

REPORT OF APOLLO 13 REVIEW BOARD

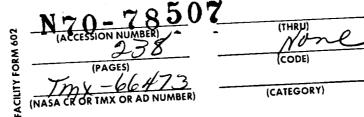
į

H

И

APPENDIX A BASELINE DATA: APOLLO 13

FLIGHT SYSTEMS AND OPERATIONS



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

0.5 0.0102 0.001285 0.01149 5.21 1 0.0204 0.002570 0.02297 10.42 2 0.0408 0.005140 0.04594 20.84 3 0.0612 0.007710 0.06891 31.26 4 0.0816 0.01280 0.09188 41.68 5 0.1020 0.012850 0.11485 52.10 6 0.1224 0.015420 0.13782 62.52 7 0.1428 0.017990 0.16079 72.94 8 0.1632 0.020560 0.18376 83.36 9 0.1836 0.023130 0.20673 93.78 10 0.2040 0.025700 0.2297 104.20 15 0.3060 0.038550 0.34455 156.30 20 0.4080 0.051400 0.45940 208.40 25 0.5100 0.064250 0.57425 260.50 30 0.6120 0.077100 0.68910 312.60 35 0.7140 0.089950 0.80395 364.70 40 0.8160 0.10280 0.91880 416.80 45 0.9180 0.11565 1.03365 468.90 50 1.0200 0.12850 1.1485 521.00 55 1.1220 0.14135 1.26335 573.10 60 1.2240 0.15420 1.3782 625.20 65 1.3260 0.16705 1.49305 677.30 70 1.4280 0.17990 1.6079	Load (amps)	⁰ 2 ^{lb/hr}	H ₂ lb/hr	H ₂ 0 lb/hr	cc/hr
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0.5	0.0102	0.001285	0.01149	5.21
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	1	0.0204	0.002570	0.02297	10.42
4 0.0816 0.010280 0.09188 41.68 5 0.1020 0.012850 0.111485 52.10 6 0.1224 0.015420 0.13782 62.52 7 0.1428 0.017990 0.16079 72.94 8 0.1632 0.020560 0.18376 85.36 9 0.1836 0.023130 0.20673 93.78 10 0.2040 0.025700 0.2297 104.20 15 0.3060 0.038550 0.34455 156.30 20 0.4080 0.051400 0.45940 208.40 25 0.5100 0.064250 0.57425 260.50 30 0.6120 0.077100 0.68910 312.60 35 0.7140 0.089950 0.80395 364.70 40 0.8160 0.10280 0.91880 416.80 45 0.9180 0.11565 1.03365 468.90 50 1.0200 0.12850 1.1485 521.00 55 1.1220 0.14135 1.26335 573.10 60 1.2240 0.15420 1.3782 625.20 65 1.3260 0.16705 1.49505 677.30 70 1.4280 0.17990 1.6079 729.40 75 1.5500 0.221845 1.95245 885.70 80 1.6320 0.20560 1.83760 835.60 85 1.7340 0.21845 1.95245 885.70 90 <td>2</td> <td>0.0408</td> <td>0.005140</td> <td>0.04594</td> <td>20.84</td>	2	0.0408	0.005140	0.04594	20.84
5 0.1020 0.012850 0.11485 52.10 6 0.1224 0.015420 0.13782 62.52 7 0.1428 0.017990 0.16079 72.94 8 0.1632 0.020560 0.18376 83.36 9 0.1836 0.023130 0.20673 93.78 10 0.2040 0.025700 0.2297 104.20 15 0.3060 0.038550 0.34455 156.30 20 0.4080 0.051400 0.45940 208.40 25 0.5100 0.064250 0.57425 260.50 30 0.6120 0.077100 0.68910 312.60 35 0.7140 0.089950 0.80395 364.70 40 0.8160 0.10280 0.91880 416.80 45 0.9180 0.11565 1.03365 468.90 50 1.0200 0.12850 1.1485 521.00 55 1.1220 0.14135 1.26335 573.10 60 1.2240 0.15420 1.3782 625.20 65 1.3260 0.16705 1.49305 677.30 70 1.4280 0.17990 1.6079 729.40 75 1.5300 0.21845 1.95245 885.70 80 1.6320 0.20560 1.83760 833.60 85 1.7340 0.21845 1.95245 885.70 90 1.8360 0.22130 2.06730 937.90 95 1.9380 0.24415 2.182	3	0.0612	0.007710	0.06891	31.26
6 0.1224 0.015420 0.13782 62.52 7 0.1428 0.017990 0.16079 72.94 8 0.1632 0.020560 0.18376 83.36 9 0.1836 0.023130 0.20673 93.78 10 0.2040 0.025700 0.2297 104.20 15 0.3060 0.038550 0.34455 156.30 20 0.4080 0.051400 0.45940 208.40 25 0.5100 0.064250 0.57425 260.50 30 0.6120 0.077100 0.68910 312.60 35 0.7140 0.089950 0.80395 364.70 40 0.8160 0.10280 0.91880 416.80 45 0.9180 0.11565 1.03365 468.90 55 1.1220 0.14135 1.26335 573.10 60 1.2240 0.15420 1.3782 625.20 65 1.3260 0.16705 1.49305 677.30 70 1.4280 0.17990 1.6079 729.40 75 1.5300 0.19275 1.72275 781.50 80 1.6320 0.20560 1.83760 835.60 85 1.7340 0.21845 1.95245 885.70 90 1.8360 0.22130 2.06730 937.90 95 1.9380 0.24415 2.18215 989.00	4	0.0816	0.010280	0.09188	41.68
7 0.1428 0.017990 0.16079 72.94 8 0.1632 0.020560 0.18376 83.36 9 0.1836 0.023130 0.20673 93.78 10 0.2040 0.025700 0.2297 104.20 15 0.3060 0.038550 0.34455 156.30 20 0.4080 0.051400 0.45940 208.40 25 0.5100 0.064250 0.57425 260.50 30 0.6120 0.077100 0.68910 312.60 35 0.7140 0.089950 0.80395 364.70 40 0.8160 0.11280 0.91880 416.80 45 0.9180 0.11565 1.03365 468.90 50 1.0200 0.12850 1.1485 521.00 55 1.1220 0.14135 1.26335 5773.10 60 1.2240 0.15420 1.3782 625.20 65 1.3260 0.16705 1.49305 677.30 70 1.4280 0.17990 1.6079 729.40 75 1.5300 0.12275 1.72275 781.50 80 1.6320 0.20560 1.83760 833.60 85 1.7340 0.21845 1.95245 885.70 90 1.8360 0.23130 2.06730 937.90 95 1.9580 0.24415 2.18215 989.00	5	0.1020	0.012850	0.11485	52.10
8 0.1632 0.020560 0.18376 83.36 9 0.1836 0.023130 0.20673 93.78 10 0.2040 0.025700 0.2297 104.20 15 0.3060 0.038550 0.34455 156.30 20 0.4080 0.051400 0.45940 208.40 25 0.5100 0.064250 0.57425 260.50 30 0.6120 0.077100 0.68910 312.60 35 0.7140 0.089950 0.80395 364.70 40 0.8160 0.10280 0.91880 416.80 45 0.9180 0.11565 1.03365 468.90 50 1.0200 0.12850 1.1485 521.00 55 1.1220 0.14135 1.263355 573.10 60 1.2240 0.15420 1.3782 625.20 65 1.3260 0.16705 1.49305 677.30 70 1.4280 0.17990 1.6079 729.40 75 1.5300 0.22560 1.83760 833.60 85 1.7340 0.21845 1.95245 885.70 90 1.8360 0.23130 2.06730 937.90 95 1.9580 0.24415 2.18215 989.00	6	0.1224	0.015420	0.13782	62.52
90.18360.0231300.2067393.78100.20400.0257000.2297104.20150.30600.0385500.34455156.30200.40800.0514000.45940208.40250.51000.0642500.57425260.50300.61200.0771000.68910312.60350.71400.0899500.80395364.70400.81600.102800.91880416.80450.91800.115651.03365468.90501.02000.128501.1485521.00551.12200.141351.26335573.10601.22400.154201.3782625.20651.32600.167051.49305677.30701.42800.179901.6079729.40751.53000.205601.83760835.60851.73400.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	7	0.1428	0.017990	0.16079	72.94
10 0.2040 0.025700 0.2297 104.20 15 0.3060 0.038550 0.34455 156.30 20 0.4080 0.051400 0.45940 208.40 25 0.5100 0.064250 0.57425 260.50 30 0.6120 0.077100 0.68910 312.60 35 0.7140 0.089950 0.80395 364.70 40 0.8160 0.10280 0.91880 416.80 45 0.9180 0.11565 1.03365 468.90 50 1.0200 0.12850 1.1485 521.00 55 1.1220 0.14135 1.26335 573.10 60 1.2240 0.15420 1.3782 625.20 65 1.3260 0.16705 1.49305 677.30 70 1.4280 0.17990 1.6079 729.40 75 1.5300 0.22560 1.83760 833.60 85 1.7340 0.21845 1.95245 885.70 90 1.8360 0.23130 2.06730 937.90 95 1.9380 0.24415 2.18215 989.00	8	0.1632	0.020560	0.18376	83 .3 6
15 0.3060 0.038550 0.34455 156.30 20 0.4080 0.051400 0.45940 208.40 25 0.5100 0.064250 0.57425 260.50 30 0.6120 0.077100 0.68910 312.60 35 0.7140 0.089950 0.80395 364.70 40 0.8160 0.10280 0.91880 416.80 45 0.9180 0.11565 1.03365 468.90 50 1.0200 0.12850 1.1485 521.00 55 1.1220 0.14135 1.26335 573.10 60 1.2240 0.15420 1.3782 625.20 65 1.3260 0.16705 1.49305 677.30 70 1.4280 0.17990 1.6079 729.40 75 1.5300 0.20560 1.83760 835.60 85 1.7340 0.21845 1.95245 885.70 90 1.8360 0.23130 2.06730 937.90 95 1.9380 0.24415 2.18215 989.00	9	0.1836	0.023130	0.20673	93.78
200.40800.0514000.45940208.40250.51000.0642500.57425260.50300.61200.0771000.68910312.60350.71400.0899500.80395364.70400.81600.102800.91880416.80450.91800.115651.03365468.90501.02000.128501.1485521.00551.12200.141351.26335573.10601.22400.154201.3782625.20651.32600.167051.49305677.30701.42800.179901.6079729.40751.53000.192751.72275781.50801.63200.205601.83760833.60851.73400.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	10	0.2040	0.025700	0.2297	104.20
250.51000.0642500.57425260.50300.61200.0771000.68910312.60350.71400.0899500.80395364.70400.81600.102800.91880416.80450.91800.115651.03365468.90501.02000.128501.1485521.00551.12200.141351.26335573.10601.22400.154201.3782625.20651.32600.167051.49305677.30701.42800.179901.6079729.40751.53000.128751.72275781.50801.63200.205601.83760833.60851.73400.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	15	0.3060	0.038550	0.34455	156.30
300.61200.0771000.68910312.60350.71400.0899500.80395364.70400.81600.102800.91880416.80450.91800.115651.03365468.90501.02000.128501.1485521.00551.12200.141351.26335573.10601.22400.154201.3782625.20651.32600.167051.49305677.30701.42800.179901.6079729.40751.53000.192751.72275781.50801.63200.205601.83760833.60851.73400.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	20	0.4080	0.051400	0.45940	208.40
350.71400.0899500.80395364.70400.81600.102800.91880416.80450.91800.115651.03365468.90501.02000.128501.1485521.00551.12200.141351.26335573.10601.22400.154201.3782625.20651.32600.167051.49305677.30701.42800.179901.6079729.40751.63200.205601.83760833.60801.63200.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	25	0.5100	0.064250	0.57425	260.50
400.81600.102800.91880416.80450.91800.115651.03365468.90501.02000.128501.1485521.00551.12200.141351.26335573.10601.22400.154201.3782625.20651.32600.167051.49305677.30701.42800.179901.6079729.40751.53000.192751.72275781.50801.63200.205601.83760835.60851.73400.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	30	0.6120	0.077100	0.68910	312.60
450.91800.115651.03365468.90501.02000.128501.1485521.00551.12200.141351.26335573.10601.22400.154201.3782625.20651.32600.167051.49305677.30701.42800.179901.6079729.40751.53000.192751.72275781.50801.63200.205601.83760833.60851.73400.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	35	0.7140	0.089950	0.80395	364.70
501.02000.128501.1485521.00551.12200.141351.26335573.10601.22400.154201.3782625.20651.32600.167051.49305677.30701.42800.179901.6079729.40751.53000.192751.72275781.50801.63200.205601.83760835.60851.73400.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	40	0.8160	0.10280	0.91880	416.80
551.12200.141351.26335573.10601.22400.154201.3782625.20651.32600.167051.49305677.30701.42800.179901.6079729.40751.53000.192751.72275781.50801.63200.205601.83760833.60851.73400.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	45	0.9180	0.11565	1.03365	468.90
601.22400.154201.3782625.20651.32600.167051.49305677.30701.42800.179901.6079729.40751.53000.192751.72275781.50801.63200.205601.83760833.60851.73400.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	50	1.0200	0.12850	1.1485	521.00
651.32600.167051.49305677.30701.42800.179901.6079729.40751.53000.192751.72275781.50801.63200.205601.83760833.60851.73400.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	55	1.1220	0.14135	1.26335	573.10
701.42800.179901.6079729.40751.53000.192751.72275781.50801.63200.205601.83760835.60851.73400.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	60	1.2240	0.15420	1.3782	625.20
751.53000.192751.72275781.50801.63200.205601.83760835.60851.73400.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	65	1.3260	0.16705	1.49305	677.30
801.63200.205601.83760833.60851.73400.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	'70	1.4280	0.17990	1.6079	729.40
851.73400.218451.95245885.70901.83600.231302.06730937.90951.93800.244152.18215989.00	75	1.5300	0.19275	1.72275	781.50
901.83600.231302.06730937.90951.93800.244152.18215989.00	80	1.6320	0.20560	1.83760	833.60
95 1.9380 0.24415 2.18215 989.00	85	1.7340	0.21845	1.95245	885.70
	90	1.8360	0.23130	2.06730	937.90
100 2.0400 0.25700 2.2970 1042.00	95	1.9380	0.24415	2.18215	989.00
	100	2.0400	0.25700	2.2970	1042.00

TABLE A2.6-II. - REACTANT CONSUMPTION AND WATER PRODUCTION

DRMULAS: $O_2 = 2.04 \times 10^{-2} I$ $H_2 O = 10.42 \text{ cc/amp/hr}$ $H_2 = 2.57 \times 10^{-3} I$ $H_2 O = 2.297 \times 10^{-2} \text{ lb/amp/hr}$

THE REPERTENCE FOR MARKEN Ľ

precautions are necessary to assure positive power transfer since power to any one inverter control motor switch is routed in series through the switch of another inverter. A third precaution must be exercised to preclude a motor switch lockout when dc power to inverter 3 is being transferred from dc main bus A to dc main bus B, or vice versa. The AC INVERTER 3 switch (MDC-3) should be held in the OFF position for 1 second when performing a power transfer operation from one main dc bus to the other.

Performance and Design Data

<u>Alternating current and direct current data.</u> The ac and dc performance and design data for the EPS is as follows:

Alternating current

Phases	3
Displacement	120 ± 2°
Steady-state voltage	ll5.5 (+1, -1.5) V ac (average 3 phases)
Transient voltage	115 (+35, -65) V ac
Recovery	To 115 ± 10 V within 15 ms, steady state within 50 ms
Unb ala nce	2 V ac (worst phase from average)
Frequency limites Normal (synchronized to central timing equipment)	400 ± 3 Hz
Emergency (loss of central timing equipment)	400 ± 7 Hz
Wave characteristics (sine wave) Maximum distortion Highest harmonic Crest factor	5 percent 4 percent 1.414 ± 10 percent
Rating	1250 V ac

 Direct current Steady-state voltage limits Normal 29 ± 2.0 V dc Minimum CM bus 26.2 V dc 26.5 V dc (allows for cyclic loads) Min Precautionary CM bus 31.0 V dc Maximum CM bus Max Precautionary CM 30.0 V dc (allows for cyclic loads) bus During postlanding and 27 to 30 V dc preflight checkout periods Ripple voltage 1 V peak to peak

Operational Limitations and Restrictions

<u>Fuel cell power plants</u>.- Fuel cell power plants are designed to function under atmospheric and high-vacuum conditions. Each must be able to maintain itself at sustaining temperatures and minimum electrical loads at both environment extremes. To function properly, fuel cells must operate under the following limitations and restrictions:

External nonoperating temperature	-20° to +140° F.
Operating temperature inside SM	+30° to 145° F.
External nonoperating pressure	Atmospheric
Normal voltage	27 to 31 V dc
Minimum operating voltage at terminals	
Emergency operation	20.5 V dc at 2295 watts (gross power level)
Normal operation	27 V dc

.

.....

A-67

E

UUUUUUUUU

Maximum operating voltage 31.5 V dc at terminals Fuel cell disconnect 75 amperes no trip, 112 amperes overload disconnect after 25 to 300 seconds Maximum reverse current 1 second minimum before disconnect Minimum sustaining power/ 420 watts fuel cell power plant (with in-line heater OFF) In-line heater power 160 watts (sustain F/C skin temp (5 to 6 amps)above 385° F min) 2295 watts at 20.5 V dc min. Maximum gross power under emergency conditions Nitrogen pressure 50.2 to 57.5 psia (53 psia, nominal) Reactant pressure 58.4 to 68.45 psia (62.5 psia, Oxygen nominal) Hydrogen 57.3 to 67.0 psia (61.5 psia, nominal) Reactant consumption/fuel cell power plant PPH = Amps x (2.57×10^{-3}) PPH = Amps x (2.04×10^{-2}) Hydrogen Oxygen Minimum skin temperature +385° F for self-sustaining operation Minimum skin temperature +360° F for recovery in flight Maximum skin temperature +500° F -260° to +400° F Approximate external environment temperature range outside SC (for radiation)

Fuel cell power plant +385° to +450° F normal operating temperature range Condenser exhaust normal +150° to +175° F operating temperature Purging nominal frequency Dependent on mission load profile and reactant purity after tank fill 0, purge duration 2 minutes H₂ purge duration 80 seconds Additional flow rate while purging Oxygen Up to $0.6 \, lb/hr$ Hydrogen Up to 0.75 lb/hr (nominal 0.67 lb/hr) Cryogenic storage subsystem .- The cryogenic storage subsystem must be able to meet the following requirements for proper operation of the fuel cell power plants and the ECS: Minimum usable quantity Oxygen 320 lbs each tank (min) Hydrogen 28 lbs each tank (min) Temperature at time of fill Oxygen -297° F. (approx.) Hydrogen -423° F. (approx.) Operating pressure range Oxygen Normal 865 to 935 psia Minimum 150 psia Hydrogen Normal 225 to 260 psia Minimum 100 psia Temperature probe range Oxygen -325° to +80° F -425° to -200° F Hydrogen Maximum allowable difference in quantity balance between tanks

L

1.1

1

L.,

*---

1

H

M Y I

Hydrogen tanks No. 1 3 percent
and 2
Pressure relief valve
operation
Crack pressure
Oxygen 983 psig min.
Hydrogen 273 psig min.
Reseat pressure
Oxygen 965 psig min.
Hydrogen 268 psig min.
Full flow, maximum
relief
Oxygen 1010 psig max.
Hydrogen 285 psig max.

Additional data. - Additional data about limitations and restrictions may be found in the CSM/LM Spacecraft Operational Data Book SNA-8-D-027, Vol I, (CSM SD68-447).

Systems Test Meter

The SYSTEMS TEST meter and the alphabetical and numerical switches, located on panel 101 in the CM LEB, provide a means of monitoring various measurements within the SC, and verifying certain parameters displayed only by event indicators. The following can be measured using the SYSTEMS TEST meter, the respective switch positions, and the range of each sensor. Normal operating parameters of measurable items are covered in the telemetry listing.

Conversion of the previously listed measurements to the SYSTEMS TEST meter indications are listed in Table A2.6-IV. The XPNDR measurements are direct readouts and do not require conversion.

1.

M U

H