem: Momentary loss of all MSFN data sources via GSFC.

Impact/Resolution: All data and teletype incoming to the MCC were reported as having errors. The error counters on the Communication Controller's console indicated no errors. The problem was of such short duration that GSFC checks revealed no valid reason for the interruption.

Time: 1351Z

Problem: Temporary loss of HSK Nets 2 and 6.

Impact/Resolution: The impact was temporary loss of the Network Coordination voice circuit with HSK and Net 6 telemetry from HSK. The problem on Net 2 was an outage between Canberra Switch and HSK; Net 2 was restored on Net 3 at 1352Z. The momentary loss of Net 6 was attributed to trouble with the microwave system between Canberra and Sydney. At 1401Z, the original Net 2 circuit was returned to normal service.

E. April 15, 1970 (F+4 days)

There were no significant problems this day.

F. April 16, 1970 (F+5 days)

Time: 1413Z

Problem: Momentary loss of MAD Nets 4.

Impact/Resolution: Telemetry on this net was momentarily impaired until GSFC took immediate restoral action on a back up circuit.

Time: 1505Z

Problem: Suspected loss of ACN Nets 4 and 6.

Impact/Resolution: The Telemetry Instrumentation Controller was unable to turn on ACN Telemetry. GSFC, on checking with ACN, indicated that commands were getting into the Data Transfer Unit on site, therefore the problem was believed to be an on-site . After several attempts at ACN to change the telemetry configuration, the problem was isolated at 1515Z to an incorrect DTU configuration at ACN.

Time: 1559Z

Problem: Loss of ACN Net 2 Voice Coordination Circuit and ACN Telemetry.

Impact/Resolution: The SATCOM to ACN dropped in and out 3 times for short periods (the Andover Earth Station reported to GSFC that they had lost carrier from ACN). At 1601Z, a receive-only loss of the ACN SATCOM was experienced. This problem was traced to a transmitter problem at the ACN Earth Station. The ACN SATCOM was placed on the standby transmitter and all nets were "made good" by 1602Z.

G. April 17, 1970 (F+6 days)

No significant problems this date.

3.7 Air/Ground Communications

3.7.1 Air/Ground voice communications were considered excellent, even though a considerable portion of the mission was flown with the power amplifier off in the spacecraft. The MSFN support of the LM backup voice mode on low power was considered excellent. The quality provided made it possible for the MCC flight controllers to operate in the low power mode and thus conserve critical electrical power on the LM spacecraft.

3.7.2 The following is a chronological summary of those air/ground problems which had mission impact or significantly delayed air/ground voice operations:

A. April 11, 1970 (F-0 day)

Air ground communications were satisfactory on this date.

B. April 12, 1970 (F+1 day)

Air ground communications were satisfactory on this date.

C. April 13, 1970 (F+2 days)

Air ground communications were satisfactory on this date.

D. April 14, 1970 (F+3 days)

Time: 14/0659Z to 14/0735Z

Problem: Intermittent AOS and LOS via GDS.

Impact/Resolution: MCC encountered intermittent loss of air/ground communications when GDS and HSK were attempting to maintain separate track on the CCS and LM transponder. Air to ground voice communications were logged as satisfactory at 0735Z.

Time: 14/1025Z

Problem: CAPCOM did not uplink via HSK.

Impact/Resolution: The impact was momentary loss of air ground communications uplink. HSK missed one Quindar key; at 1027Z, the HSK Quindar sensitivity was adjusted and no further problems were encountered.

Time: 14/1034Z

Problem: Spacecraft was not copying all of CAPCOM uplink via HSK.

Impact/Resolution: Part of the uplink conversation was missed by the spacecraft. HSK reported solid uplink via HSK station facilities. The spacecraft was in the PTC mode at this time.

E. April 15, 1970 (F+4 days)

Time: 15/0932Z

Problem: Momentary appearance of tone on GCSS Conference.

Impact/Resolution: No loss of air/ground voice communications was realized. The tone appeared at the time of handover from GDS to HSK. While its duration was extremely short, GSFC Voice Control advised that the tone was coming in on the HSK line. There was no recurrence of the tone to allow further trouble-shooting for a positive source and cause identification.

F. April 16, 1970 (F+5 days)

Time: 16/0558Z

Problem: Loss of an initial voice uplink to spacecraft.

Impact/Resolution: The CAPCOM did not uplink on his first transmission via GDS. At the time of the incident, someone plugged his headset into the CCS jack associated with the CAPCOM keyset. When this occurs, with air/ground accessed, this generally results in the Quindar transmitter dropping the first key. The problem was overcome by the CAPCOM "re-keying" the air/ground circuit.

G. April 17, 1970 (F+6 days)

Time: 0346Z

Problem: Loss of the Quindar "SPACE" tone (off condition) at GDS.

Impact/Resolution: GDS missed 3 or 4 Quindar space tones during the process of a CAPCOM transmission to the spacecraft. No injury was done to the transmission itself, since it is the "MARK" tone which activates the site uplink. A check with GSFC indicated that both tones were passing through GSFC satisfactorily. GDS used manual key procedures at MCC direction for a short period of time after which the space tone reappeared. No Quindar adjustment was made at GDS, according to reports from the GDS Comm Tech.

3.8 Onboard Television

3.8.1 Apollo 13 carried 525 line sequential color cameras on both CSM and LM. In addition a "backup" slow scan camera was aboard the LM. Due to the anomaly all TV transmissions after a GET of 59 hours were cancelled. However, until that time, the CSM color camera, and ground system provided excellent color television.

3.8.2 The following is a chronological summary of onboard television activity for Apollo 13.

A. April 11, 1970 (F-0 day)

Time: 11/2050Z - 11/2056Z

Configuration: MILA was configured to receive, record, and relay sequential color television to KSC and MCC. MCC and Building 8 were to convert sequential video to color and release to TV networks.

FM Signal Strength: -90 DBM

Picture Quality: Very good, with minor breakups in video. These breakups were accompanied by similar fluctuations in the FM signal strength and were attributed to tne omni antennas.

Time: 11/2222Z - 11/2333Z

Configuration: Goldstone was configured to receive, record, and relay sequential color television to MCC. MCC and building 8 were to convert sequential video to color and release to TV networks.

FM Signal Strength: -89 DBM

Picture Quality: Excellent. Occasionally some microphone noise appeared in the video. This noise was believed to be caused by a crewman holding the camera by its lens.

B. April 13, 1970 (F+2 days)

Time: 13/0126Z - 13/0215Z

Configuration: Goldstone was configured to receive, record, and relay sequential color television to MCC. Madrid was configured to receive, record and release sequential color television to Europe. MCC and Building 8 were to convert sequential video to color and release to TV networks.

FM Signal Strength: -82 DBM at a GDS 210' site
-93 DBM at Madrid

Picture Quality: Excellent.

C. April 14, 1970 (F+3 days)

Time: 14/0227Z - 14/0259Z

Configuration: Goldstone was configured to receive, record and relay sequential color television to MSC. MCC and building 8 were to convert sequential video to color and release to TV networks.

FM Signal Strength: -83 DBM at GDS 210' Site

Picture Quality: Excellent

3.9 M&O Operations

3.9.1 M&O provided excellent support during the Apollo 13 mission. The problems experienced by M&O were generally of a minor nature and the total number of problems encountered was extremely low. The following is a summary of the more significant problems:

A. April 11, 1970 (F-0 day)

Time: 1632Z

Problem: D/TV Channel #5 had bright spots on the "Charactron" face indicating a bad "charactron."

Impact/Resolution: Channel #5 was offline for one hour and 38 minutes. The charactron tube was replaced.

Time: 1705Z

Problem: CP "C" not receiving GMT through the SCU.

Impact/Resolution: The problem prohibited the "C" machine from being brought up for support. The problem was cleared by selecting a new cross-point in the SCU.

B. April 12, 1970 (F+1 day)

Time: 0132Z

Problem: "B" system hardcopy disabled.

Impact/Resolution: All consoles on the "B" system were unable to make hardcopies for one hour and fourteen minutes. A relay on the second floor, which enables second floor hardcopy machines, was stuck. The relay was bypassed in the circuit.

Time: 1735Z

Problem: L-1 Eidophor lost video presentation.

Impact/Resolution: Eidophor presentation lost to MOCR for 12 minutes. The VSM output card was replaced to restore video.

C. April 13, 1970 (F+2 days)

No problems this GMT day.

D. April 14, 1970 (F+3 days)

Time: 0934Z

Problem: Unable to load "C" system configuration into the SCU.

Impact/Resolution: Were unable to use the "C" CP for support for five hours and 54 minutes. The "C" system was configured for support by manually doing crosspoints. However, the SCU operator was not able to close all of the normal crosspoints. Those left open were Alt PCM/GS, DSC and Alt MSFN. It was decided not to do further work on the problem until after the mission.

Time: 1430Z

Problem: The Biomed Analog Recorder was not recording.

Impact/Resolution: No real time impact. The recordings are used for data reductions in Building 12. A ground strap was installed to solve the problem.

E. April 15, 1970 (F+4 days)

Time: 0931Z

Problem: Recovery 6x12 lost drive in the X-axis.

Impact/Resolution: The plotter was down for 49 minutes while a belt was changed on the servo motor.

F. April 16, 1970 (F+5 days)

Time: 0358Z

Problem: R-1 Eidophor lost video presentation.

Impact/Resolution: Colored Eidophor presentation was lost for two minutes. A new cathode was rotated into position to correct the problem.

G. April 17, 1970 (F+6 days)

No problems this GMT day.

4.0 Scheduling

4.1 Premission Activities and Utilization Summaries

4.1.1 Major Milestones

The MCC resources were placed in an Apollo 13 configuration on November 29, 1969. Apollo 13 delivery dates were as follows:

December 9, 1969	CCATS Software Program
December 24, 1969	ALDS Software Program
December 31, 1969	GSSC Software Program
January 2, 1970	RSDP Software Program
January 2, 1970	APCU Software Program
January 5, 1970	RTCC Software Program
February 1, 1970	ALSEP Software Program

The following chronological history depicts all Apollo 13 premission testing supported by the MCC. This testing includes all simulations, pad tests, and validation tests conducted by Flight Control and Operations Support.

November 20, 1969	TM Checkout
December 4, 1969	Acquisition Message Generation
5	Tape Build
31	Val 501
31	Val 602
January 6, 1970	Val 501
6	Math Model LOI Sim
7	Math Model LM Act/Des Sim
8	MCC/MSFN Vals 1040.1, 1040.2 - KSC, ALDC 2041, 2043 - GSFC, MIL
8	CMS LOI Sim
9	CMS/LMS LM Act/Des Sim
9	Val test Format 30 - GSFC, MIL
9	MCC/MSFN Vals 1041.1, 1041.2 - GSFC, MIL
12	MCC/MSFN Vals 3040, 1040.3 - KSC, ALDC 1041.3 - GSFC, MIL
13	CMS TLI Sim
14	Math Model Ascent Sim
15	MCC/MSFN Vals 1051, 2051,-GSFC, MIL
15	LMS Descent Aborts Sim
16	CMS/LMS Ascent Sim
21	CMS Launch Aborts Sim
27	CMS Reentry Sim
29	CMS/LMS LM Act/Des Sim
February 3, 1970	LMS C/O
3	CMS TLI Sim
4	ALSEP C/O
4	ALSEP C/O
5	LMS Descent Sim
5	MCC/MSFN Vals 1051, 2051 - GSFC, TEX
6	Math Model Lunar Surface Sim
11	CMS DOI Sim
12	CMS EVA No. 1 (KSC)

February 13, 1970	LM Color TV C/O
13	MCC/MSFN Vals 1041.1, 1041.2, 2044, 1043 - GSFC, MIL Track Acquisition Message and JPL Vectors Cos 4/Medable Decom C/O - GSFC, MIL Track and TLM Loading C/O - GSFC, MIL, BDA, GDS, NT&TF, TEX
13	MCC/MSFN Val 1040.3 - ALDC, KSC
16	Math Model ALSEP 3 Sim
17	CMS TEI Sim
17	Special Launch Sim for NBC Movie
18	CMS Launch Sim
19	SESL Tape Playback
19	LV Redundancy Test
25	Flight Readiness Test
March 2, 1970	EVA No. 2 (Flagstaff, Ariz)
2,	CMS Lunar Photo - Sequence 2 - Sim
3	CMS/LMS LM Ascent/Descent Sim
4	Math Model ALSEP 3 Sim
5	LMS Descent Sim
5	A/G Remoting Test - GSFC, GDS, GYM, HAW
6	A/G Remoting Test - GSFC, GWM, CRO, HSK
6	A/G Remoting Test - GSFC, ACN, BDA, CYI, MAD, MIL, TEX
6	Medable Decom C/O
6	MCC/MSFN Val 1041.2 - GSFC, MIL
9	Math Model FIDO /BSE Sim
10	LMS Descent Sim
11	Math Model ALSEP 3 Sim
11	CMS/LMS Ascent Sim
12	JJ Tracking Data Flow Test - GSFC, CRO, CYI, GWM, HAW, HSK, MAD
13	Math Model Lunar Impact Sim
13	A/G Remoting Test - GSFC, VAN
14	LV SIT (CMD History Test) - GSFC, KSC, MIL

March	16	EVA No. 2 (Flagstaff, Ariz) - Voice Only
	17	CMS TLI Sim
	18 - 20	MCC/MSFN Vals 1040.1, 2044 - GSFC, GWM, HAW, HSK, CRO, ACN, CYI, MIL, MAD, BDA, VAN, TEX, GYM, GDS
		Format 30 C/O, 1041.3 - GDS, GSFC, BDA
		3044, 3047 - VAN, GSFC
		3046, 3047 - HAW, CRO, GSFC, GYM, MAD, MAD-X, GWM, GDS, GDS-X, TEX, MIL, ACN, CYI, BDA, HSK, HSK-X
	18	CMS/LMS LOI Sim
	19	Astro Comm C/O - KSC
	19	Math Model ALSEP 3 Sim
	20	Medable Decom C/O
	20	LV SIT - TTY CMD History
	20	CMS Reentry and LMS Ascent Sim
	21	End-to-End Comm Val 4041 - KSC
	23	Math Model LOI/DES Sim
	23 - 25	Wet CDDT
	26	Dry CDDT
	30	Math Model FIDO/BSE Sim
	31	Math Model ALSEP 3 Sim
	31	LMS Descent Sim
April	1, 1970	Network Sim
	2	CMS/LMS Ascent Sim
	3	CMS LOI/DOI Sim
	3	A/G Remoting Test
	4	Spacecraft Time Conversion C/O
	6	CMS Launch Sim
	6	Format 30 Checkout - GSFC, MIL, HSK
	7	CMS/LMS Act/Des Sim
	7	A/G Remoting Test - GSFC, ACN, BDA, CRO, CYI, GDS, GWM, GYM, HAW, HSK, MAD, MIL, TEX
	8	T-53 Hour Checkout
	9	1.2 HF Checkout - GSFC, VAN

April	9, 1970	TLM and Color TV Val - GSFC, GDS
	9 - 11	Terminal Count
	11 - 17	Mission

4.1.2 MSFN Site Utilization

Table VIII represents the total hours that the MCC interfaced with each MSFN site for all Apollo 13 premission support. This includes all simulations, validations, and pad tests. Table II shows the number of hours devoted to TLM, CMD, or TRK data validation by the MCC with the various sites.

MSFN SITE UTILIZATION ANALYSIS

TABLE VIII

Site	Pre-Mission I/F Hours	Prime Time MSC	Prime Time SITE	Premium Time MSC	Premium Time SITE	Table II TLM	Table II CMD	Table II TKG
ACN	28.0	20.5	12.0	7.5	16.0	1.0	1.0	1.0
ALDC	388.0	259.5	265.0	128.5	123.0	7.5		
BDA	40.5	22.5	24.5	18.0	16.0	7.0	1.0	3.0
CRO	20.5	9.5	8.0	11.0	12.5	1.0	1.0	3.0
CYI	22.0	12.5	10.5	9.5	11.5	1.0	1.0	3.0
GDS	45.5	37.0	33.0	8.5	12.5	8.0	1.0	3.0
GWM	21.5	9.0	8.5	12.5	13.0	1.0	1.0	3.0
GYM	28.0	21.5	20.0	6.5	8.0	1.0	1.0	1.0
HAW	31.5	21.5	17.0	10.0	14.5	1.0	1.0	3.0
HSK	23.5	8.5	11.5	15.0	12.0	1.0	1.0	3.0
MAD	29.5	21.0	14.5	8.5	15.0	1.0	1.0	3.0
MIL	157.0	84.0	129.0	73.0	28.0	25.0	13.5	3.0
TEX	25.0	18.5	19.0	6.5	6.0	7.5	5.5	3.0
VAN	19.0	12.5	12.5	6.5	6.5	1.0	1.0	1.0

4.1.3 Mission Program Build and Testing

The build and testing of the Apollo 13 RTCC program utilized 799 hours of IBM 360/75 time. The build began in August 1969 and updates were added after the program was delivered in January 1970.

The CCATS program was delivered in December 1969. A total of 364 hours were utilized on the UNIVAC 494 computers for the building and testing of the program.

The development and testing of the ALSEP program for Apollo 13 required 160 hours of 360/75 time. Development began in September 1969 and continued with some system testing after the program was delivered in February 1970.

4.2 Network Status recording for Apollo 13 began with ISI #1. Upon being placed in Mission Status, the site status was maintained and displayed via TV to the Mission Operations Control Room. This status was obtained from daily site status messages from Station M&O and from coordination with the Network Support Team at GSFC. Status messages were received at specific intervals during the support count, with the last being a voice check at T-2:30 minutes. After launch, status was reported verbally to the Network Controller and by TTY to the status monitor. During Apollo 13 (ISI #1 to splash) the status monitor received 715 status messages.

The LOS, AOS and maximum elevation were extracted from the PSAT tables and used with the mission tracking requirements to determine remote site release criteria. A site was released totally or partially dependent upon the following:

A. USB maximum elevation of less than 6 degrees
B. Site not required for 6 hours.
C. MCC tracking requirements

4.2.1 Network Status at launch is listed below. The red can support items indicate that some piece of equipment in the system was down, but that backup units were available or the outage would not cause a major effect on the systems support. Red cannot support items indicate that a system (or systems) was unable to provide required support.

Site	Status
ACN	Green
AGN	Green
BDA	Green
CYI	Green
CRO	Red can support
GDS	Green
GDSX	Green
GYM	Green
GWM	Green
HAW	Green
HSK	Red can support
MAD	Red can support
MADX	Green
MIL	Green
TEX	Green
VAN	Red can support
ARIA	Green

The "Red Can Support" system problems were as follows:

a) Carnarvon - the SPAN radio telescope control oven temperature was out of limits. (ETO 13/0030Z.

b) Honeysuckle - the RSDP 642B NR 1/CMD was faulting intermittently. ETO unknown.

c) Madrid - timing problem with the Loran C receiver Model LFT 504. ETO 12/1630Z.

d) USNS Vanguard - the CDP 1230/DTU H.S. data output was erratic. ETO post-mission. Also, the C-band receivers were drifting. No ETO.

4.2.2 Network Support of Apollo 13 is listed below, the hours shown indicate the interface time between the site and MCC. The times indicated are total support times from T-3 hours in the terminal count until the site was released from Mission support. The total site release messages sent were 108.

Site	Hours
KSC	3:12
CNV	3:12
ALDS/DATA CORE	7:53
AOCC	7:49
ARIA 1	7:19
ARIA 2	7:19
ARIA 3	7:19
ARIA 4	7:49
GWM	64:30
ACN	65:11
VAN	5:57
GYM	81:56
HSK	62:05
HSK-X	66:13
MAD	81:19
MAD-X	80:29
CYI	60:15
CRO	68:14
BDA	82:10
MLA	14:27
MIL	83:25
TEX	69:47
GDS	86:56
GDS-X	86:56
HAW	86:41
PARKES	33:25
MARS	41:54

4.2.3 Utilization of the RTCC and CCATS computers in direct support of the Apollo 13 mission constituted a total of 354.5 hours in the RTCC and 340.5 hours on the CCATS computers. A breakdown of these hours is as follows:

	RTCC Hours	CCATS Hours
Flight Control	287.5	241.0
Operations Support	67.0	99.5
	354.5	340.5

During the Apollo 13 mission, no major premission testing was conducted for the next mission.

NASA — MSC — Coml., Houston, Texas

APOLLO

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MISSION OPERATIONS REPORT

APOLLO 13

APRIL 28, 1970

FCD
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