ADDENDUM 1

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MSC APOLLO 13 INVESTIGATION TEAM

FINAL REPORT

PANEL 3

FLIGHT OPERATIONS AND NETWORK

ADDENDUM 1

JUNE 1970

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

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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
56:35: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

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 trajecto
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

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 and CO_2 PP dropped to 0.1 mm Hg.
93:55:XX	LMP red hose on ECS package CDR red hose on 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

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 evant 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
138:26: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

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 ossible momentary battery, bus, or feeder short (Figures 9-1 to 9-5).

During post mission analysis of the Apollo 13 data, a voice report y the crew at 97:14:42 GET of a thump and a shower of snowflakes from the escent stage led to the detection of a significant "glitch" in the electrical parameters at 97:13:55 GET. The Electrical Power System was conigured with batteries 1-4 on high taps and the crosstie BAL LOAD cb's losed at the time of the transients. The PCM was in the low bit rate ode 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 0 and 37 amperes during the same period.

3. CDR bus volts dropped to a minimum of 28.9 volts during one ample.

4. LMP bus volts dropped to a minimum of 27.7 volts during one ample.

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 ± 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.

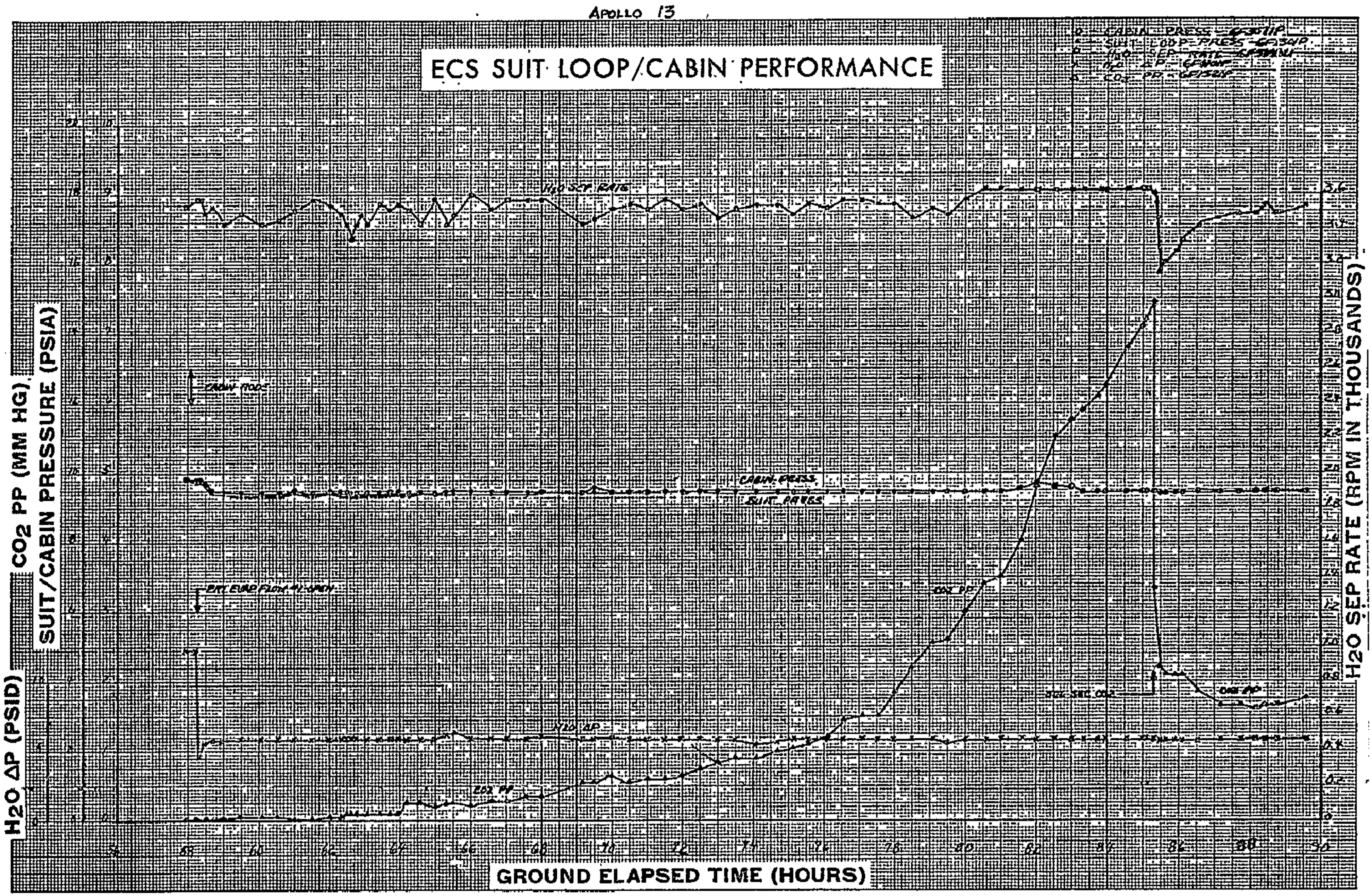
All plots except for Figure 9-4 were made using RTCC processed data with LM display times, which are time tagged at the remoted site. This reference time is called LEMEGMT. Figure 9-4 was plotted using the Program Office bandpass printouts and the GET has been biased by a spacecraft-to-earth RF transmission time.

TABLE 3

EPS Parameter LBR Sampling Sequence

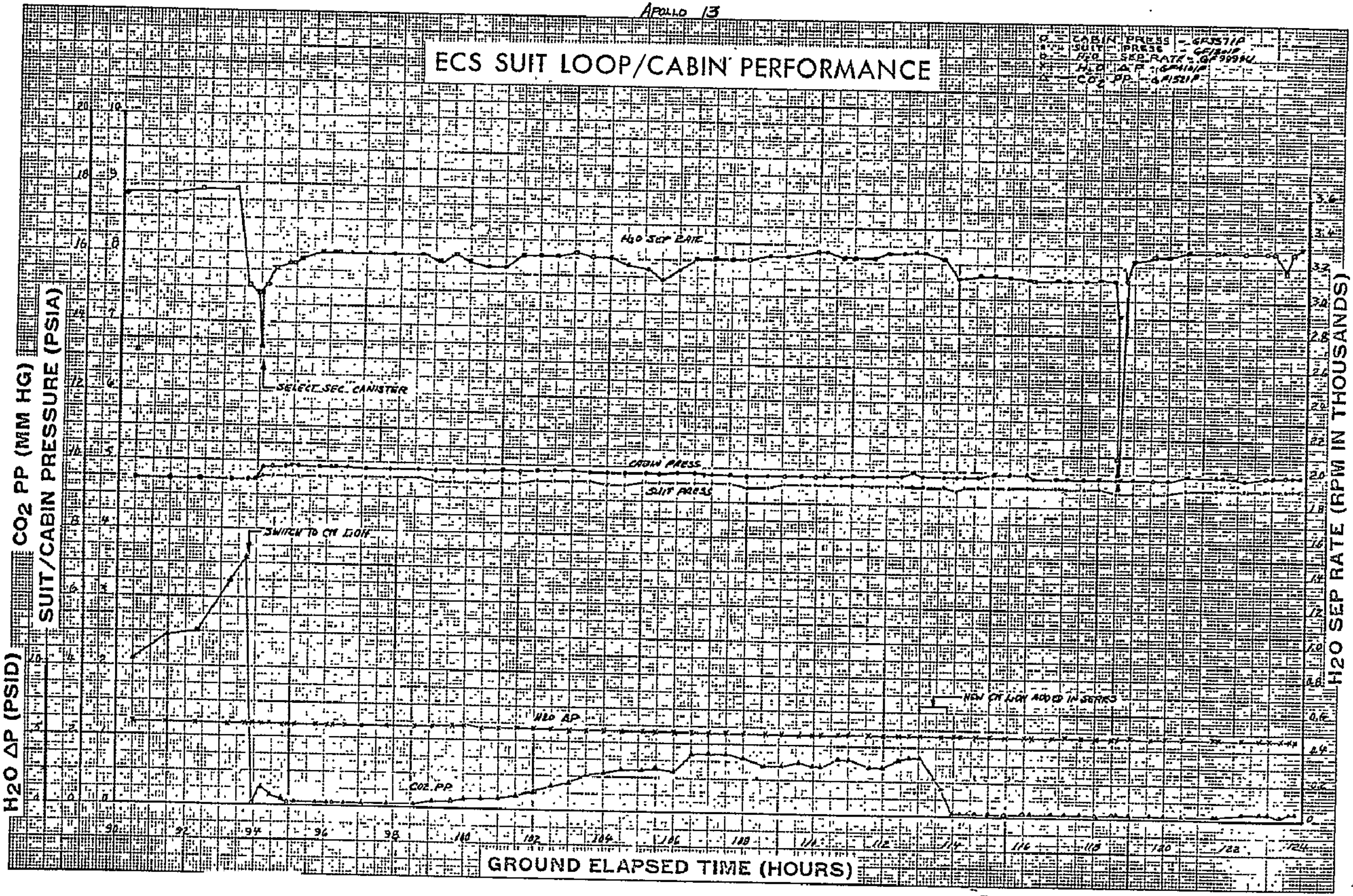
PARAMETER		LBR WORD		
BATTERY 3 CURRENT	-	PRIMARY	-	67
BATTERY 4 CURRENT	-	PRIMARY	-	71
BATTERY 1 CURRENT	-	PRIMARY	-	96
BATTERY 4 CURRENT	-	REDUNDANT	-	99
BATTERY 3 CURRENT	-	REDUNDANT	-	100
BATTERY 1 CURRENT	-	REDUNDANT	-	111
BATTERY 2 CURRENT	-	PRIMARY	-	127
CDR BUS VOLTS	-		-	131
LMP BUS VOLTS	-	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
CO2 PP (MM HG)
SUIT/CABIN PRESSURE (PSIA)
H2O ΔP (PSID)
H2O SEP RATE (RPM IN THOUSANDS)
GROUND ELAPSED TIME (HOURS)
H2O SEP RATE
CABIN PRESS
SUIT PRESS
H2O ΔP
CO2 PP

Figure 1-



APOLLO 13
ECS SUIT LOOP/CABIN PERFORMANCE
CABIN PRESS
SUIT PRESS
H2O SEP RATE
H2O ΔP
CO2 PP
CO2 PP (MM HG)
SUIT/CABIN PRESSURE (PSIA)
H2O ΔP (PSID)
H2O SEP RATE (RPM IN THOUSANDS)
GROUND ELAPSED TIME (HOURS)
H2O SEP RATE
SELECT SEC. CANISTER
CABIN PRESS
SUIT PRESS
SWITCH TO CM LiOH
NEW CM LiOH ADDED IN SERIES
H2O ΔP
CO2 PP

Figure 1-2

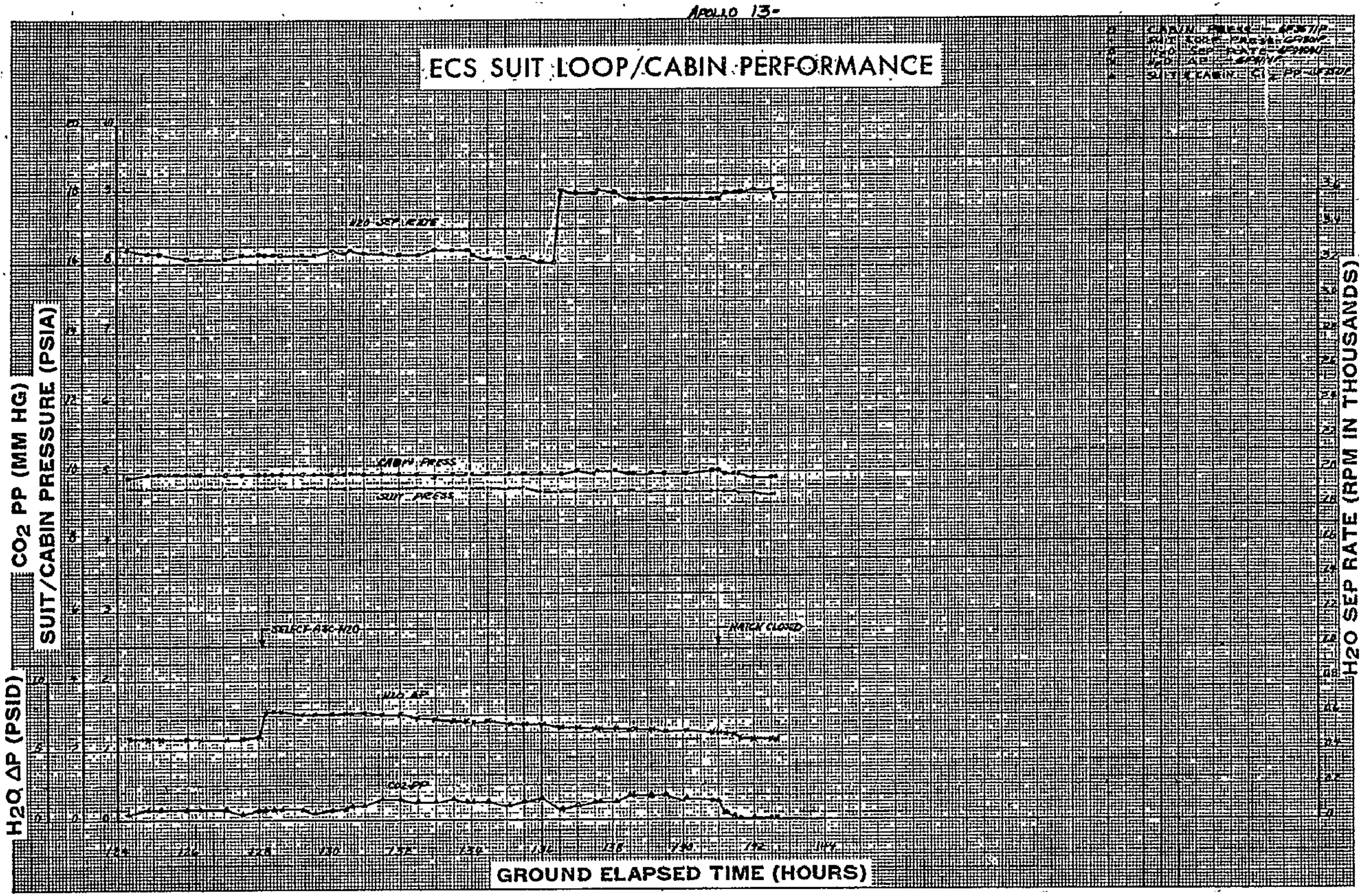

APOLLO 13-
ECS SUIT LOOP/CABIN PERFORMANCE
H2O SEP RATE
CABIN PRESS
SUIT PRESS
HATCH CLOSED
CO2 PP
SUIT/CABIN PRESSURE (PSIA)
CO2 PP (MM HG)
H2O ΔP (PSID)
H2O SEP RATE (RPM IN THOUSANDS)
GROUND ELAPSED TIME (HOURS)

Figure 1-3

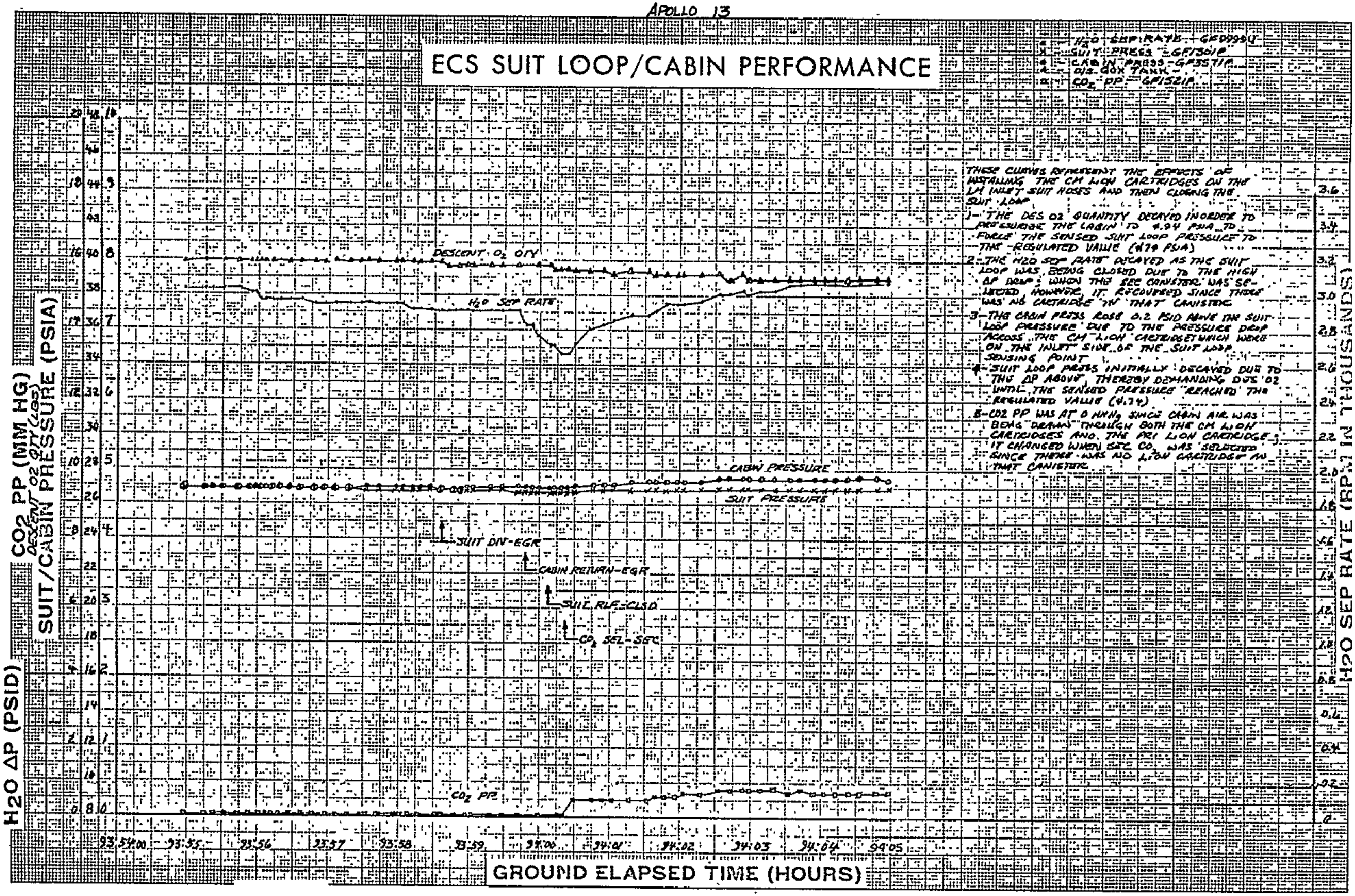

APOLLO 13
ECS SUIT LOOP/CABIN PERFORMANCE
H2O SEP RATE - GF0995U
SUIT PRESS - GF1301P
CABIN PRESS - GF3571P
CO2 PP - GF1521P
THESE CURVES REPRESENT THE EFFECTS OF INSTALLING THE CM LiOH CARTRIDGES ON THE LM INLET SUIT HOSES AND THEN CLOSING THE SUIT LOOP
1- THE DES O2 QUANTITY DECAYED IN ORDER TO PRESSURIZE THE CABIN TO 4.94 PSIA TO FORCE THE SENSED SUIT LOOP PRESSURE TO THE REGULATED VALUE (4.74 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 (4.74)
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)
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
GROUND ELAPSED TIME (HOURS)

Figure 1-4

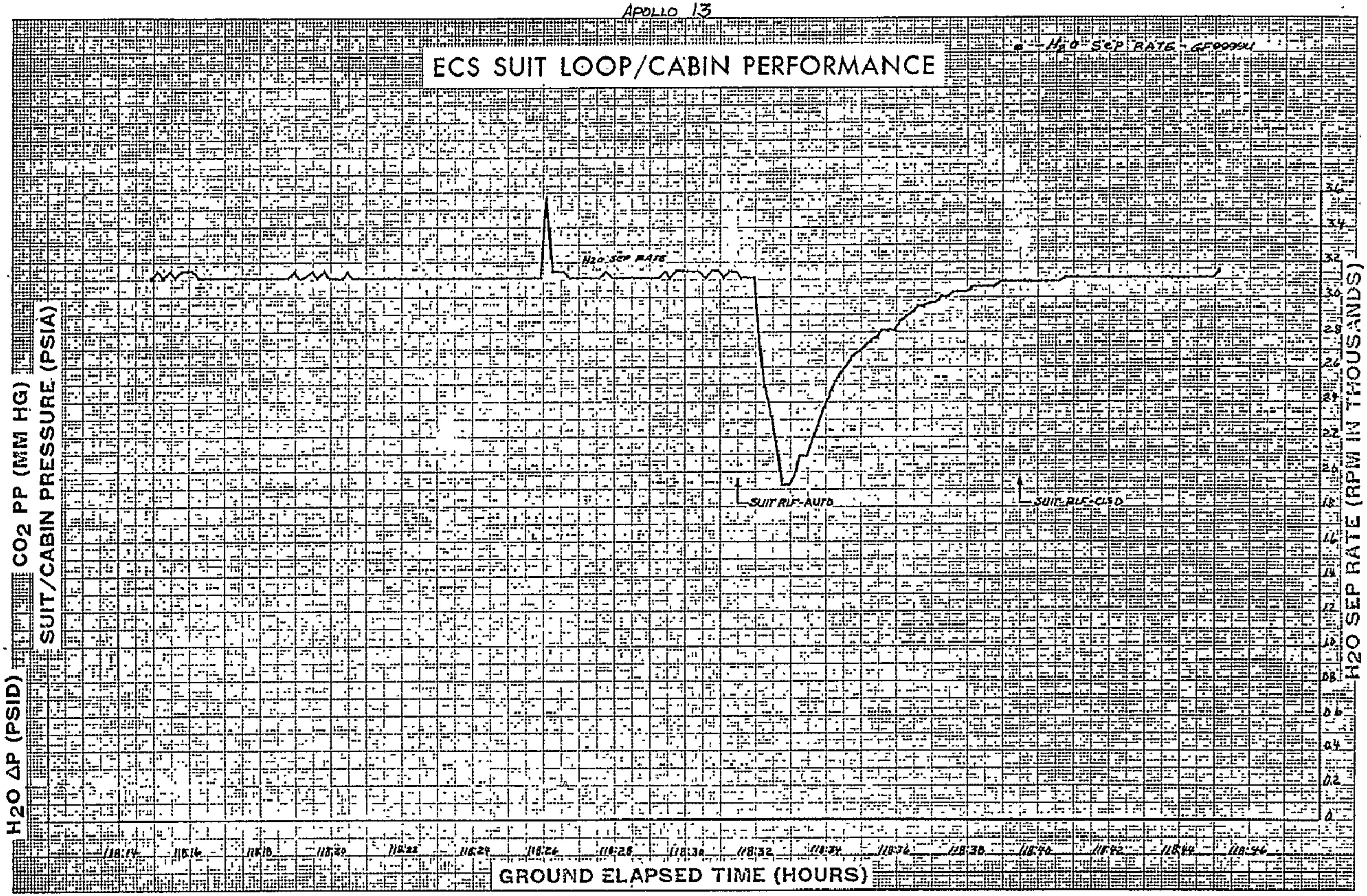

APOLLO 13
ECS SUIT LOOP/CABIN PERFORMANCE
H2O SEP RATE
H2O ΔP (PSID)
CO2 PP (MM HG)
SUIT/CABIN PRESSURE (PSIA)
H2O SEP RATE (RPM IN THOUSANDS)
SUIT R/F-AUTO
GROUND ELAPSED TIME (HOURS)

Figure 1-5

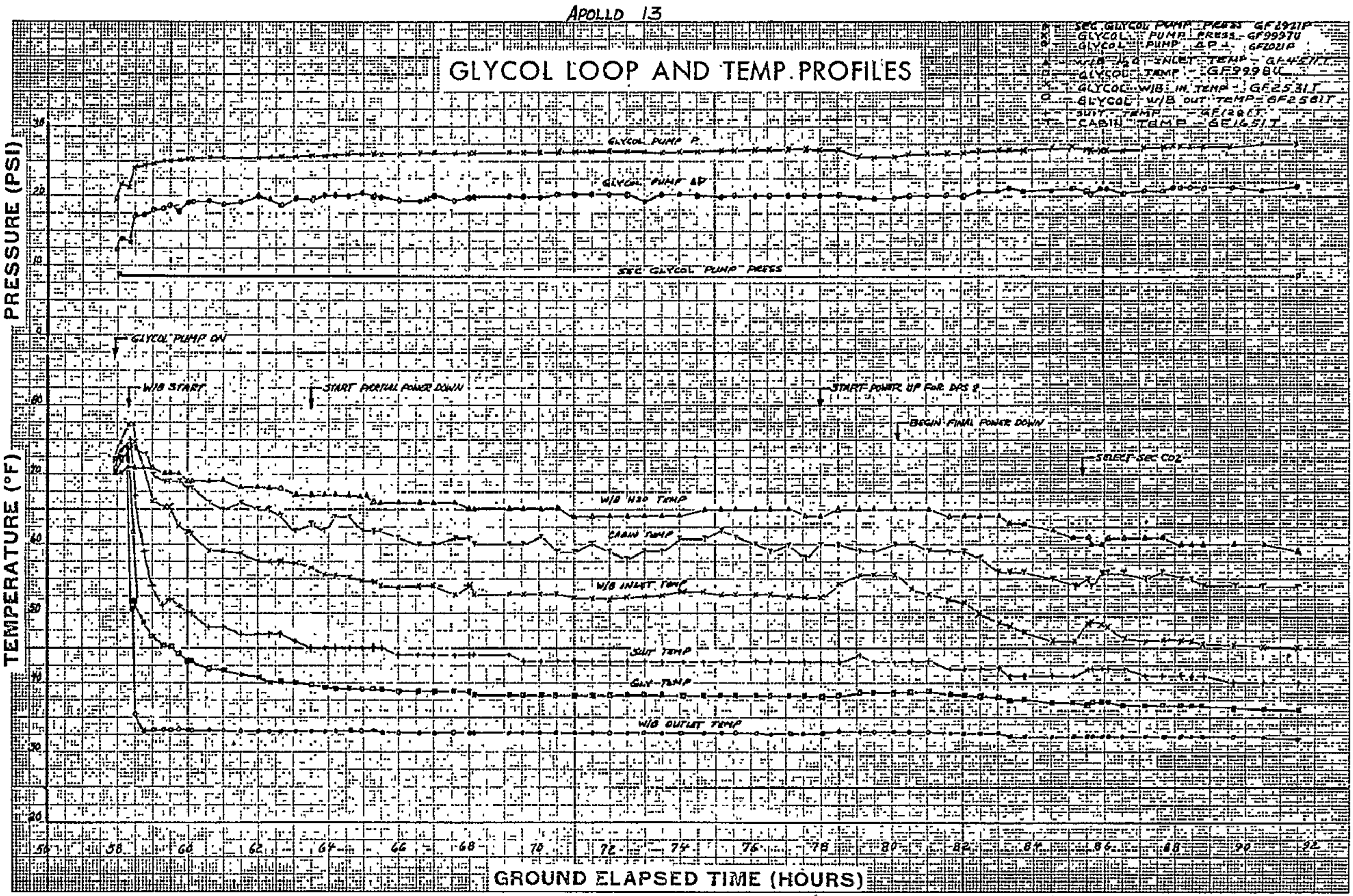

APOLLO 13
GLYCOL LOOP AND TEMP. PROFILES
SEC GLYCOL PUMP PRESS GF2921P
GLYCOL PUMP PRESS - GF9997U
GLYCOL PUMP ΔP
W/B H2O INLET TEMP
GLYCOL TEMP - GF9998U
GLYCOL W/B IN TEMP - GF2531T
GLYCOL W/B OUT TEMP - GF2581T
SUIT TEMP
CABIN TEMP - GF1651T
PRESSURE (PSI)
TEMPERATURE (°F)
GLYCOL PUMP P
GLYCOL PUMP 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
GROUND ELAPSED TIME (HOURS)

Figure 2-1

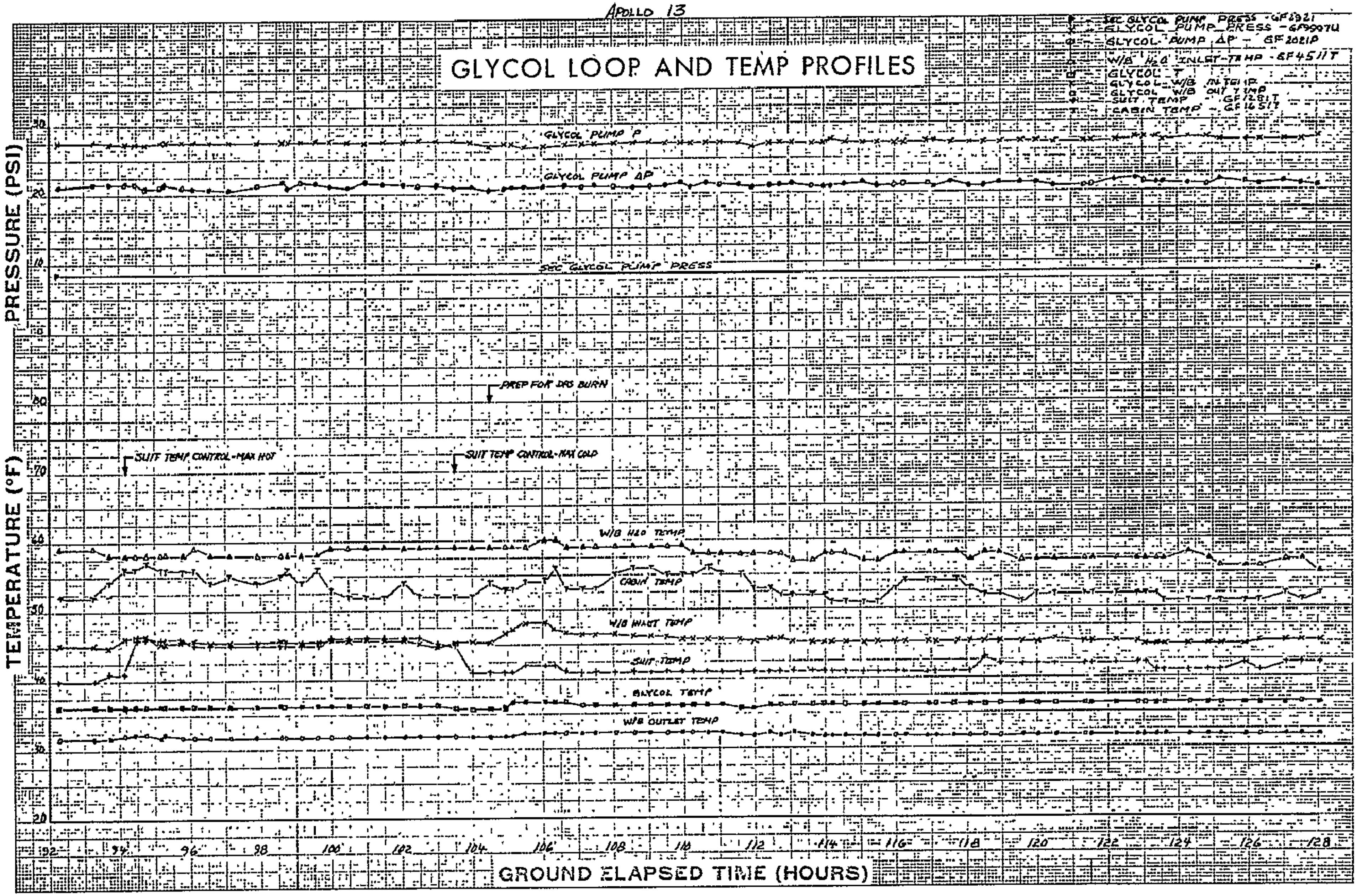

APOLLO 13
GLYCOL LOOP AND TEMP PROFILES
SEC GLYCOL PUMP PRESS
GLYCOL PUMP PRESS
GLYCOL PUMP ΔP
W/B H2O INLET TEMP - GF4511T
GLYCOL T
GLYCOL W/B IN TEMP
GLYCOL W/B OUT TEMP
SUIT TEMP - GF1281T
CABIN TEMP - GF1651T
PRESSURE (PSI)
TEMPERATURE (°F)
GLYCOL PUMP P
GLYCOL PUMP ΔP
SEC GLYCOL PUMP PRESS
PREP 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
92
94
96
98
100
102
104
106
108
110
112
114
116
118
120
122
124
126
128
GROUND ELAPSED TIME (HOURS)

Figure 2-2

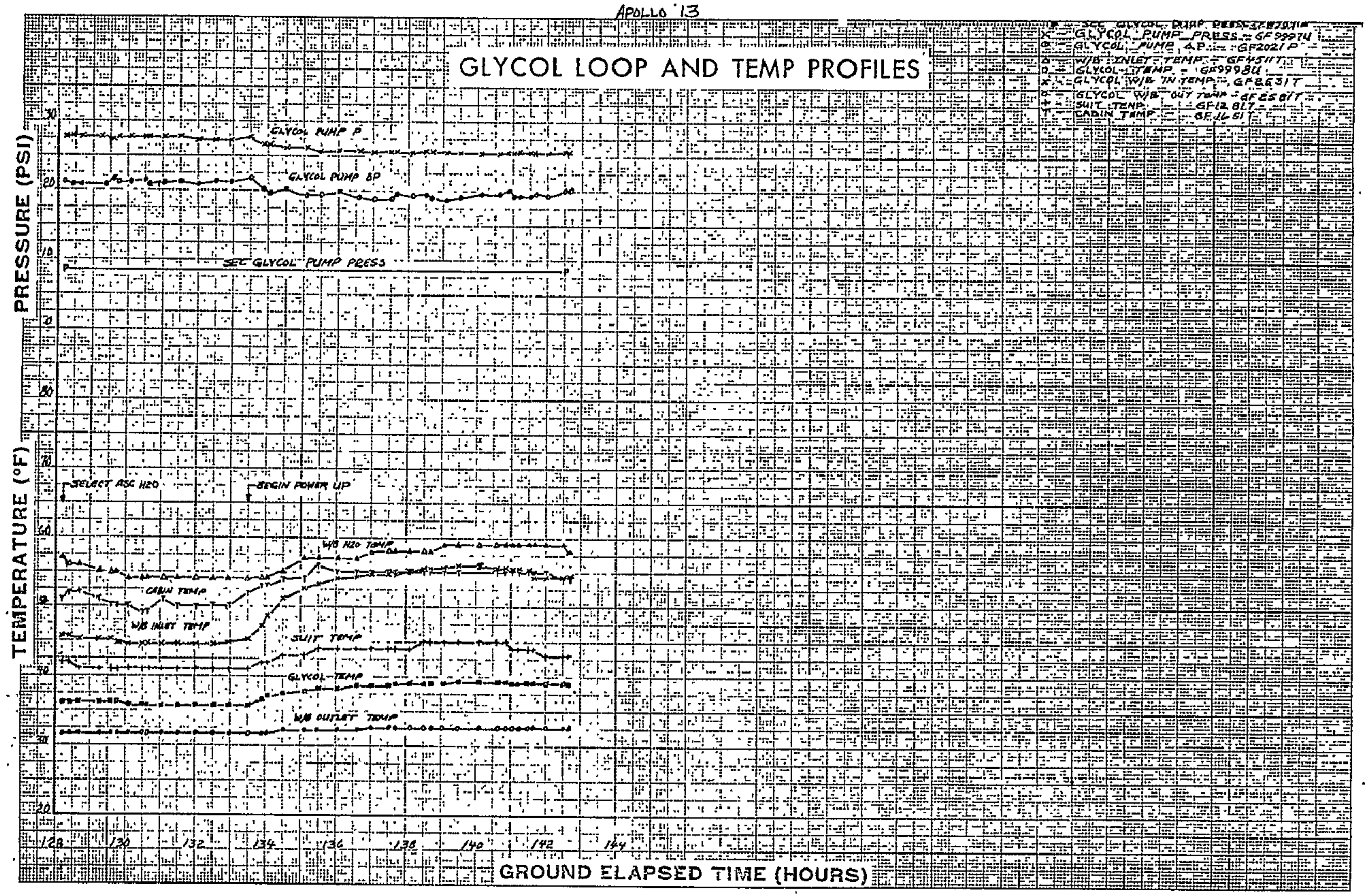

APOLLO 13
GLYCOL LOOP AND TEMP PROFILES
GLYCOL PUMP PRESS
GLYCOL PUMP ΔP
W/B INLET TEMP
GLYCOL TEMP
GLYCOL W/B IN TEMP
GLYCOL W/B OUT TEMP
SUIT TEMP
CABIN TEMP
PRESSURE (PSI)
TEMPERATURE (°F)
GLYCOL PUMP P
GLYCOL PUMP ΔP
SEC GLYCOL PUMP PRESS
SELECT ASC H2O
BEGIN POWER UP
W/B H2O TEMP
CABIN TEMP
W/B INLET TEMP
SUIT TEMP
GLYCOL TEMP
W/B OUTLET TEMP
128
130
132
134
136
138
140
142
144
GROUND ELAPSED TIME (HOURS)

Figure 2-3

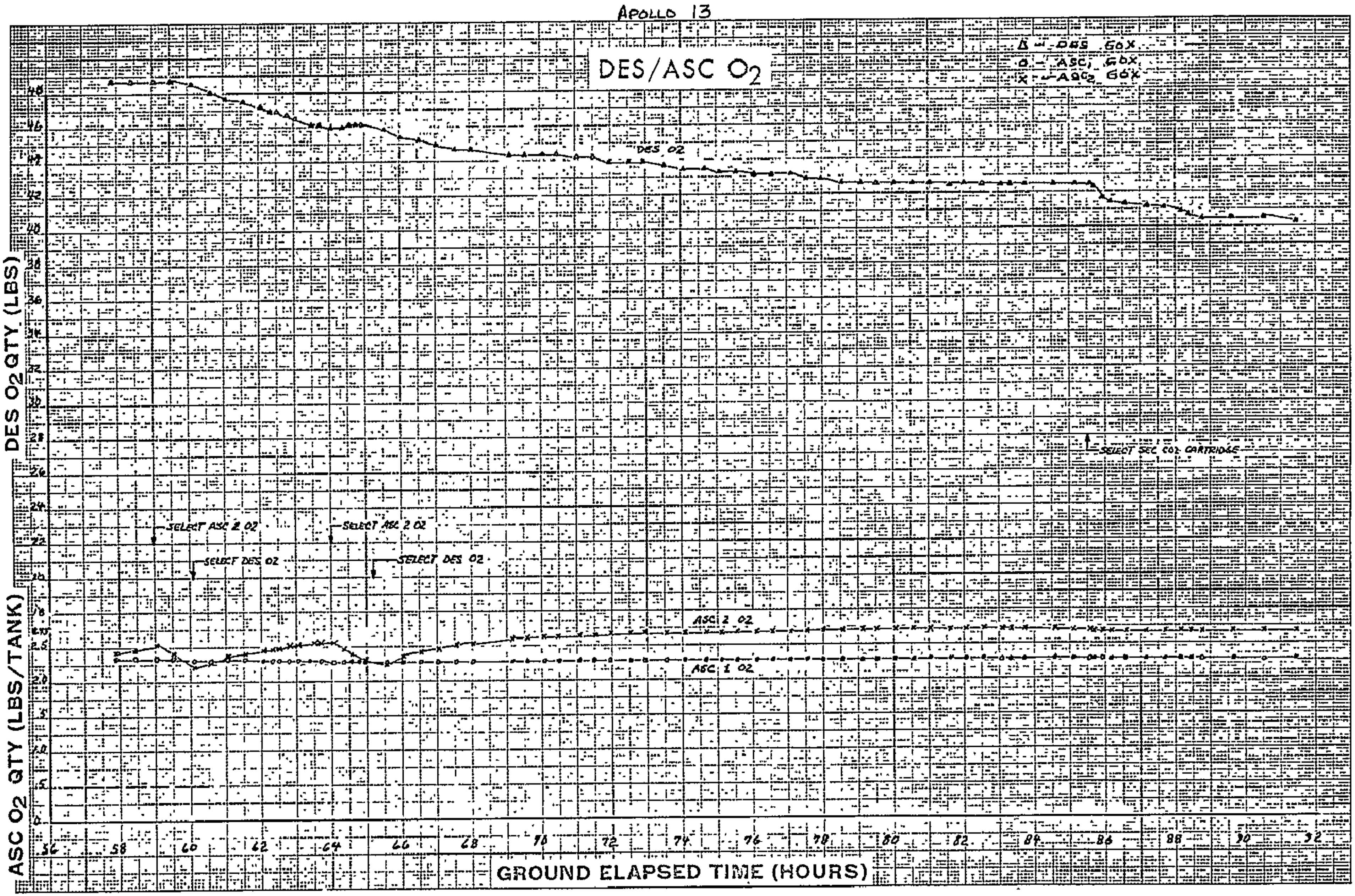

APOLLO 13
DES/ASC O_2
Δ — DES GOX
○ — ASC1 GOX
X — ASC2 GOX
DES O2
ASC 2 O2
ASC 1 O2
SELECT ASC 2 O2
SELECT DES O2
SELECT ASC 2 O2
SELECT DES O2
SELECT SEC CO2 CARTRIDGE
DES O_2 QTY (LBS)
ASC O_2 QTY (LBS/TANK)
56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92
GROUND ELAPSED TIME (HOURS)

Figure 3-1

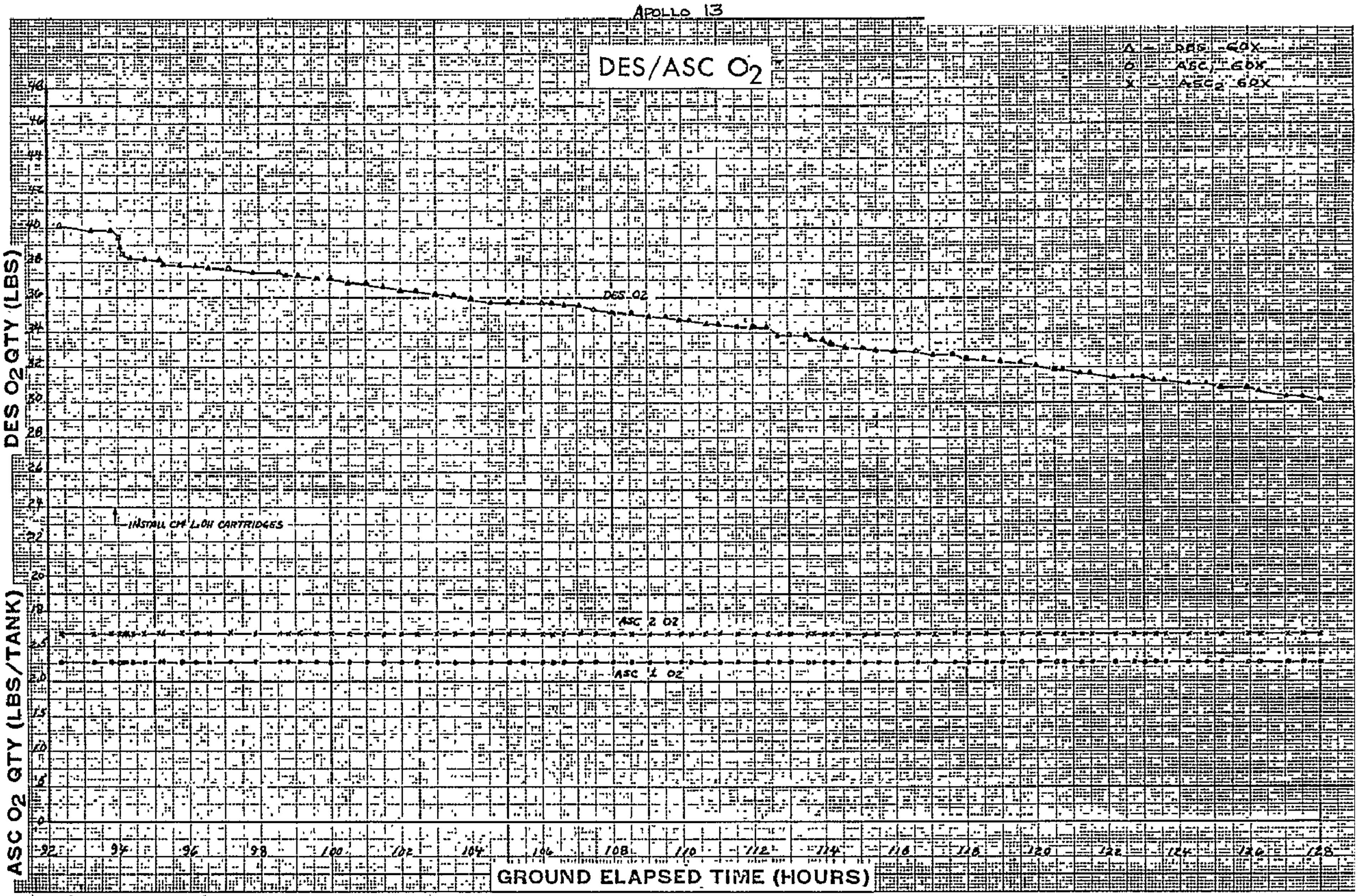

APOLLO 13
DES/ASC O2
Δ — DES GOX
O — ASC1 GOX
X — ASC2 GOX
DES O2 QTY (LBS)
ASC O2 QTY (LBS/TANK)
DES O2
INSTALL CM LiOH CARTRIDGES
ASC 2 O2
ASC 1 O2
GROUND ELAPSED TIME (HOURS)

Figure 3-2

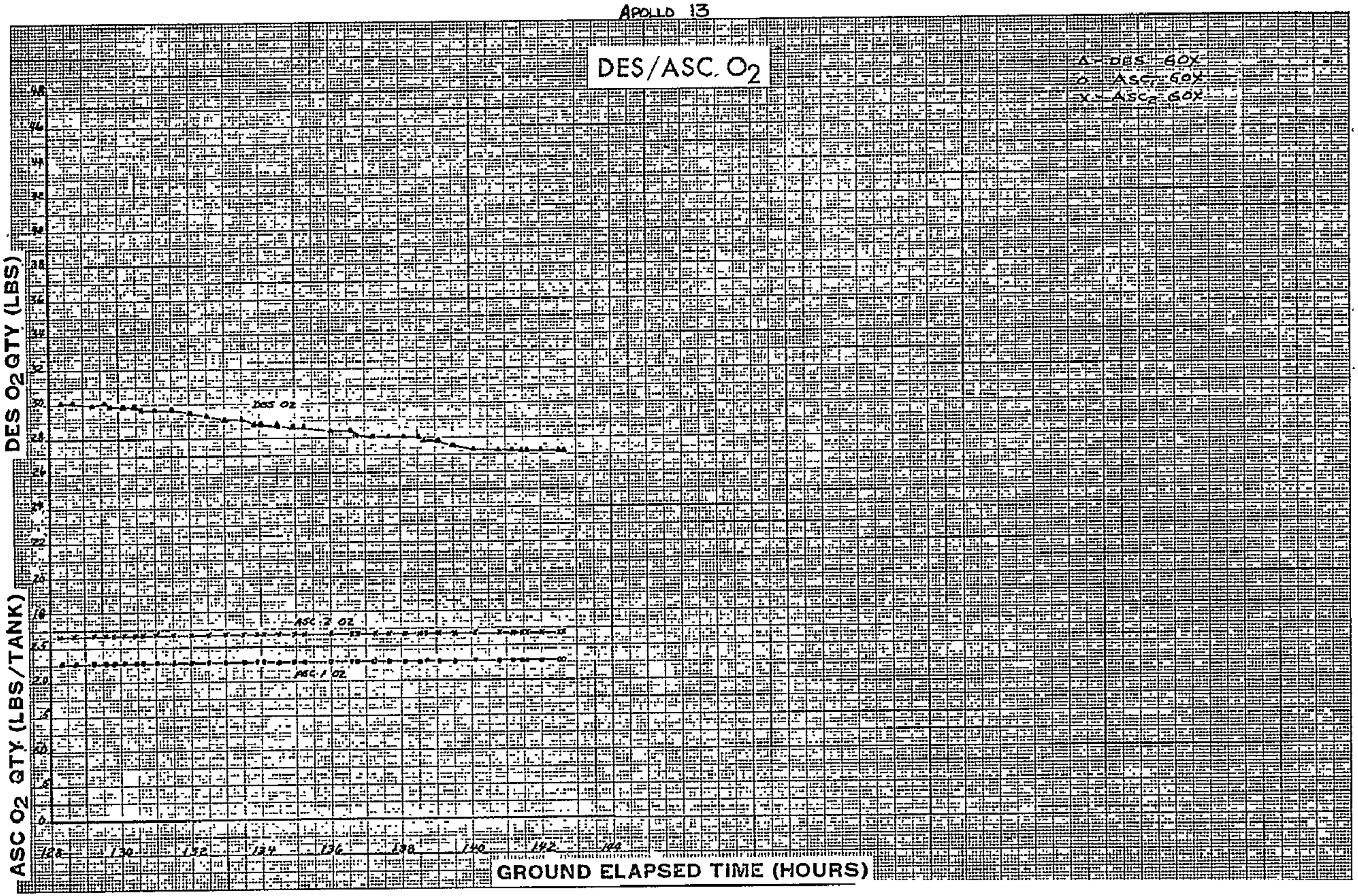

APOLLO 13
DES/ASC. O_2
Δ - DES GOX
o - ASC1 GOX
x - ASC2 GOX
DES O_2 QTY (LBS)
ASC O2 QTY (LBS/TANK)
DES O2
ASC 2 O2
ASC 1 O2
128
130
132
134
136
138
140
142
144
GROUND ELAPSED TIME (HOURS)

Figure 3-3

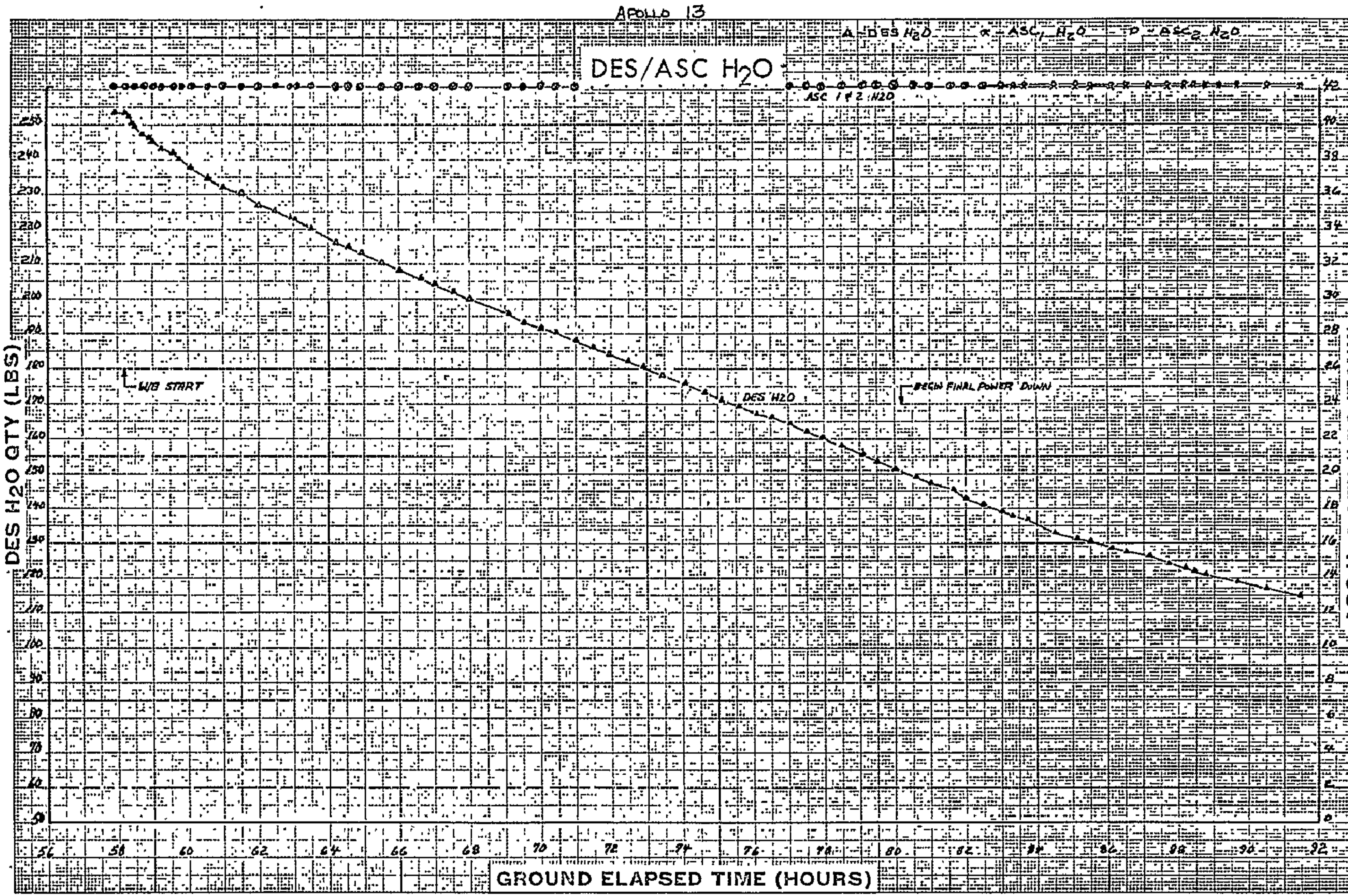

APOLLO 13
DES/ASC H2O
DES H2O QTY (LBS)
ASC H2O QTY (LBS/TANK)
GROUND ELAPSED TIME (HOURS)
W/B START
DES H2O
BEGIN FINAL POWER DOWN
ASC 1 & 2 H2O

Figure 4-1

APOLLO 13

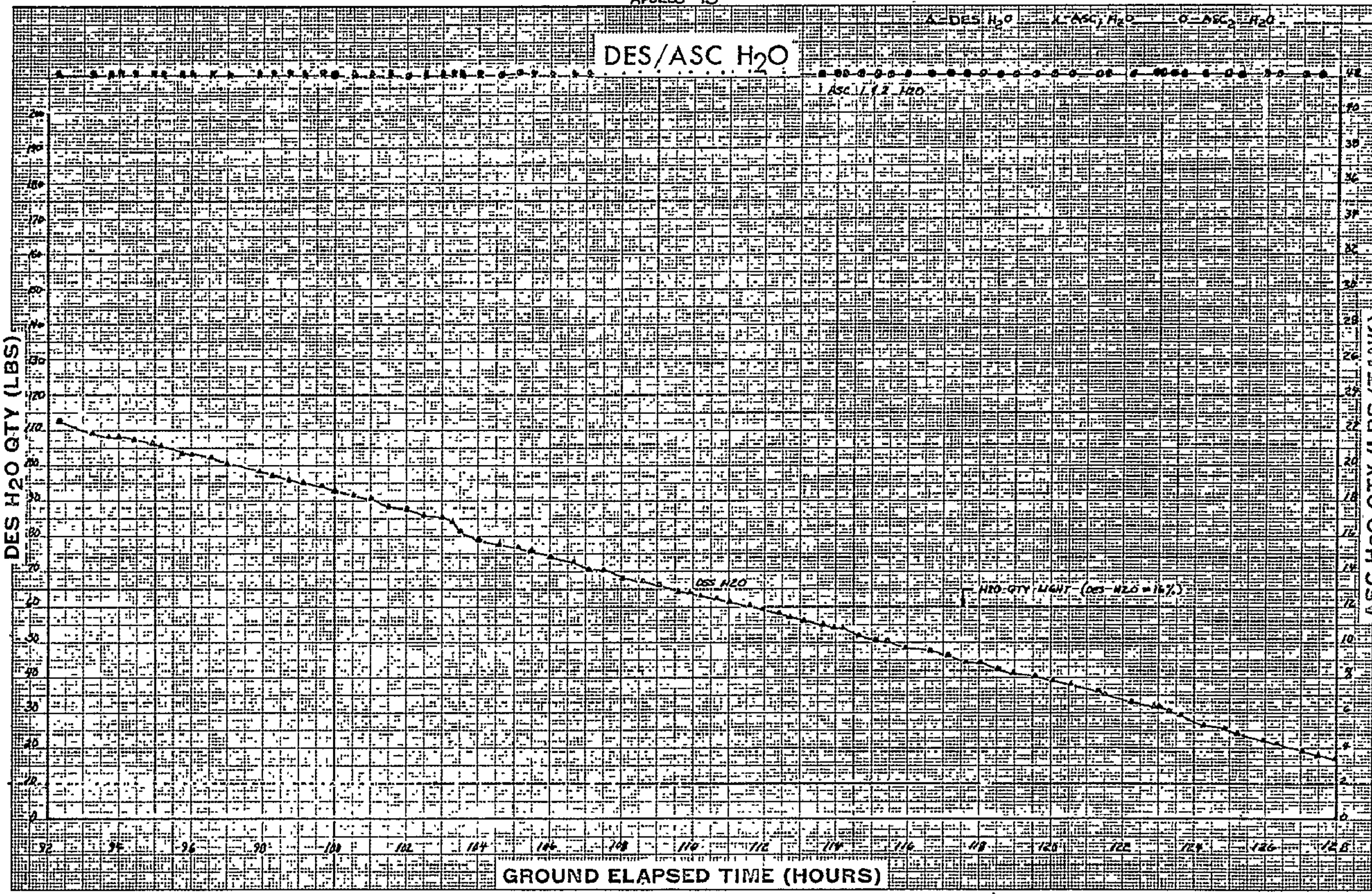


Figure 4-2

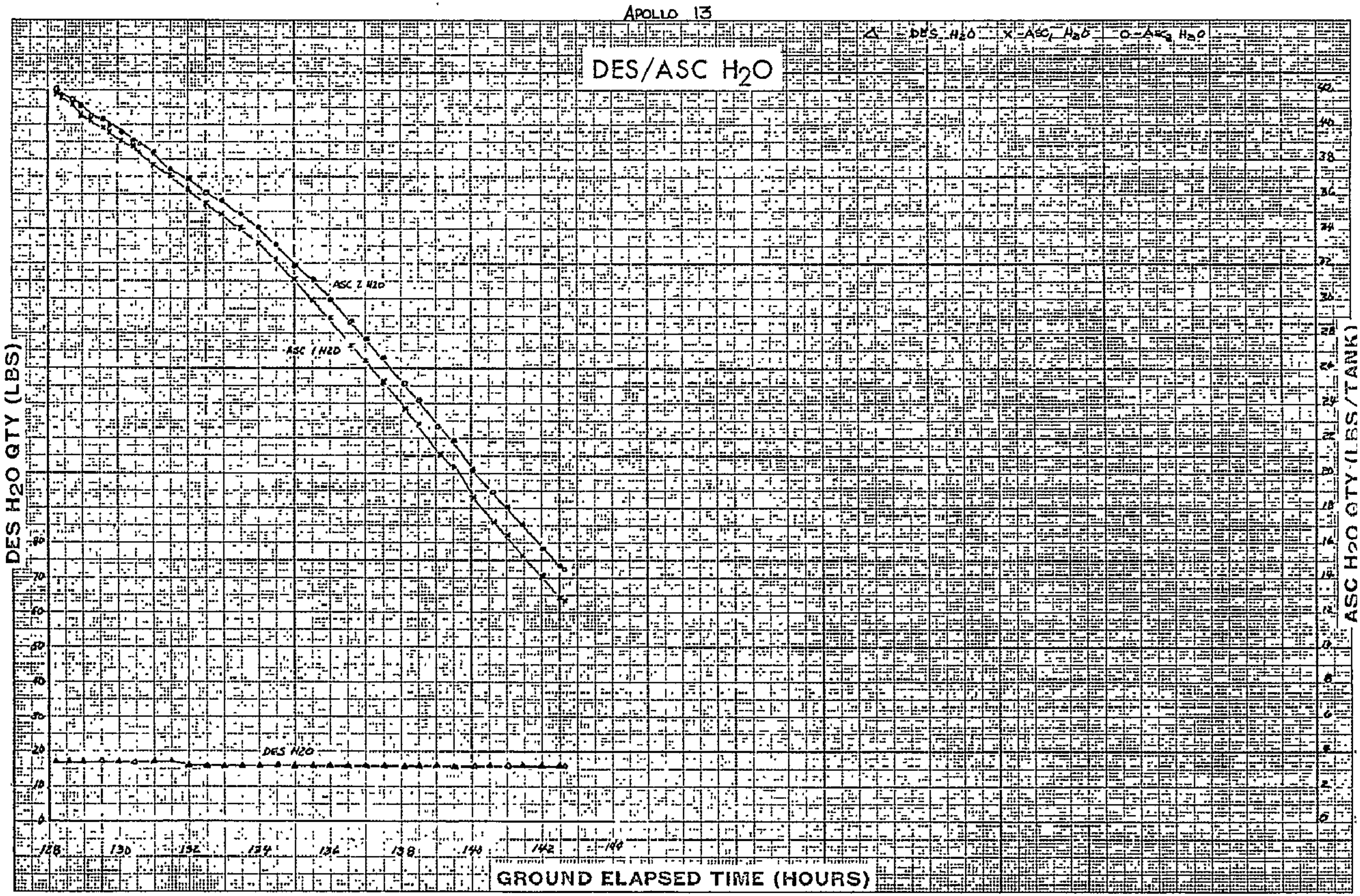

APOLLO 13
DES/ASC H2O
Δ - DES H2O   x - ASC1 H2O   o - ASC2 H2O
ASC 2 H2O
ASC 1 H2O
DES H2O
DES H2O QTY (LBS)
ASC H2O QTY (LBS/TANK)
GROUND ELAPSED TIME (HOURS)
128
130
132
134
136
138
140
142
144

Figure 4-3

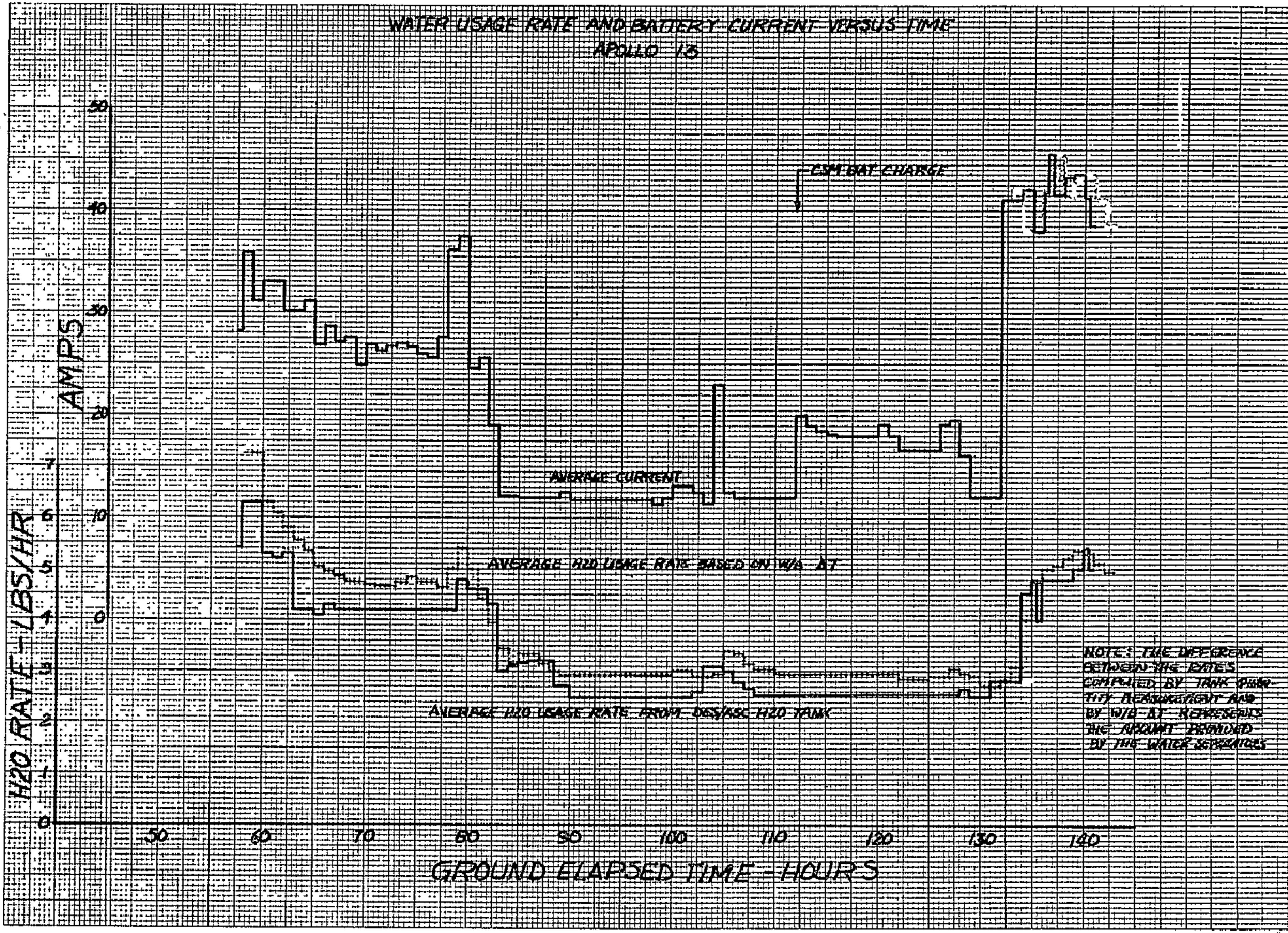

WATER USAGE RATE AND BATTERY CURRENT VERSUS TIME
APOLLO 13
CSM BAT CHARGE
AVERAGE CURRENT
AVERAGE H2O USAGE RATE BASED ON W/B ΔT
AVERAGE H2O USAGE RATE FROM DES/ASC H2O TANK
NOTE: THE DIFFERENCE BETWEEN THE RATES COMPUTED BY TANK QUANTITY MEASUREMENT AND BY W/B ΔT REPRESENTS THE AMOUNT REMOVED BY THE WATER SEPARATORS
AMPS
H2O RATE - LBS/HR
GROUND ELAPSED TIME - HOURS
50
60
70
80
90
100
110
120
130
140

Figure 5

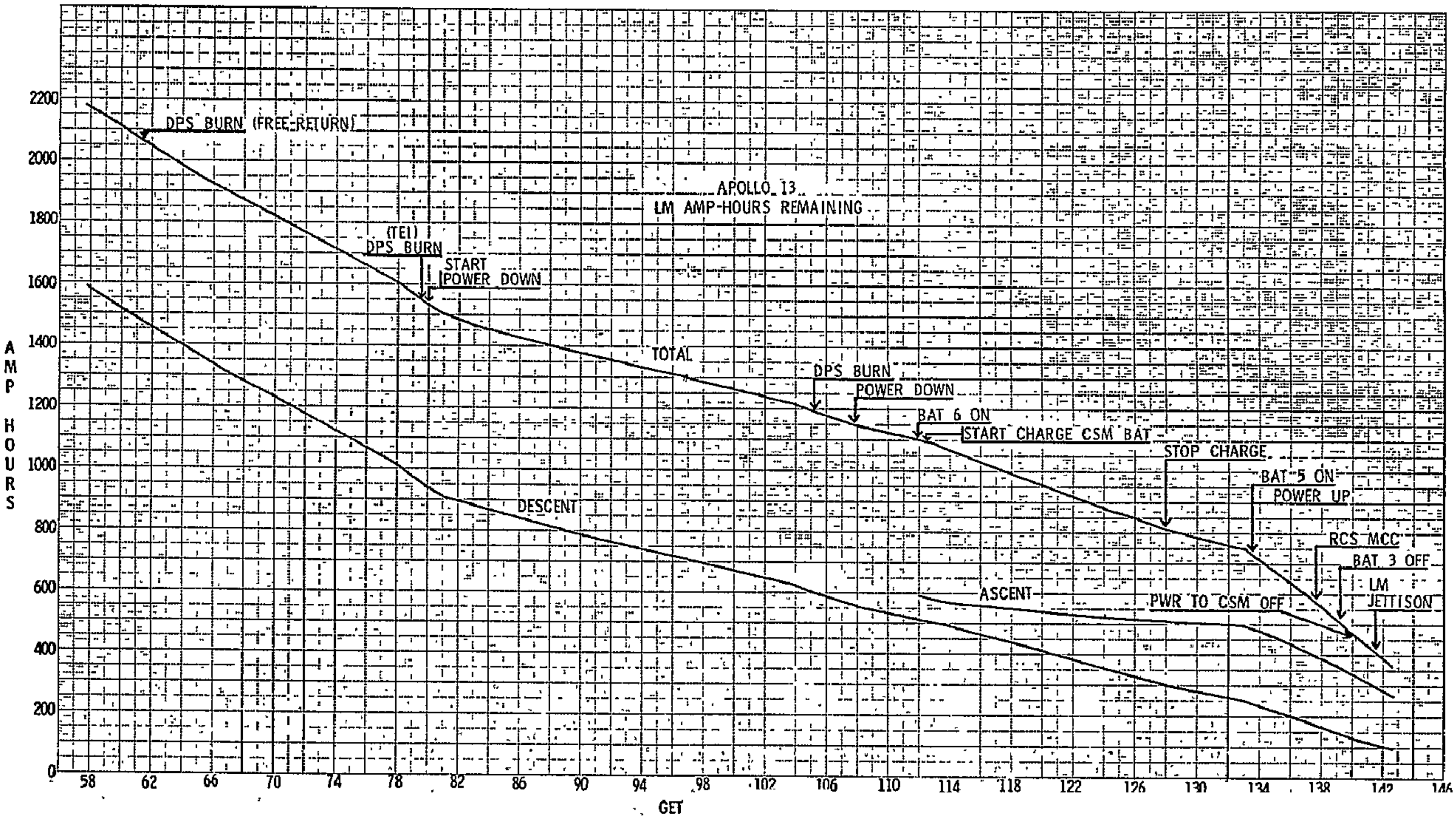

APOLLO 13
LM AMP-HOURS REMAINING
AMP HOURS
GET
DPS BURN (FREE-RETURN)
(TEI)
DPS BURN
START
POWER DOWN
TOTAL
DPS BURN
POWER DOWN
BAT 6 ON
START CHARGE CSM BAT
STOP CHARGE
BAT 5 ON
POWER UP
RCS MCC
BAT 3 OFF
LM
JETTISON
DESCENT
ASCENT
PWR TO CSM OFF
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
58
62
66
70
74
78
82
86
90
94
98
102
106
110
114
118
122
126
130
134
138
142
146

Figure 6

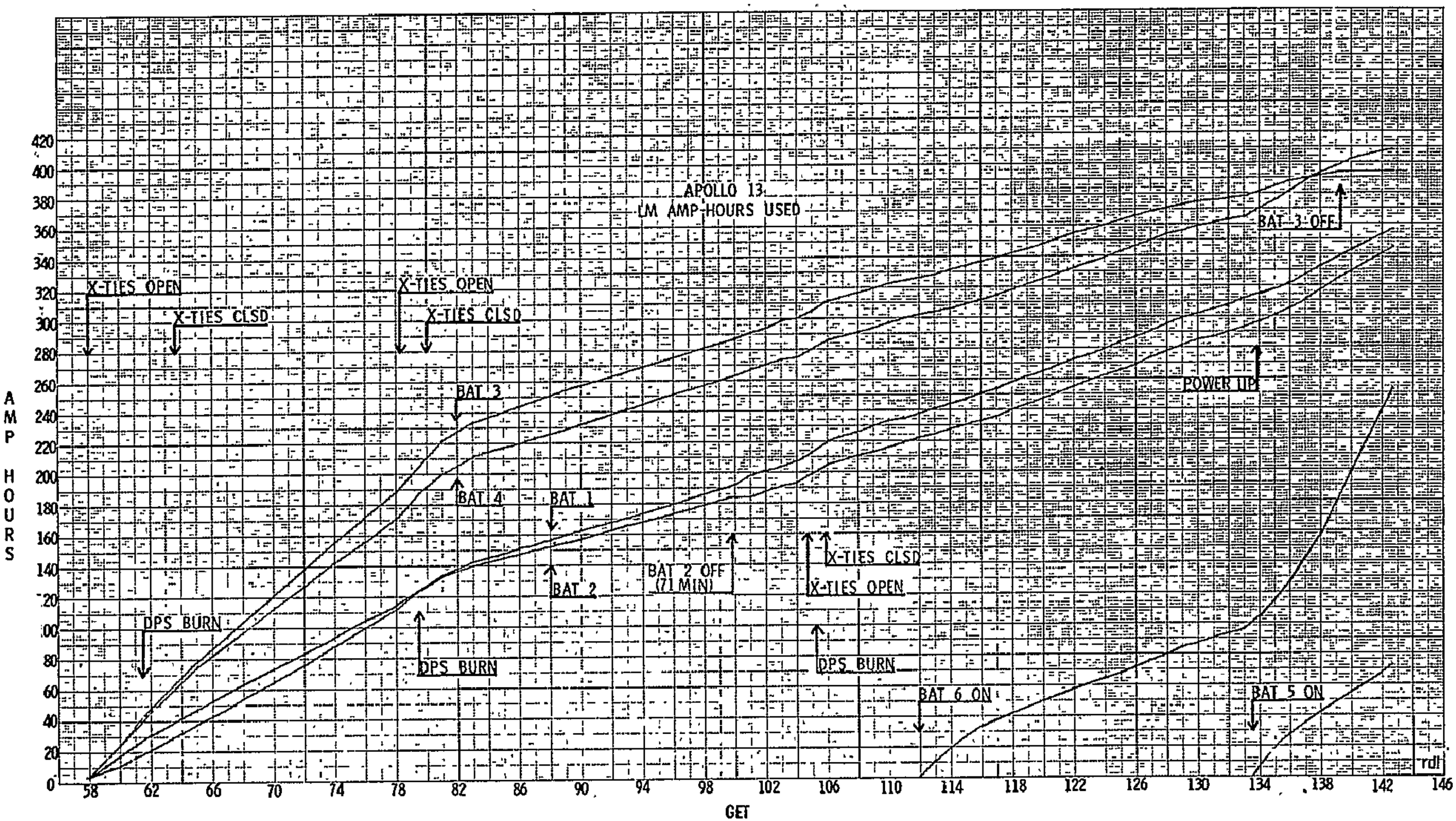

APOLLO 13
LM AMP-HOURS USED
AMP HOURS
GET
X-TIES OPEN
X-TIES CLSD
X-TIES OPEN
X-TIES CLSD
BAT 3
BAT 4
BAT 1
BAT 2
BAT 2 OFF
(71 MIN)
X-TIES CLSD
X-TIES OPEN
DPS BURN
DPS BURN
DPS BURN
BAT 6 ON
BAT 5 ON
POWER UP
BAT 3 OFF
rdl

Figure 7

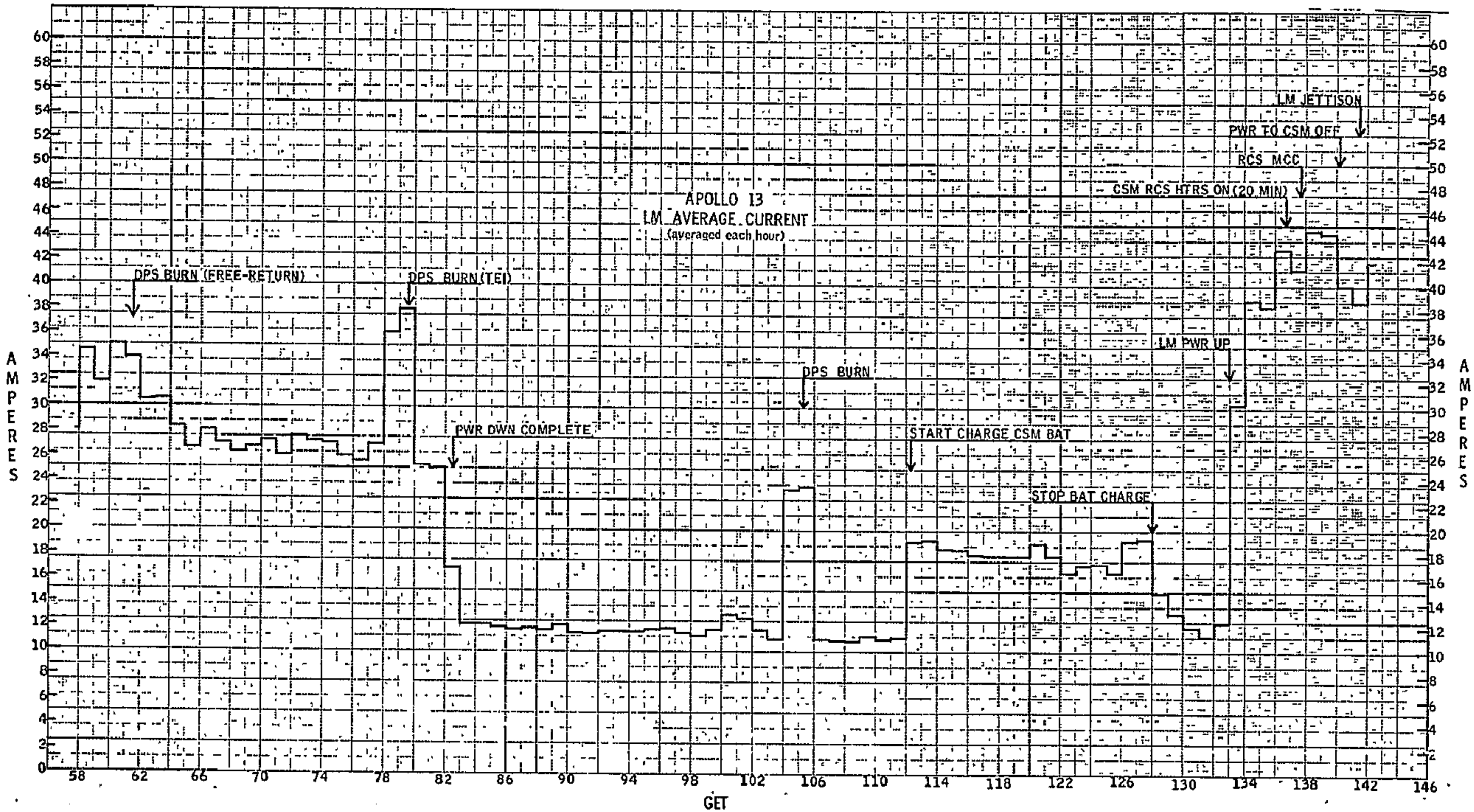
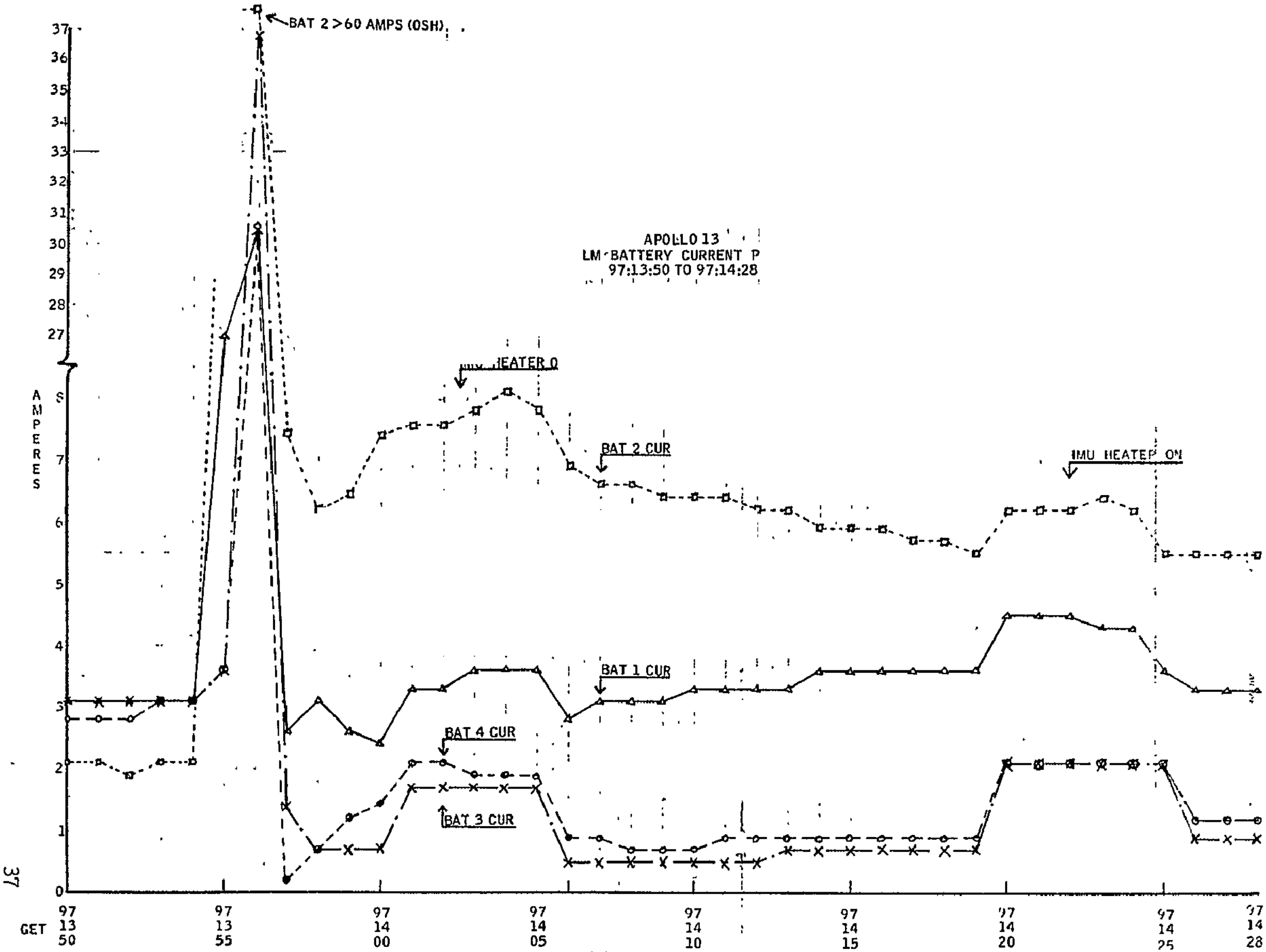
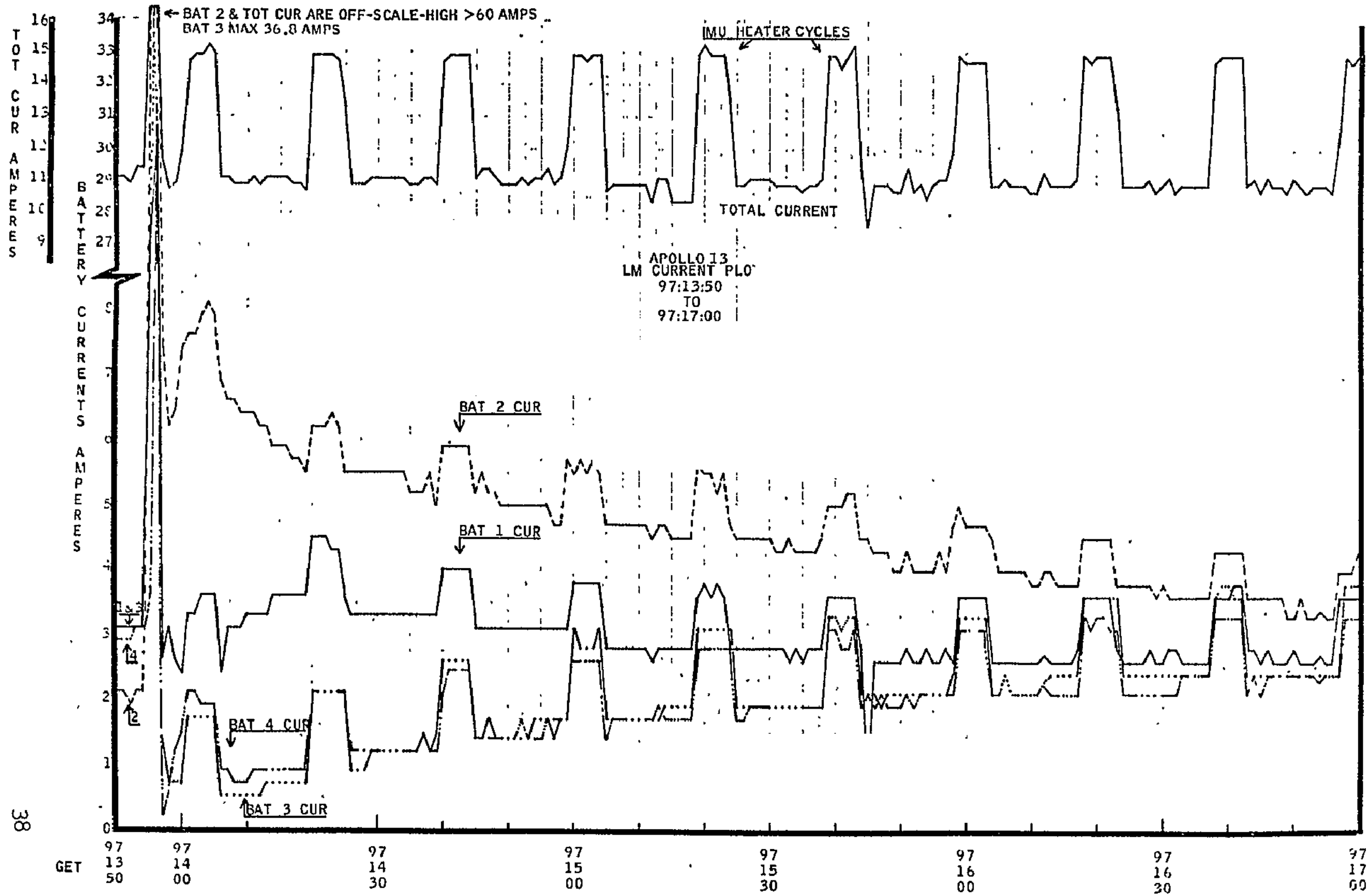

APOLLO 13
LM AVERAGE CURRENT
(averaged each hour)
DPS BURN (FREE-RETURN)
DPS BURN (TEI)
PWR DWN COMPLETE
DPS BURN
START CHARGE CSM BAT
STOP BAT CHARGE
LM PWR UP
CSM RCS HTRS ON (20 MIN)
RCS MCC
PWR TO CSM OFF
LM JETTISON
AMPERES
GET

Figure 8



BAT 2 >60 AMPS (OSH)
APOLLO 13
LM BATTERY CURRENT P
97:13:50 TO 97:14:28
AMPERES
BAT 2 CUR
IMU HEATER ON
BAT 1 CUR
BAT 4 CUR
BAT 3 CUR
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

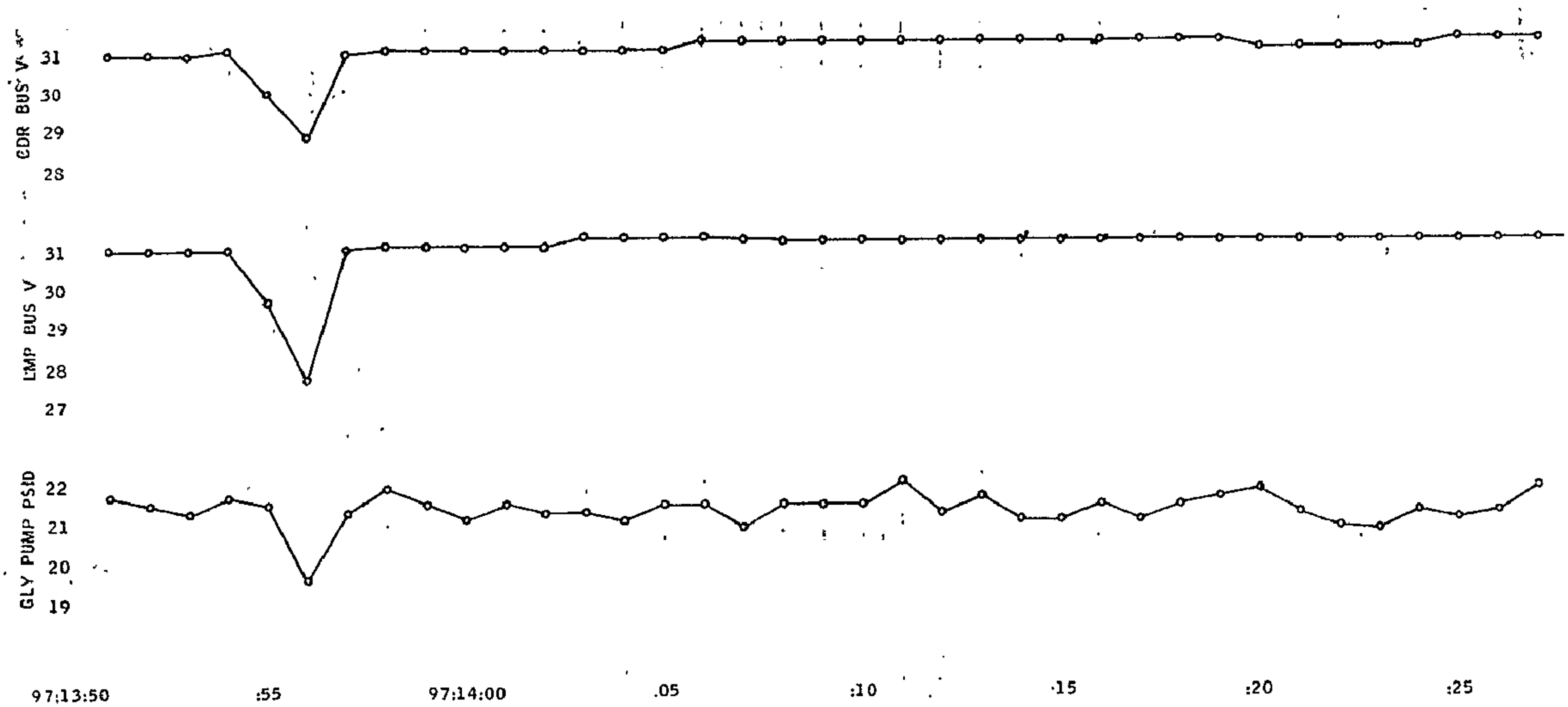


Figure 9-3

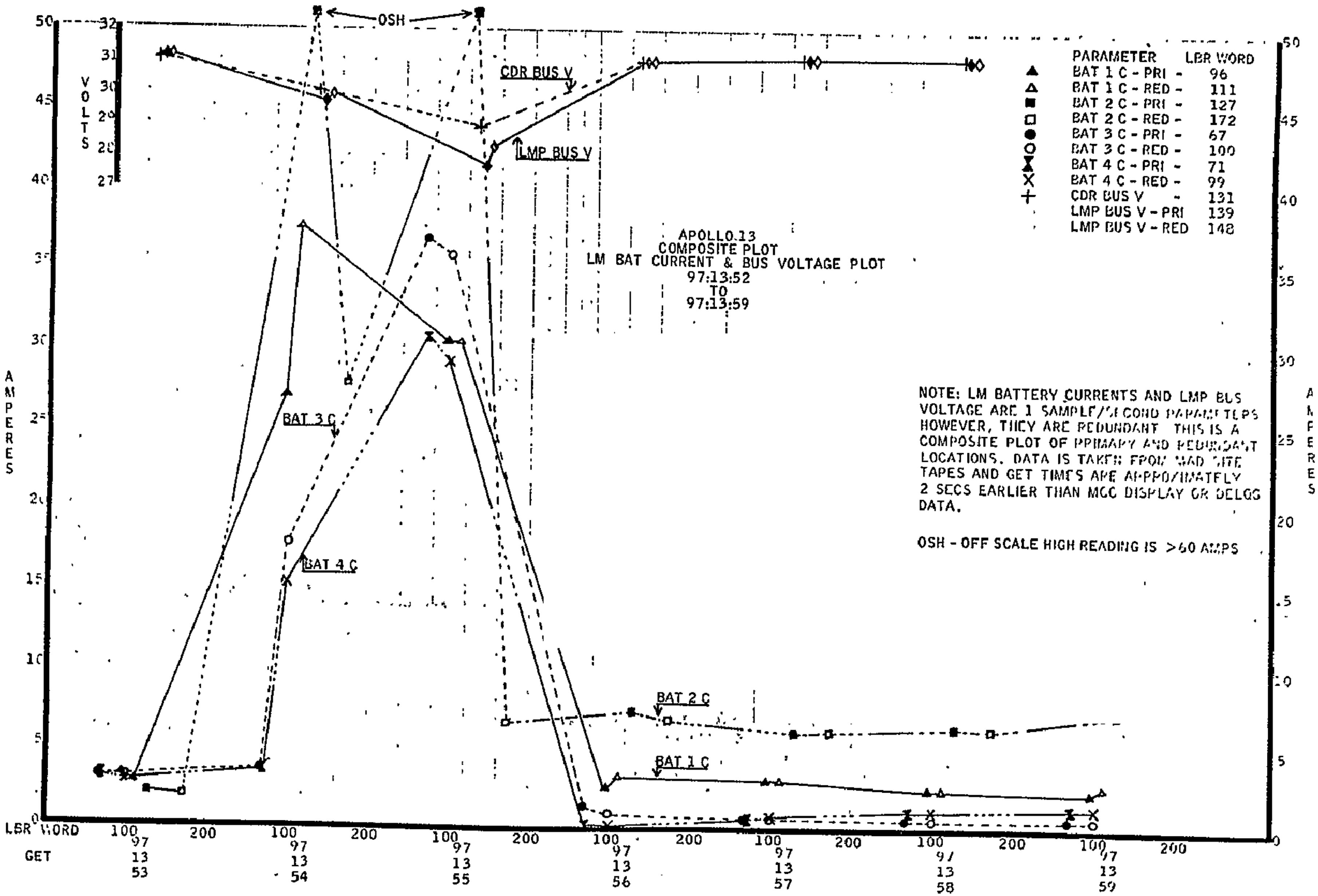

APOLLO 13
COMPOSITE PLOT
LM BAT CURRENT & BUS VOLTAGE PLOT
97:13:52
TO
97:13:59
PARAMETER LBR WORD
BAT 1 C - PRI - 96
BAT 1 C - RED - 111
BAT 2 C - PRI - 127
BAT 2 C - RED - 172
BAT 3 C - PRI - 67
BAT 3 C - RED - 100
BAT 4 C - PRI - 71
BAT 4 C - RED - 99
CDR BUS V - 131
LMP BUS V - PRI 139
LMP BUS V - RED 148
OSH
CDR BUS V
LMP BUS V
BAT 3 C
BAT 4 C
BAT 2 C
BAT 1 C
VOLTS
AMPERES
LBR WORD
GET
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

Figure 9-4

LTA-8 BATTERY CURRENTS AND BUS VOLTAGES
DURING SWITCH FROM LOW TO HIGH TAPS

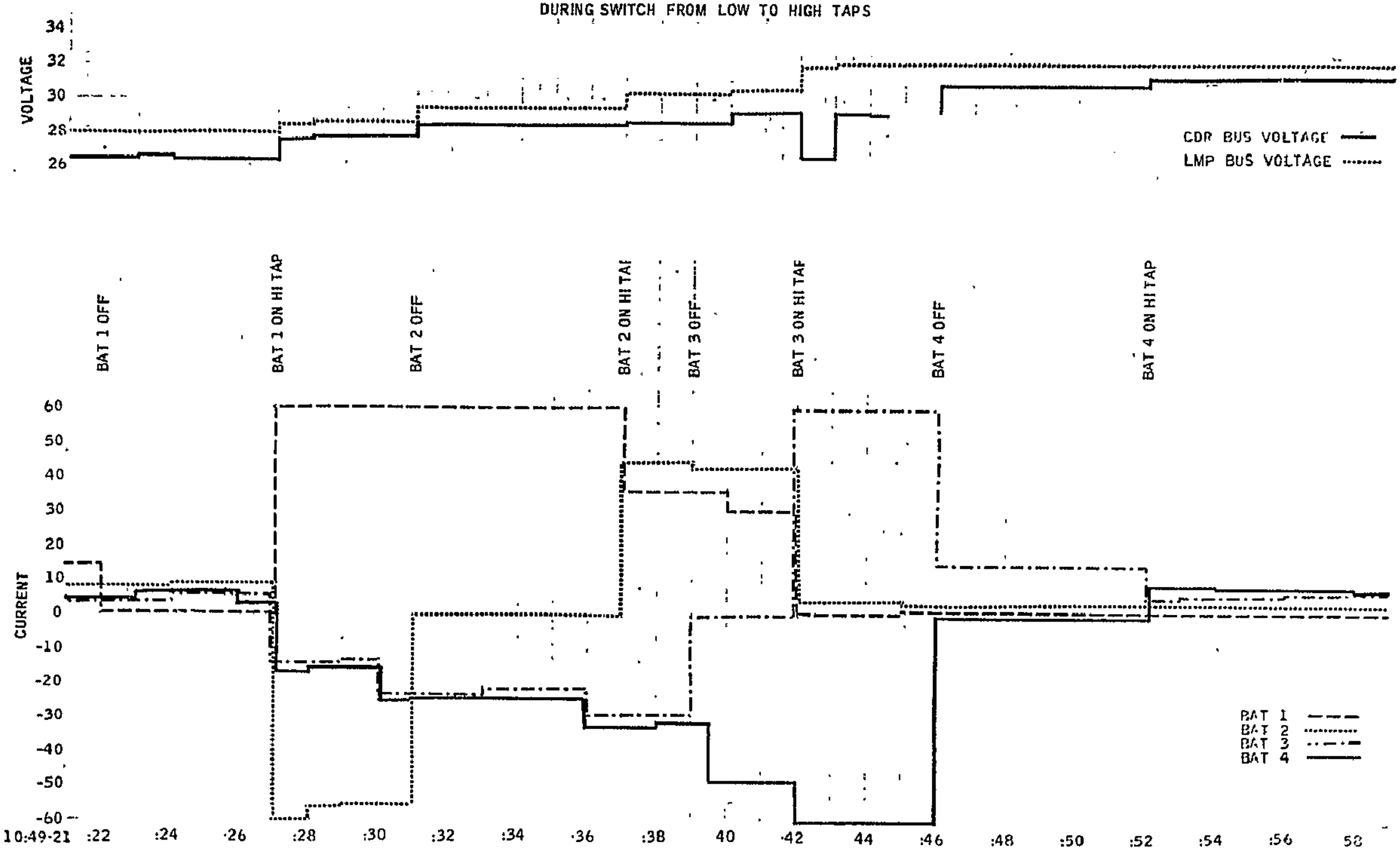


Figure 9-5

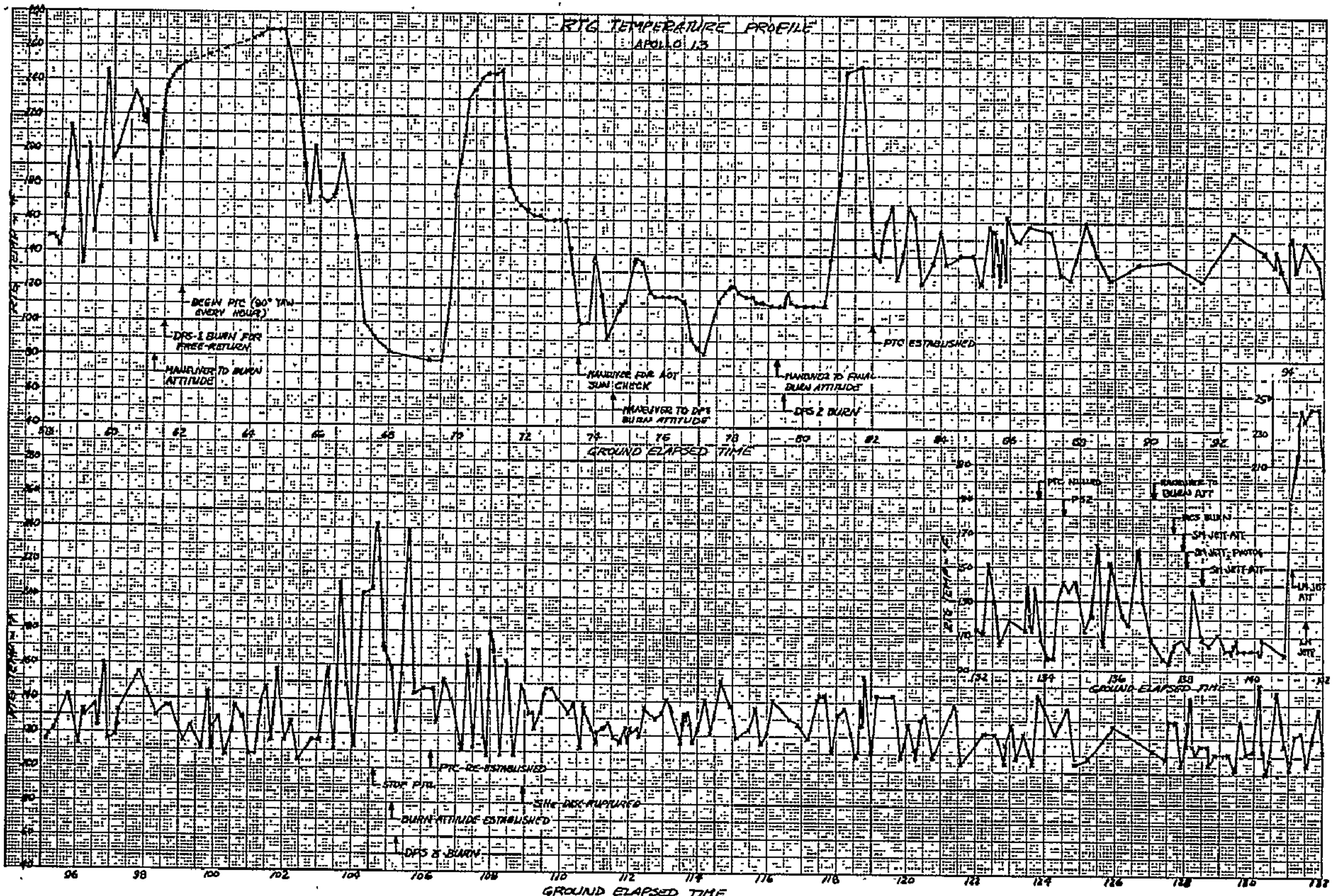

RTG TEMPERATURE PROFILE
APOLLO 13
BEGIN PTC (90° YAW EVERY HOUR)
DPS-1 BURN FOR FREE-RETURN
MANEUVER TO BURN ATTITUDE
MANEUVER FOR AOT SUN CHECK
MANEUVER TO DPS BURN ATTITUDE
MANEUVER TO FINAL BURN ATTITUDE
DPS 2 BURN
PTC ESTABLISHED
GROUND ELAPSED TIME
STOP PTC
PTC RE-ESTABLISHED
BURN ATTITUDE ESTABLISHED
DPS 2 BURN
SHe DISC RUPTURED
GROUND ELAPSED TIME
GROUND ELAPSED TIME

Figure 10

ADDENDUM-APPENDIX H

LM CONTROL

APOLLO 13

POST MISSION REPORT

PART III

May 28, 1970

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APOLLO 13 LM PROPULSION POST MISSION REPORT
PART III

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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 (ΔV = 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^{o}/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.

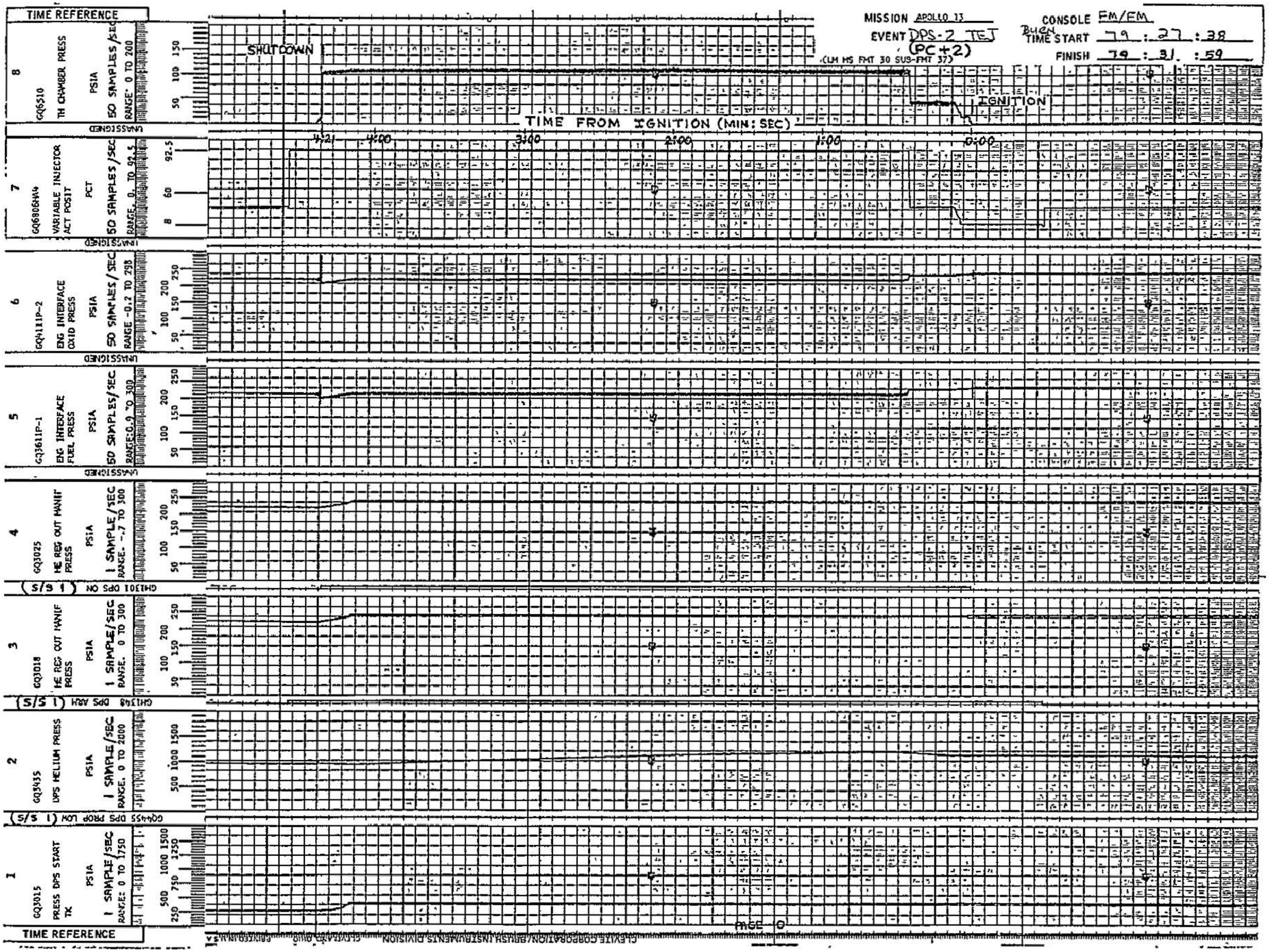
One important input that was received from SPAN during the mission was the data that the RCS could be operated in pulse mode with reasonable probability of success at quad temperatures of 70°F or greater.

M-7 BURN SUMMARY

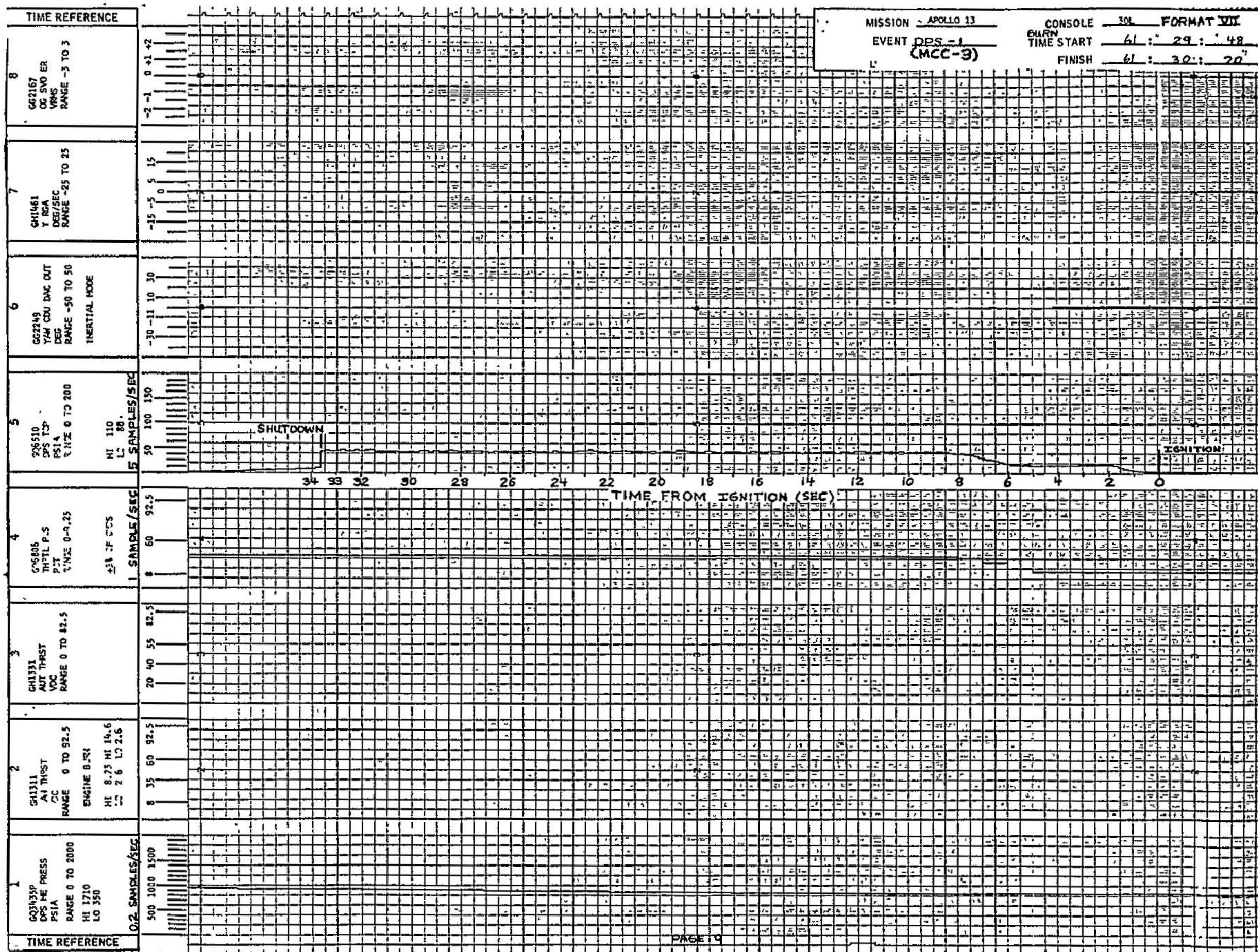
BURN	START TIME (GET)	STOP TIME (GET)	ΔV OF BURN (FPS)	SYSTEM USED	PROPELLANT USED	
					APS/DPS (LBS)	RCS (%)
MCC-3	61:29:48	61:30:20	40.0	DPS*	408.6	5.5% **
PC + 2	79:27:38	79:31:59	851	DPS*	8032	5.7% **
MCC-5	105:18:32	105:18:46	7.9	DPS*	62.1	4.7% **
MCC-7	137:39:48	137:40:12	3.1	RCS	-	7.6% **

* 10 SEC RCS ULLAGE

** INCLUDED MANEUVER TO ATTITUDE



TIME REFERENCE
MISSION APOLLO 13
EVENT DPS-2 TEJ
(PC+2)
(LM HS FMT 30 SUB-FMT 37)
CONSOLE EM/EM
TIME START 79 : 27 : 38
FINISH 79 : 31 : 59
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
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
GH1301 DPS ON (S/S 1)
3
GQ3018
HE REG OUT MANIF PRESS
PSIA
1 SAMPLE/SEC
RANGE 0 TO 300
GH1348 DPS ARM (S/S 1)
2
GQ3435
DPS HELIUM PRESS
PSIA
1 SAMPLE/SEC
RANGE 0 TO 2000
GQ4455 DPS PROP LOW (S/S 1)
1
GQ3015
PRESS DPS START TK
PSIA
1 SAMPLE/SEC
RANGE 0 TO 1750
TIME REFERENCE
PAGE 0
CLEVITE CORPORATION/BRUSH INSTRUMENTS DIVISION


MISSION APOLLO 13
EVENT DPS-1 (MCC-3)
CONSOLE 304
FORMAT VII
BURN TIME START 61 : 29 : 48
FINISH 61 : 30 : 20
TIME REFERENCE
GG2167 OG SVO ER VRMS RANGE -3 TO 3
GH1461 Y RGA DEG/SEC RANGE -25 TO 25
GG2249 YAW CDU DAC OUT DEG RANGE -50 TO 50
INERTIAL MODE
5 SAMPLES/SEC
SHUTDOWN
IGNITION
34 33 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
TIME FROM IGNITION (SEC)
1 SAMPLE/SEC
GH1331 AUT THRST VDC RANGE 0 TO 82.5
GH1311 A/I THRST VDC RANGE 0 TO 92.5
ENGINE BURN
GQ3435P DPS HE PRESS PSIA RANGE 0 TO 2000
HI 1710 LO 350
0.2 SAMPLES/SEC
TIME REFERENCE
PAGE 9

MISSION APOLLO 11

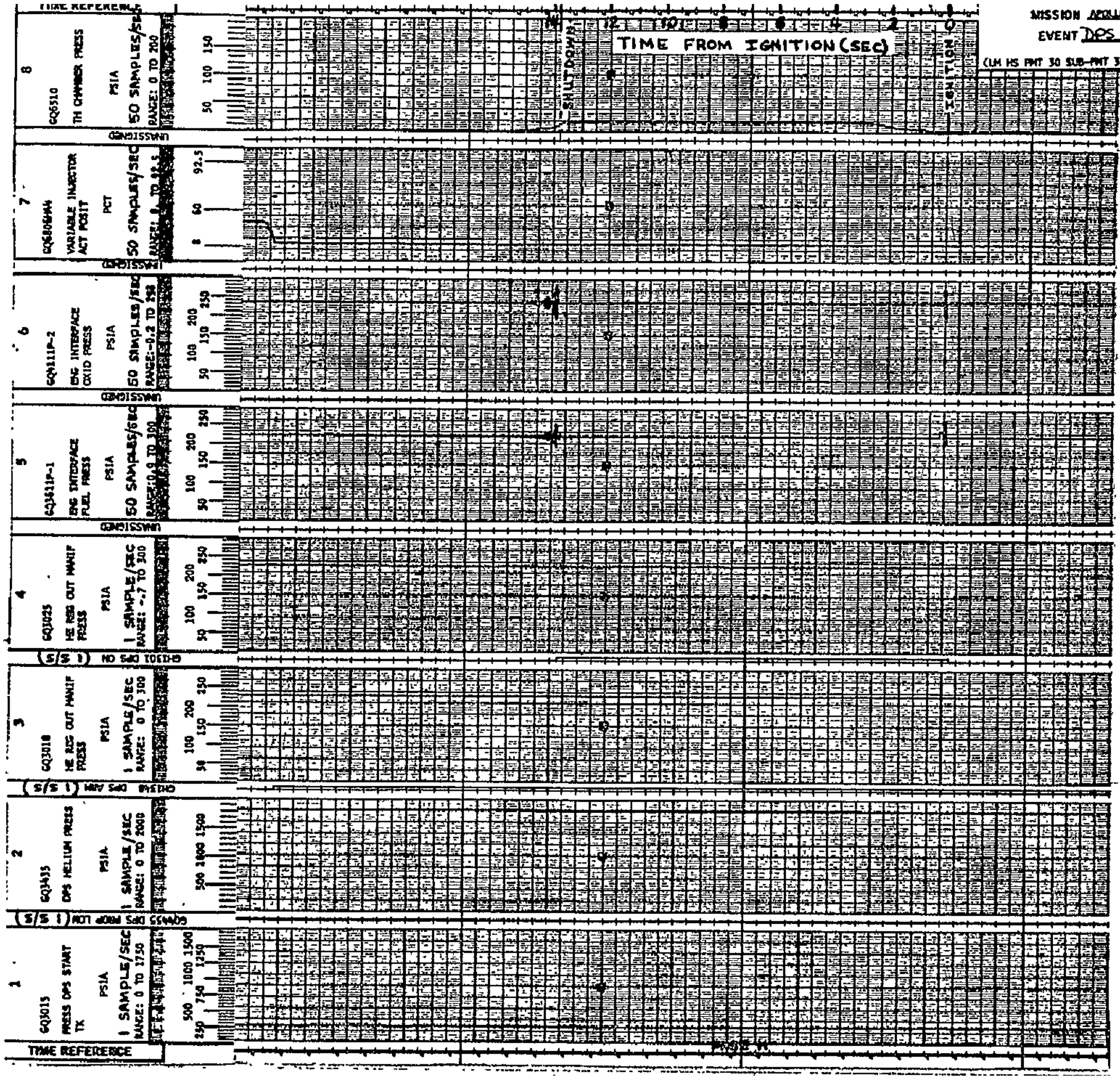
EVENT DPS-3 (MCC-5)

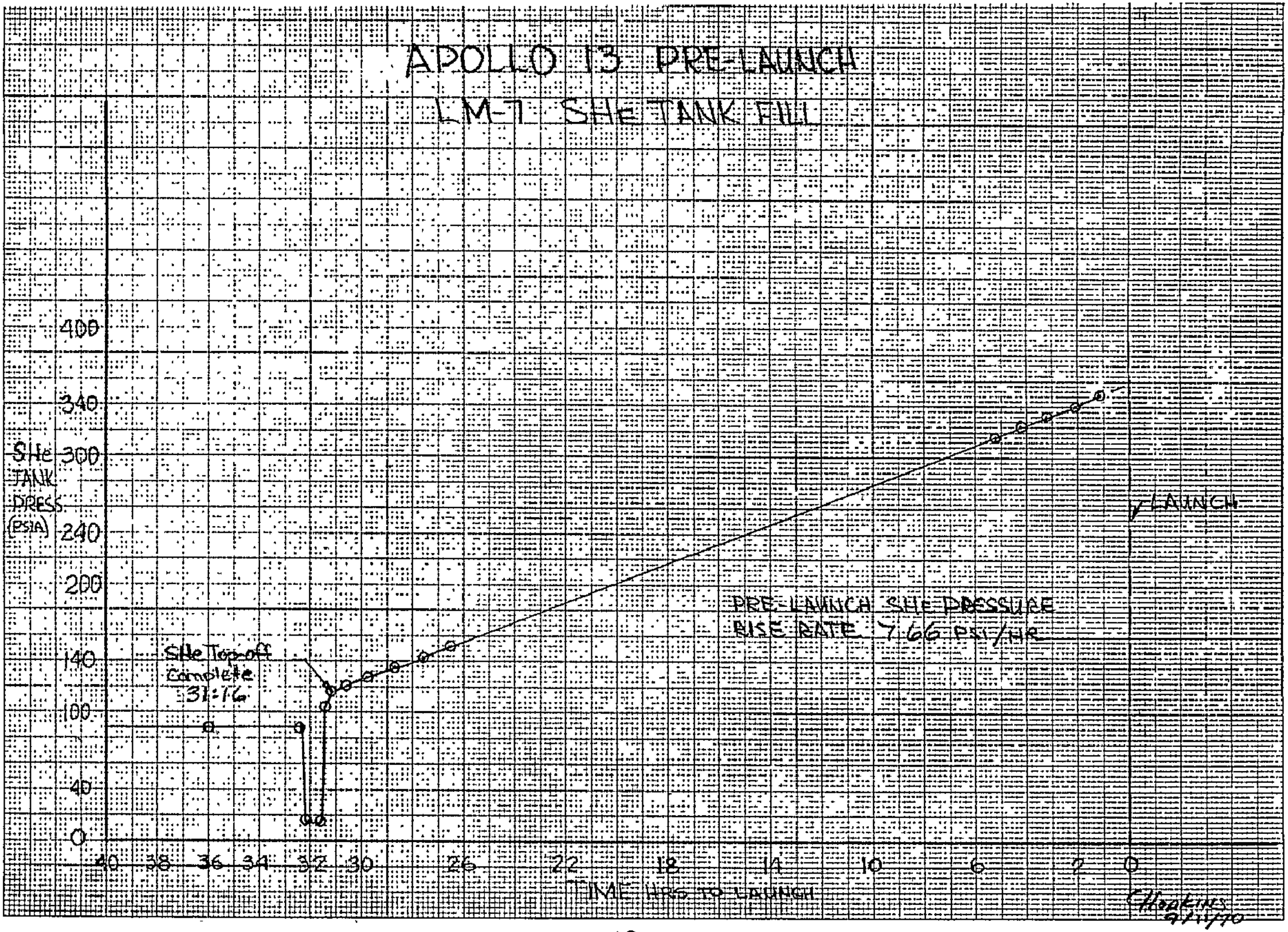
(LM HS FMT 30 SUB-FMT 37)

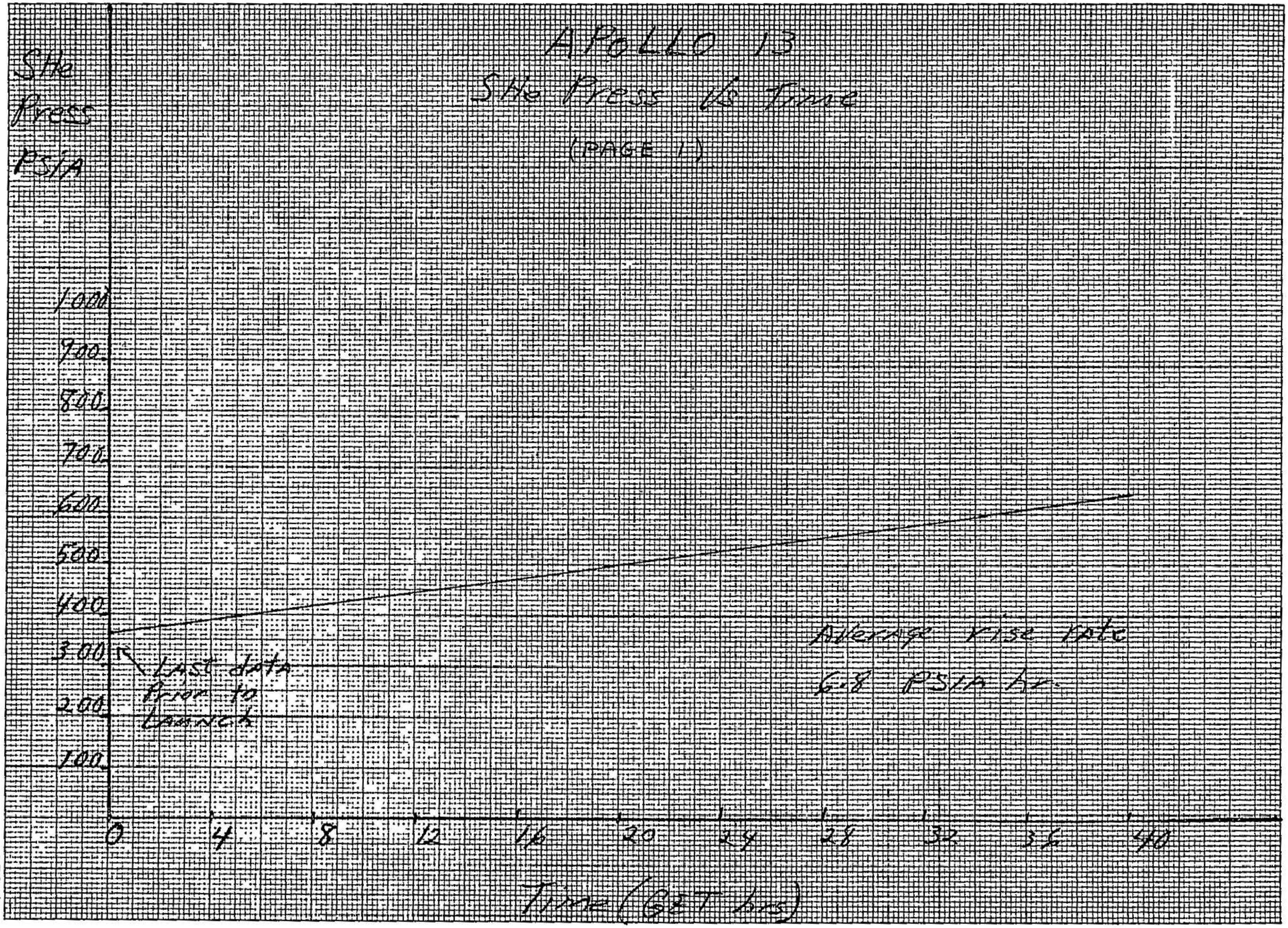
CONSOLE FM/FM

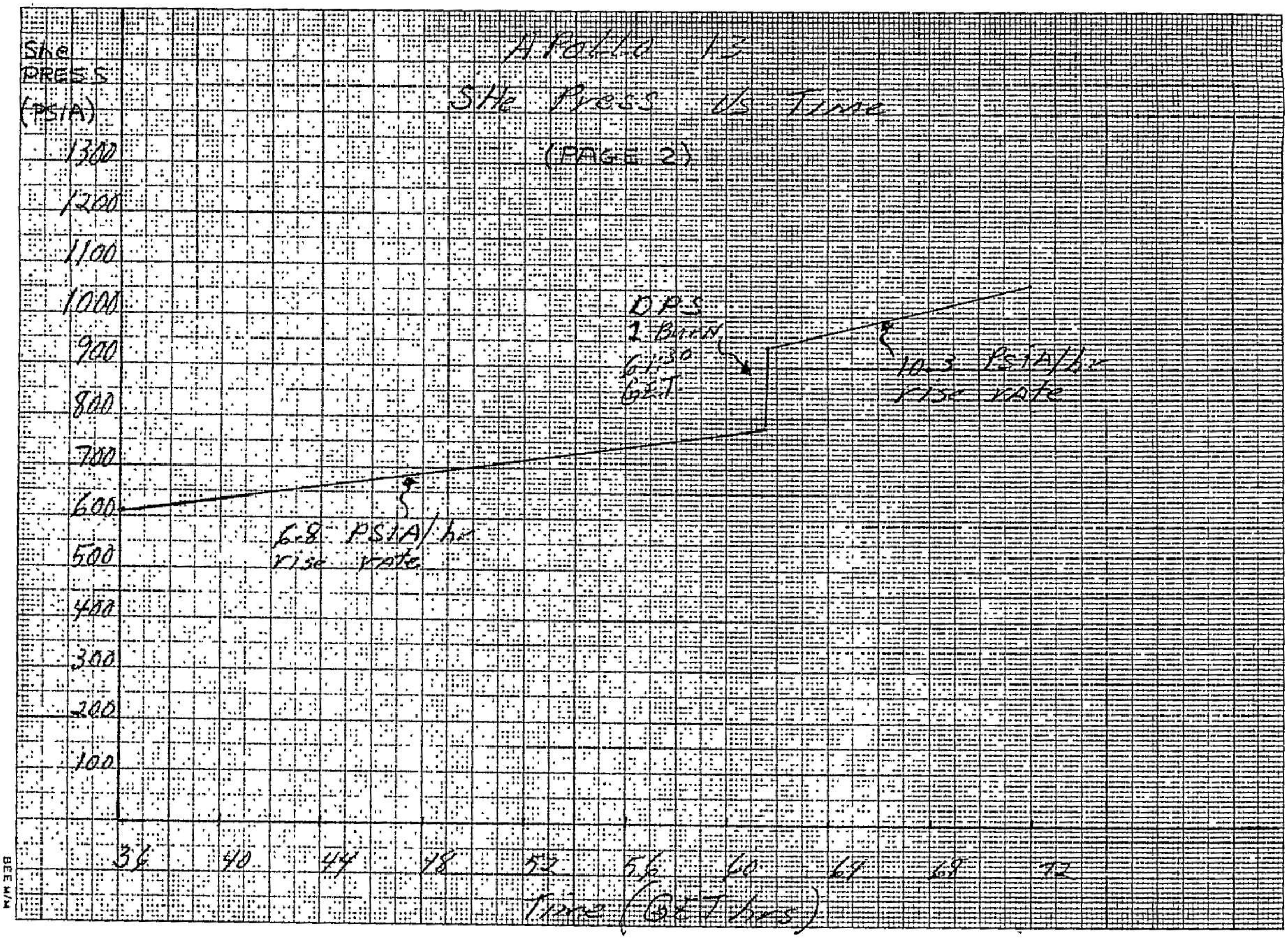
BURN TIME START 105 : 18 : 32

FINISH 105 : 18 : 46



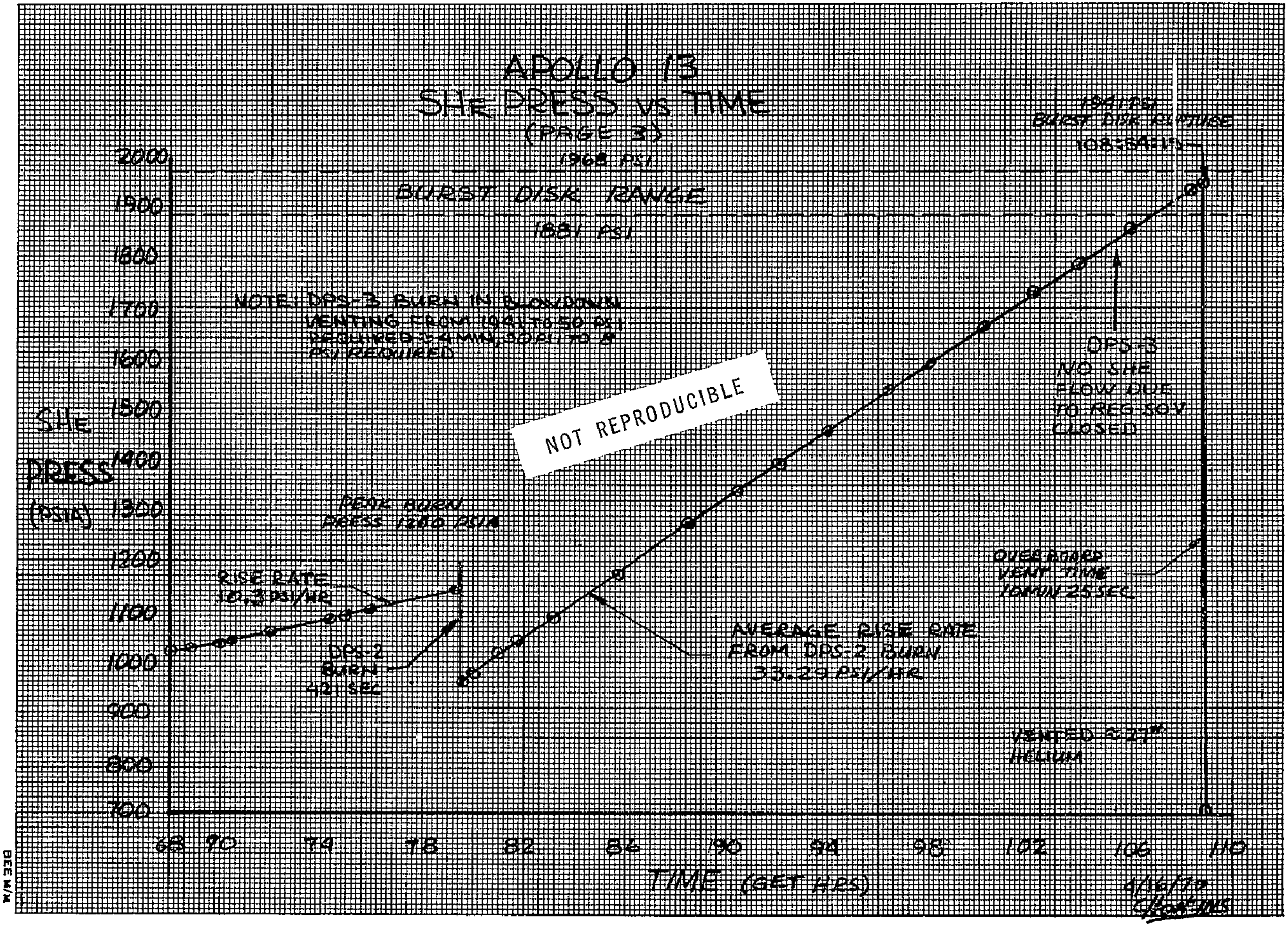

APOLLO 13 PRE-LAUNCH
LM-7 SHe TANK FILL
SHe TANK PRESS (PSIA)
400
340
300
240
200
140
100
40
0
40 38 36 34 32 30 26 22 18 14 10 6 2 0
TIME HRS TO LAUNCH
SHe Top-off Complete 31:16
LAUNCH
PRE-LAUNCH SHe PRESSURE RISE RATE 7.66 PSI/HR
Hopkins 9/11/70

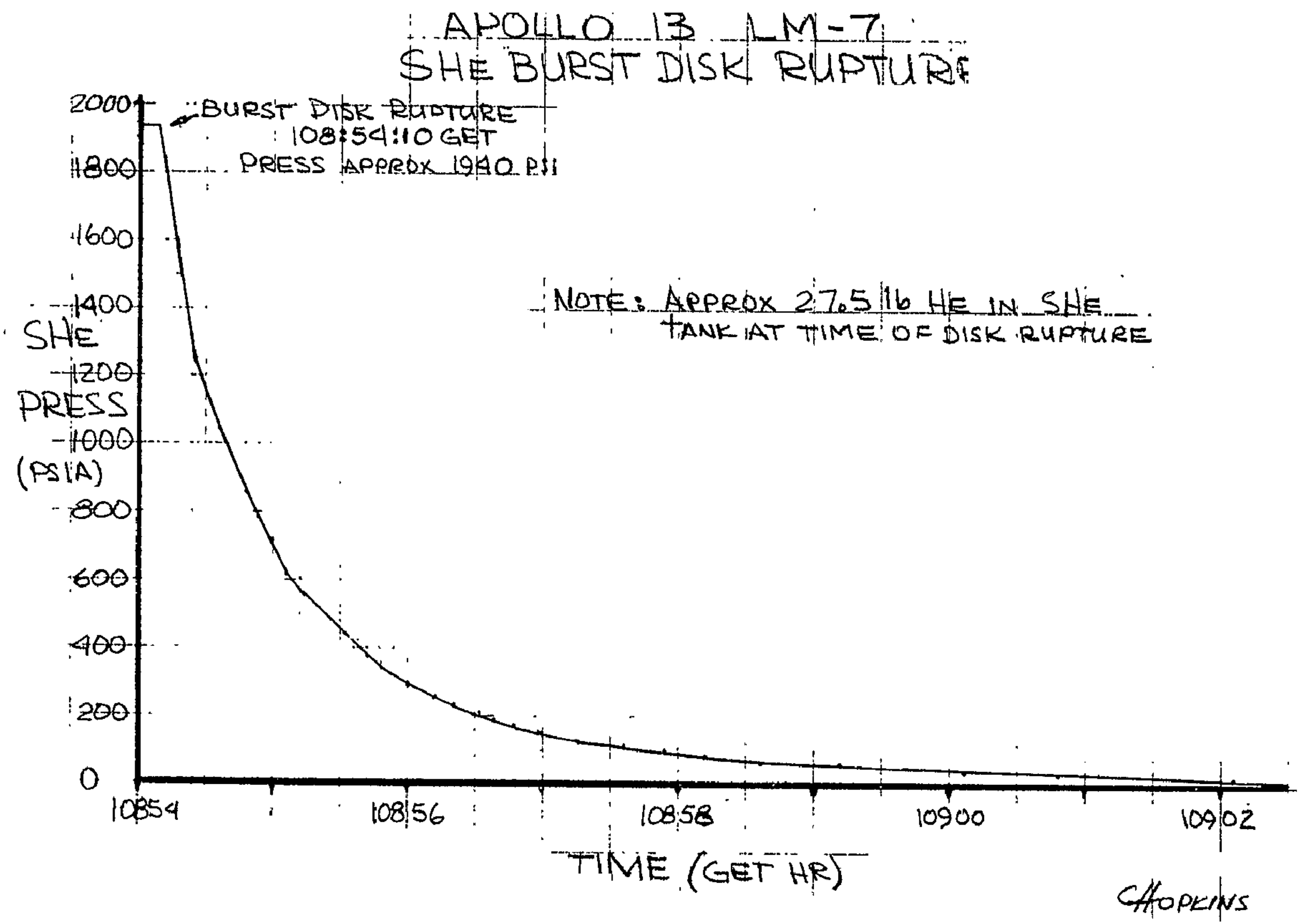

APOLLO 13
SHe Press vs Time
(PAGE 1)
SHe Press PSIA
1000
900
800
700
600
500
400
300
200
100
Last data prior to launch
Average rise rate
6.8 PSIA hr.
0
4
8
12
16
20
24
28
32
36
40
Time (GET hrs)



Apollo 13
SHe Press Vs Time
(PAGE 2)
SHe PRESS (PSIA)
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
36
40
44
48
52
56
60
64
68
72
Time (GET hrs)
DPS 1 BURN 61:30 GET
10.3 PSIA/hr rise rate
6.8 PSIA/hr rise rate

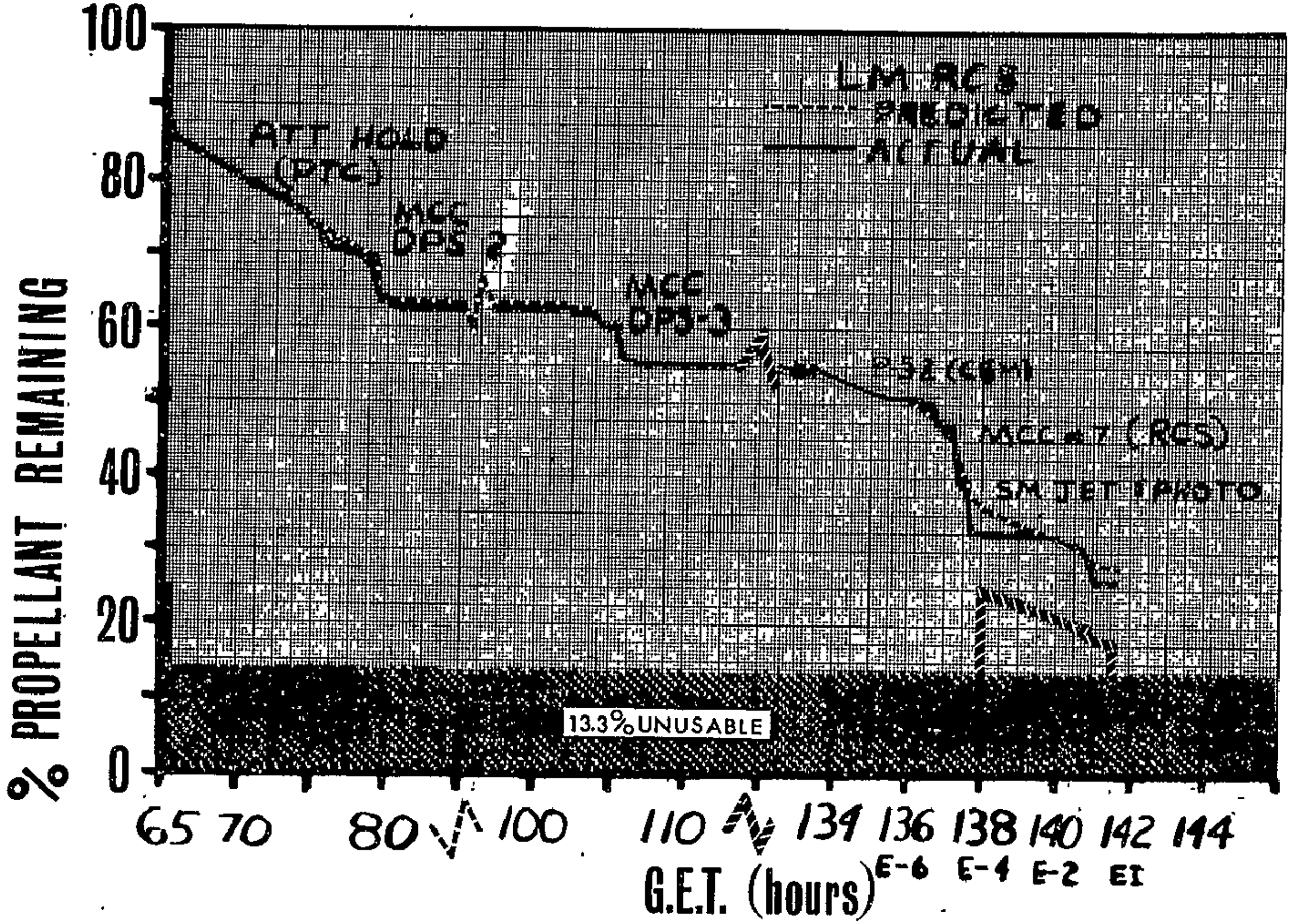
p


APOLLO 13
SHe PRESS vs TIME
(PAGE 3)
1968 PSI
BURST DISK RANGE
1881 PSI
BURST DISK RUPTURE
NOTE: DPS-3 BURN IN BLOWDOWN
VENTING FROM 1941 TO 50 PSI
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 1280 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
HELIUM
68
70
74
78
82
86
90
94
98
102
106
110
TIME (GET HRS)
4/16/70



APOLLO 13 LM-7
SHE BURST DISK RUPTURE
BURST DISK RUPTURE
108:54:10 GET
PRESS APPROX 1940 PSI
NOTE: APPROX 27.5 lb HE IN SHE TANK AT TIME OF DISK RUPTURE
SHE PRESS (PSIA)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
10854
10856
10858
10900
10902
TIME (GET HR)
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

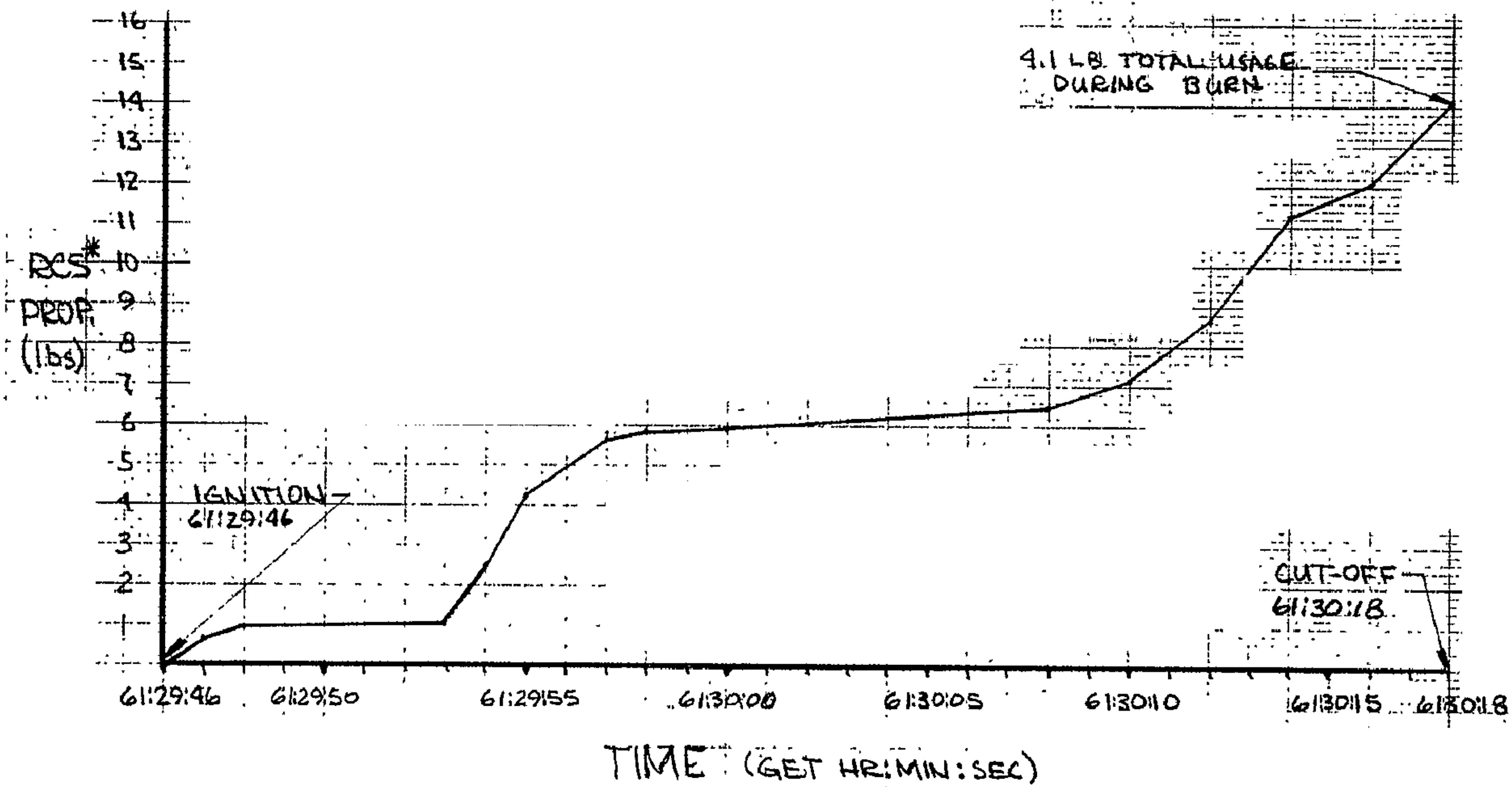
LM RCS USAGE RATES FOR VARIOUS MANEUVERS DURING APOLLO 13*

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

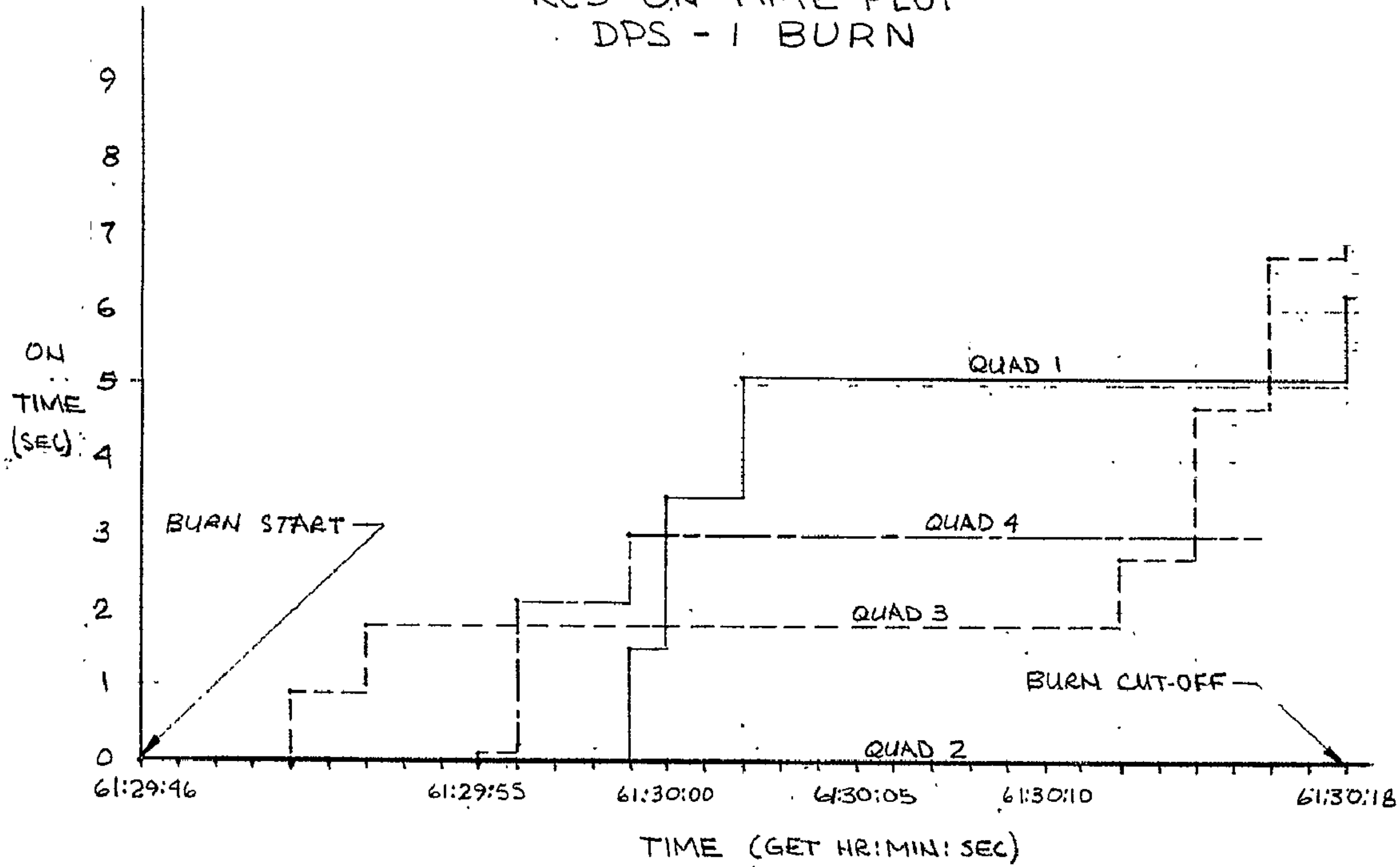
APOLLO 13
RCS PROPELLANT USAGE
DPS - 1 BURN



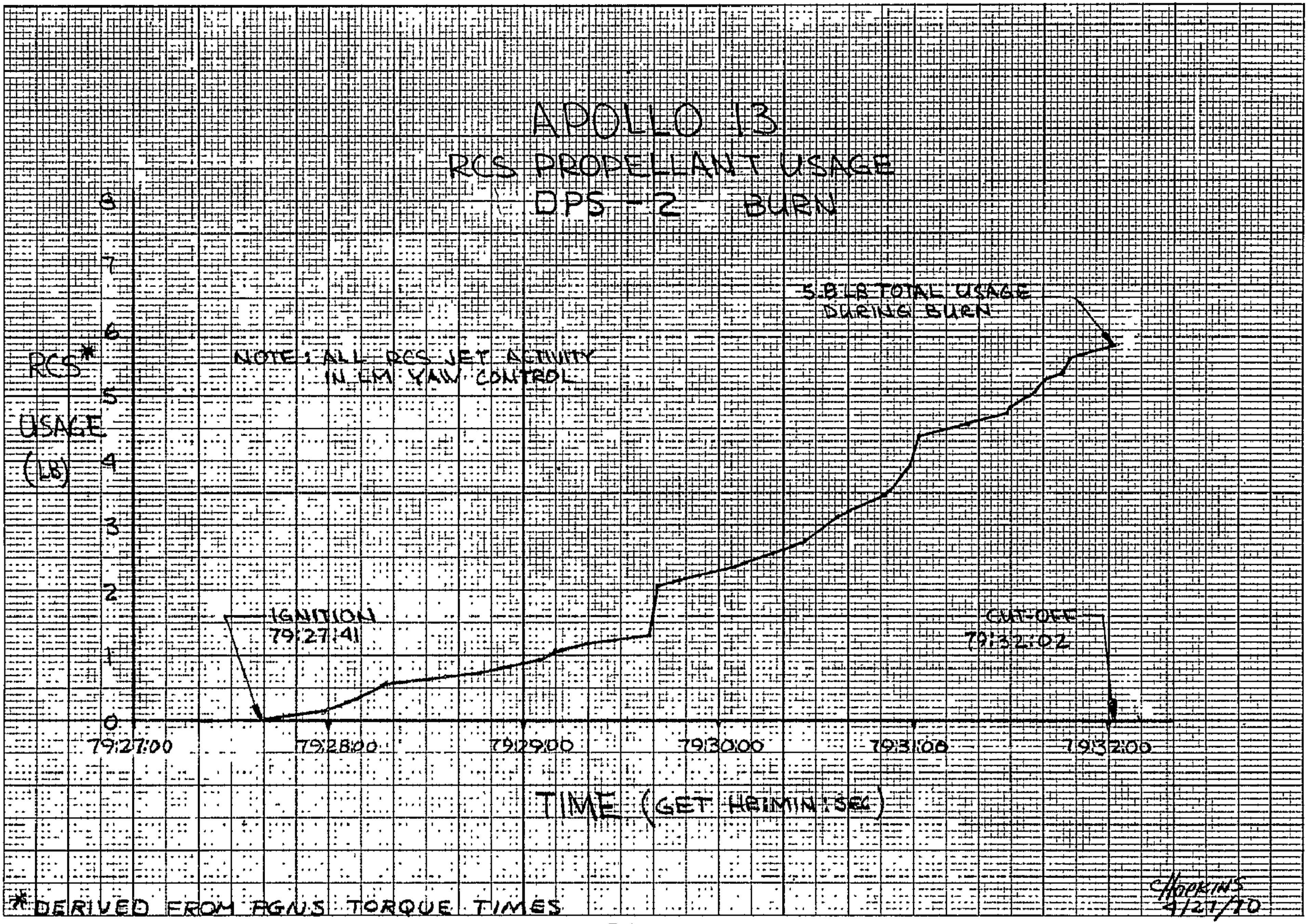
* DERIVED FROM PGNS TORQUE TIMES

CHopkins
4/27/70

APOLLO 13
RCS ON TIME PLOT
DPS - 1 BURN



C. HOPKINS
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 PGNS TORQUE TIMES
C. 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

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PGNS/AGS APOLLO 13 REPORT

PART III

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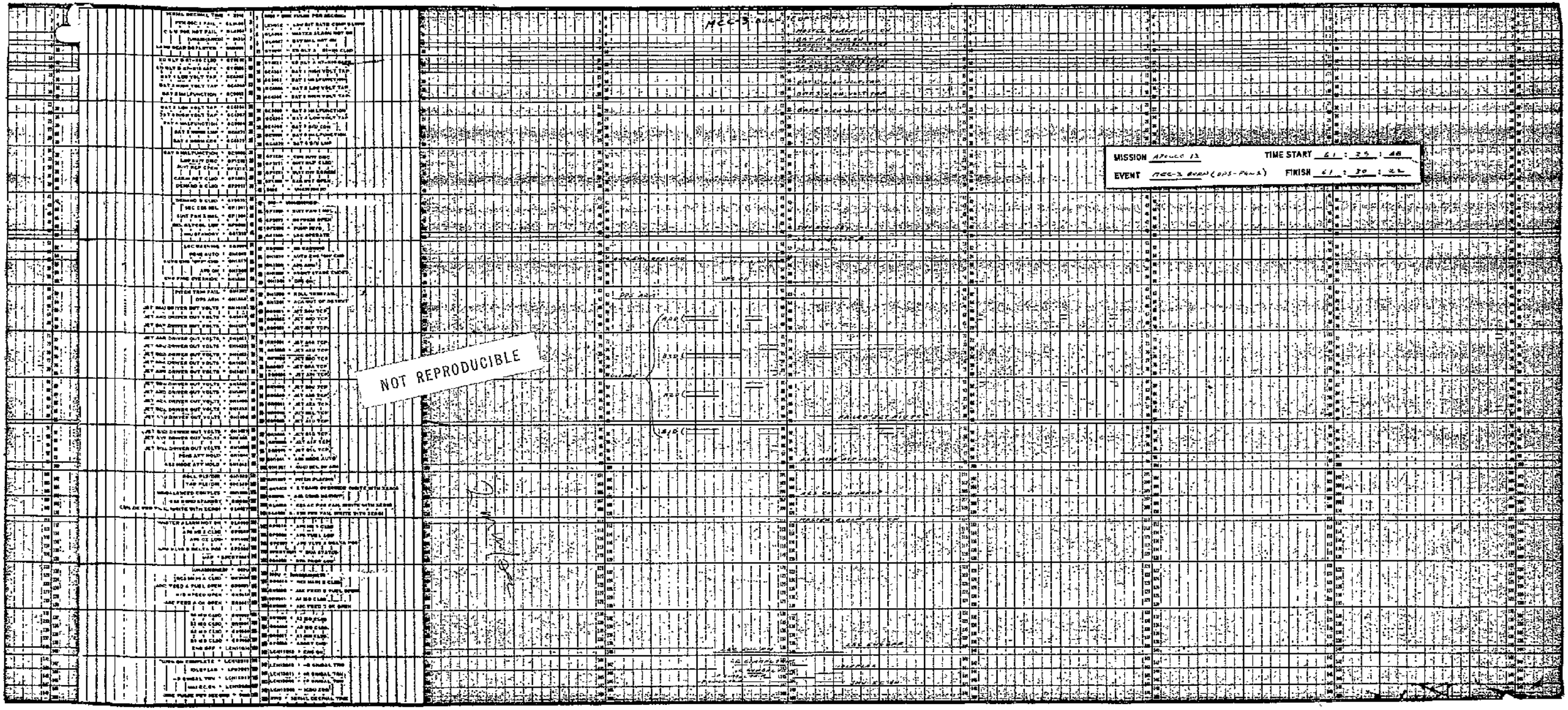

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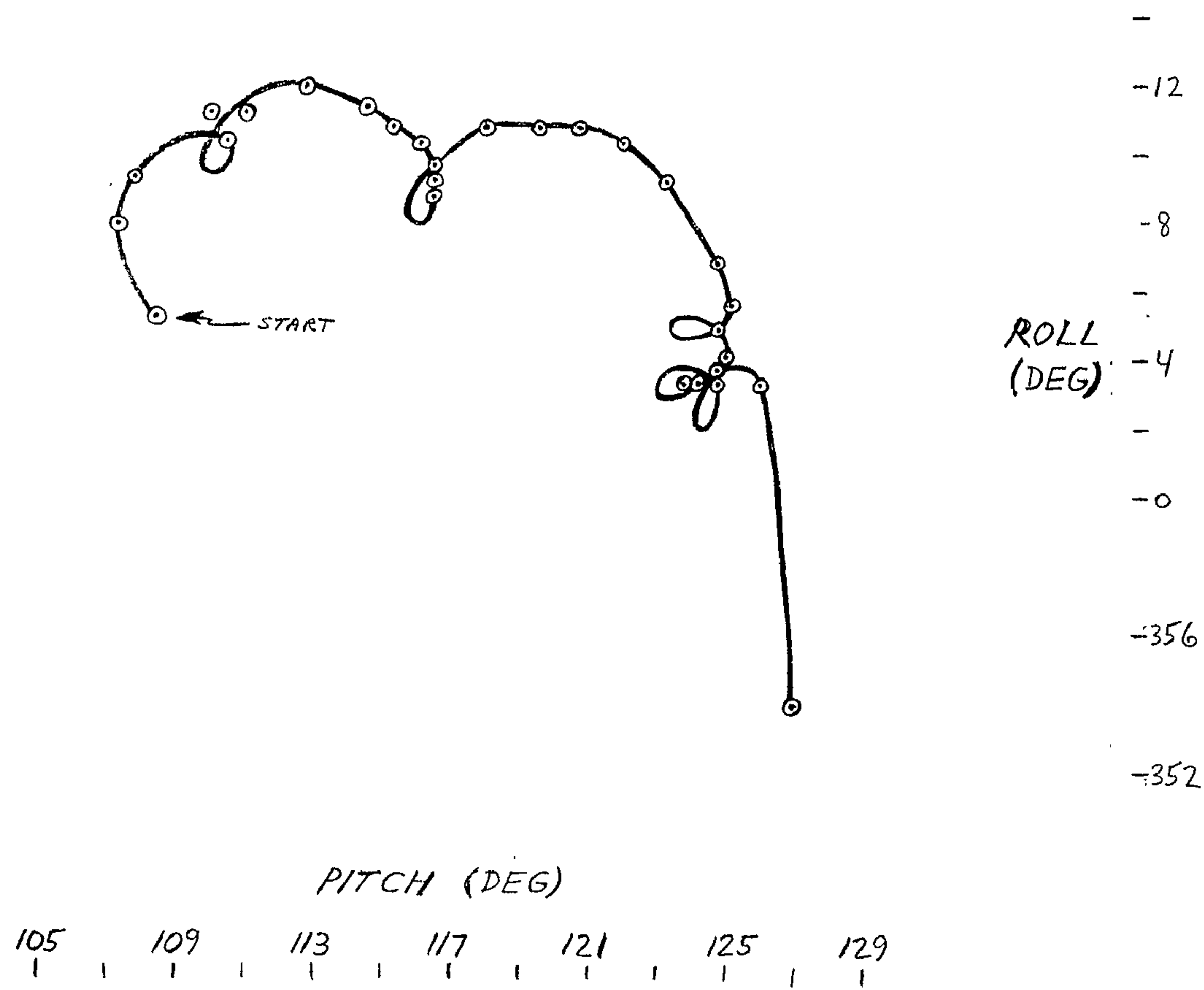
FOLDOUT FRAME 1

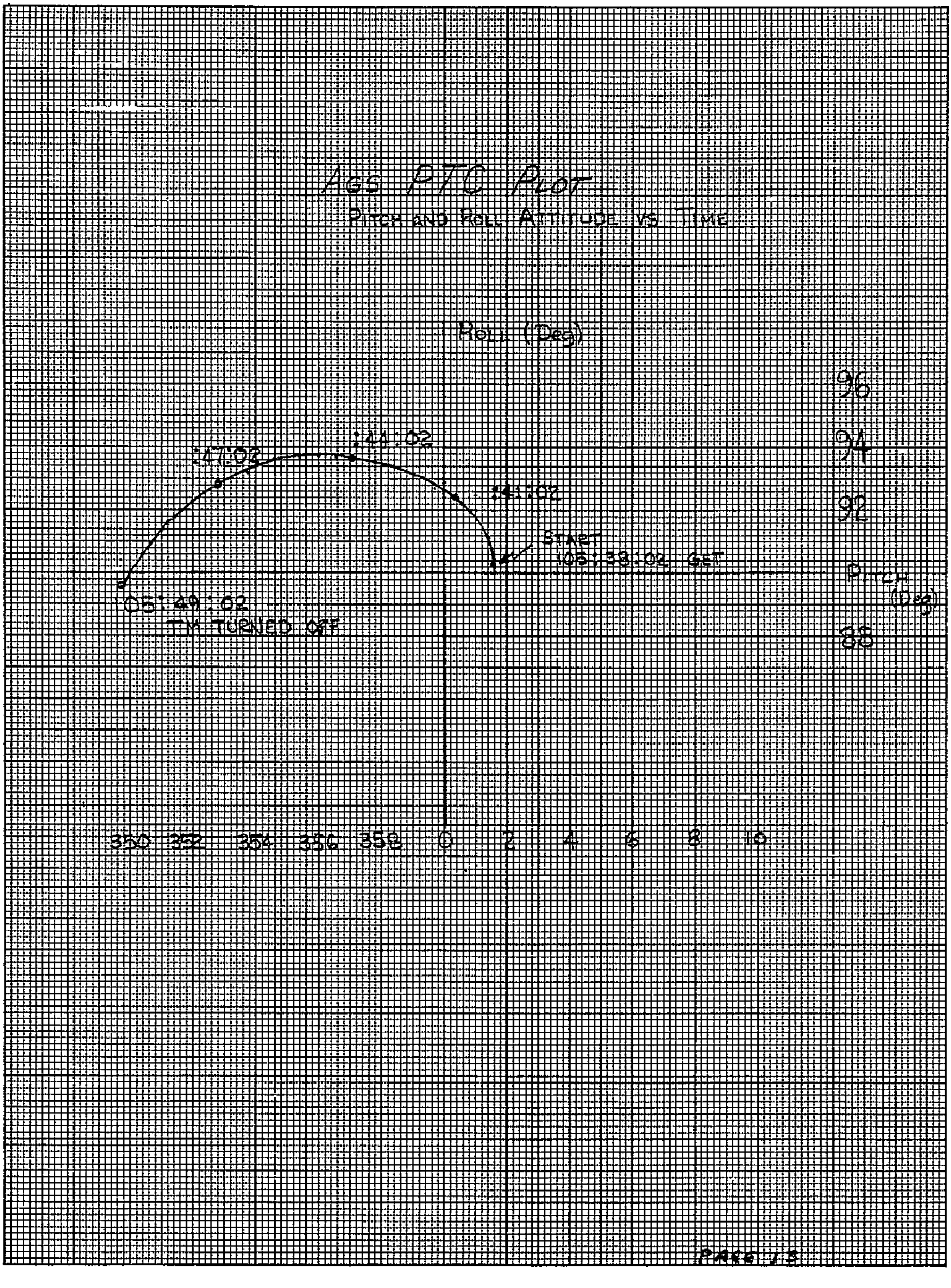
FOLDOUT FRAME 2

FOLDOUT FRAME 3

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
ROLL (Deg)
96
94
92
88
PITCH (Deg)
:44:02
:47:02
:41:02
START
105:38:02 GET
05:49:02
TM TURNED OFF
350
352
354
356
358
0
2
4
6
8
10

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