tunnel permits intervehicular transfer of crew and equipment without exposure to space environment.

Final docking latches: Twelve latches are spaced equally about the periphery of the CM docking ring. They are placed around and within the CM tunnel so that they do not interfere with probe operation. When secured, the latches insure structural continuity and pressurization between the LM and the CM, and seal the tunnel interface.

Umbilical: An electrical umbilical, in the LM portion of the tunnel, is connected by an astronaut to the CM. This connection can be made without drogue removal.

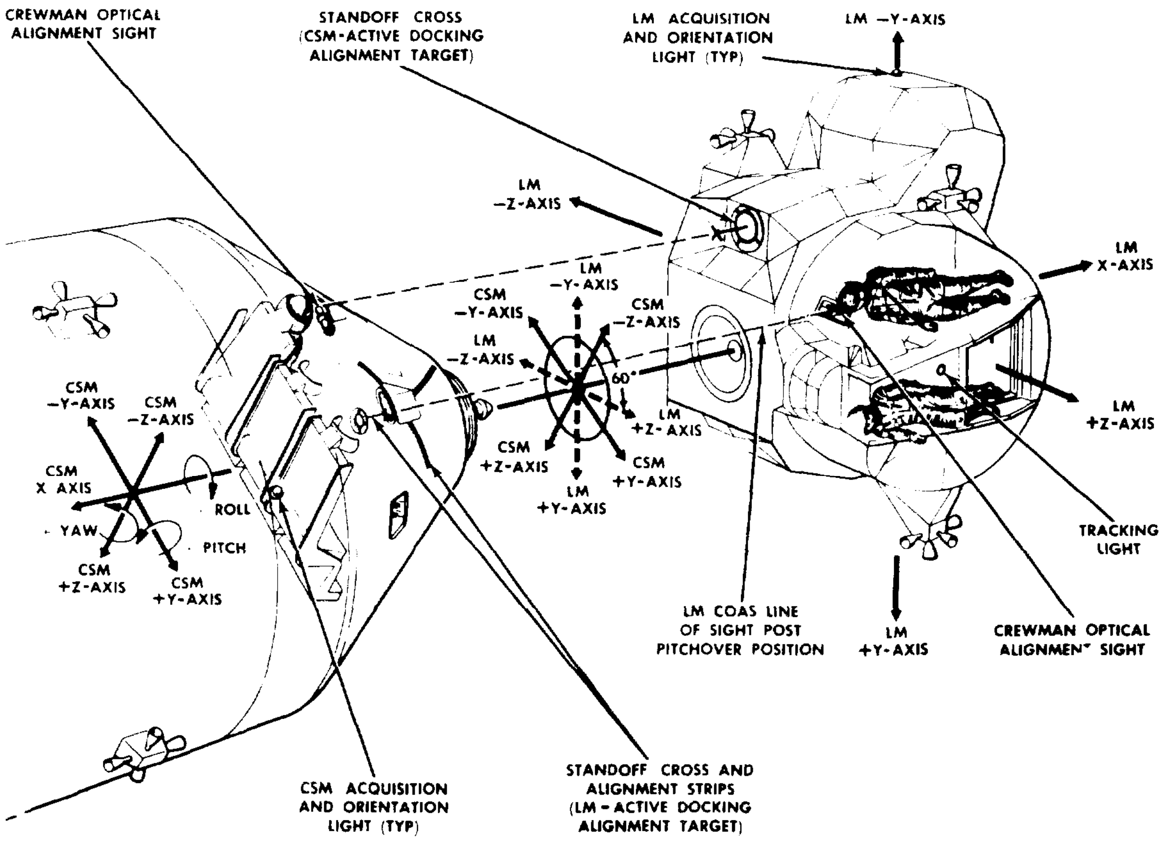


Figure A3-5.- LM-CSM reference axes.

Docking hatches.- The LM has a single docking (overhead) hatch; the CSM has a single, integral, forward hatch. The LM overhead hatch is not removable. It is hinged to open 75 degrees into the cabin.

Docking drogue.- The drogue assembly is a conical structure with provisions for mounting in the LM portion of the crew transfer tunnel. The drogue may be removed from either end of the crew transfer tunnel and may be temporarily stowed in the CM or the LM, during Service Propulsion System (SPS) burns. One of the three tunnel mounts contains a locking mechanism to secure the installed drogue in the tunnel.

Docking probe.- The docking probe provides initial CM-LM coupling and attenuates impact energy imposed by vehicle contact. The docking probe assembly consists of a central body, probe head, capture latches, pitch arms, tension linkages, shock attenuators, a support structure, probe stowage mechanism, probe extension mechanism, probe retraction system, an extension latch, a preload torque shaft, probe electrical umbilicals, and electrical circuitry. The assembly may be folded for removal and stowage from either end of the transfer tunnel.

The probe head is self-centering. When it centers in the drogue the three capture latches automatically engage the drogue socket. The capture latches can be released by a release handle on the CM side of the probe or by depressing a probe head release button from the LM side, using a special tool stowed on the right side stowage area inside the cabin.

Docking aids.- Visual alignment aids are used for final alignment of the LM and CSM, before the probe head of the CM makes contact with the drogue. The LM +Z-axis will align 50 to 70 degrees from the CSM -Z-axis and 30 degrees from the CSM +Y-axis. The CSM position represents a 180-degree pitchover and a counterclockwise roll of 60 degrees from the launch vehicle alignment configuration.

An alignment target is recessed into the LM so as not to protrude into the launch configuration clearance envelope or beyond the LM envelope. The target, at approximately stations -Y46.300 and -Z0.203, has a radioluminescent black standoff cross having green radioluminescent disks on it and a circular target base painted fluorescent white with black orientation indicators. The base is 17.68 inches in diameter. Cross members on the standoff cross will be aligned with the orientation indicators and centered within the target circle when viewed at the intercept parallel to the X-axis and perpendicular to the Y-axis and Z-axis.

Stowage Provisions

The LM has provisions for stowing crew personal equipment. The equipment includes such items as the docking drogue; navigational star charts and an orbital map; umbilicals; a low-micron antibacteria filter for attachment to the cabin relief and dump valve; a crewman's medical kit; an extravehicular visor assembly (EVVA) for each astronaut; a special multipurpose wrench (tool B); spare batteries for the PLSS packs; and other items.

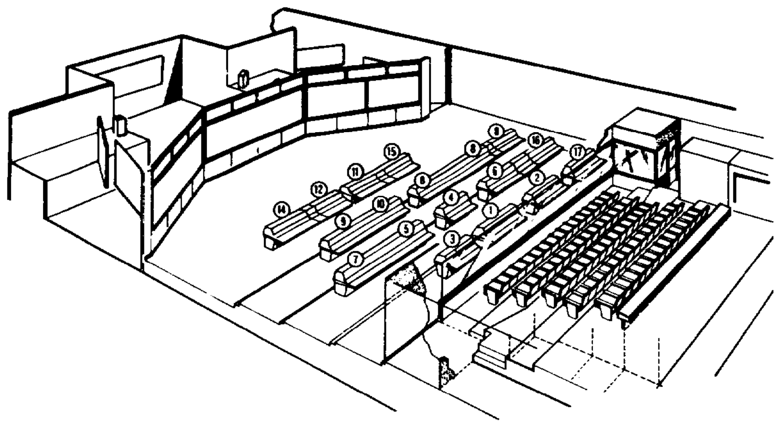
PART A4

MISSION CONTROL CENTER ACTIVITIES

INTRODUCTION

The Mission Control Center (MCC) is located at the Manned Spacecraft Center in Houston, Texas. The MCC contains the communications, computer display and command systems to effectively monitor and control the Apollo spacecraft. These data were extracted from information furnished by Flight Operations Directorate, Manned Spacecraft Center.

Flight operations are controlled from the MCC. The MCC contains two flight control rooms, but only one control room is used per mission. Each control room, called a Mission Operations Control Room (MOCR), is capable of controlling individual Staff Support Rooms (SSR) located adjacent to the MOCR. Both the MOCR's and the SSR's operate on a 24-hour basis. To accomplish this, the various flight control functions and consoles are staffed by three 9-hour shifts. Figures A4-1 and A4-2 show the floor plans and locations of personnel and consoles in the MOCR and the SSR's. Figure A4-3 shows MOCR activity during the Apollo 13 flight, and figure A4-4 shows the MOCR and SSR organizational structure.



1. Flight Operations Director: Responsible for successful completion of mission flight operations for all missions being supported.

2. Mission Director: Overall mission responsibility and control of flight test operations, which include launch preparation. In Project Mercury there were no alternative mission objectives that could be exercised other than early termination of the mission. The Apollo missions, however, offer many possible alternatives which have to be decided in real time.

3. Public Affairs Officer: Responsible for providing information on the mission status to the public.

4. Flight Director: Responsible for detailed control of the mission from lift-off until conclusion of the flight.

5. Assistant Flight Director: Responsible to the Flight Director for detailed control of the mission from lift-off through conclusion of the flight; assumes the duties of the Flight Director during his absence.

6. Experiments and Flight Planning: Plans and monitors accomplishment of flight planning and scientific experiment activities.

7. Operations and Procedures Officer: Responsible to the Flight Director for the detailed implementation of the MCC/Ground Operational Support Systems mission control procedures.

8. Vehicle Systems Engineers: Monitor and evaluate the performance of all electrical, mechanical and life support equipment aboard the spacecraft (this includes the Agena during rendezvous missions).

9. Flight Surgeon: Directs all operational medical activities concerned with the mission, including the status of the flight crew.

10. Spacecraft Communicator: Voice communications with the astronauts, exchanging information on the progress of the mission with them.

11. Flight Dynamics Officer: Monitors and evaluates the flight parameters required to achieve a successful orbital flight; gives "GO" or "ABORT" recommendations to the Flight Director.

12. Retrofire Officer: Monitors impact prediction displays and is responsible for determination of retrofire times.

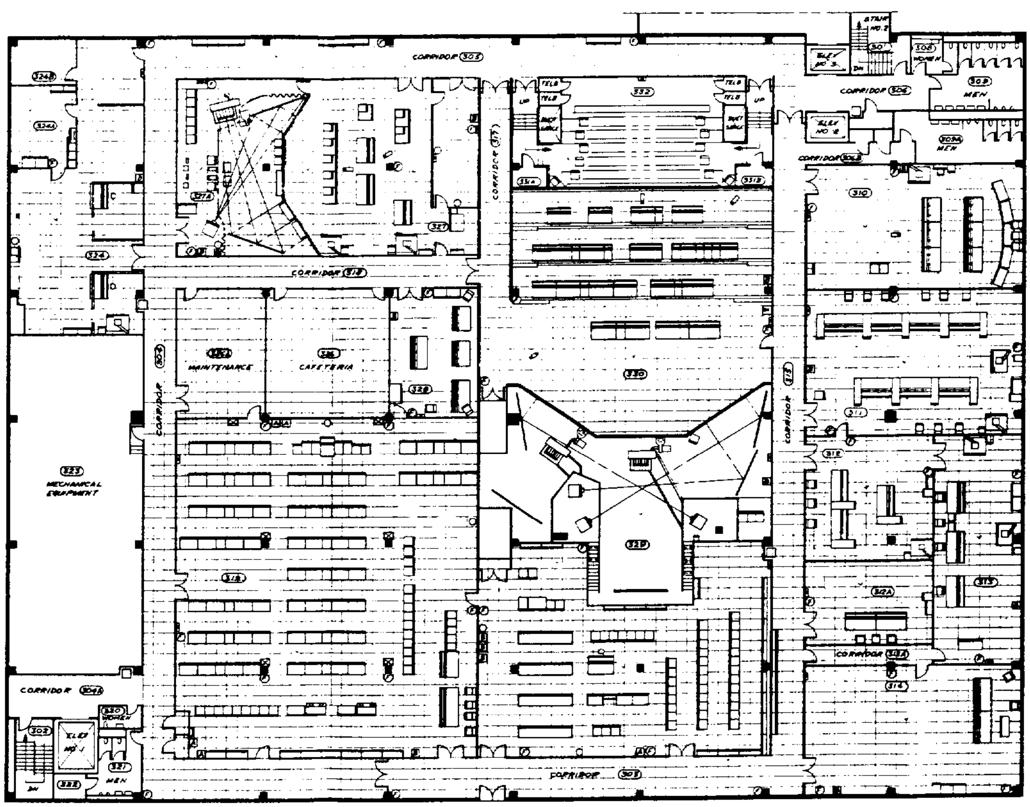
14. Booster Systems Engineer: Monitors propellant tank pressurization systems and advises the flight crew and/or Flight Director of systems abnormalities.

15. Guidance Officer: Detects Stage I and Stage II slowrate deviations and other programmed events, verifies proper performance of the Inertial Guidance System, commands onboard computation function and recommends action to the Flight Director.

16. Network Controller: Has detailed operational control of the Ground Operational Support System network.

17. Department of Defense Representative: Overall control of Department of Defense forces supporting the mission, including direction of the deployment of recovery forces, the operation of the recovery communications network, and the search, location and retrieval of the crew and spacecraft.

Figure A4-1.- Personnel and console locations.



Legend of symbols

- ⬡ Clock
- Zone fire alarm panel
- [A] "A" power panel
- [B] "B" power panel
- (F) Fire extinguisher
- ☒ Air duct
- [(B)] Ozone exhaust

Room no.	Room name
310	Flight dynamics SSR
311	Vehicle systems SSR
312	Life systems SSR
312A	Flight crew SSR
313	Operation and procedures SSR
314	ALSEP SSR
316	Control and display terminal
319	Display and timing
324, 324A, 324B	Meteorological center
327	Recovery control
327A	Recovery control display projection
328	Simulation control
329	Summary display projection
330	Mission operations control room no. 1
331A, 331B	Comm booth
332	Visitors viewing area

Figure A4-2.- Floor plan of MOCR and SSR's.

Figure A4-3.- MOCR activity during Apollo 13.

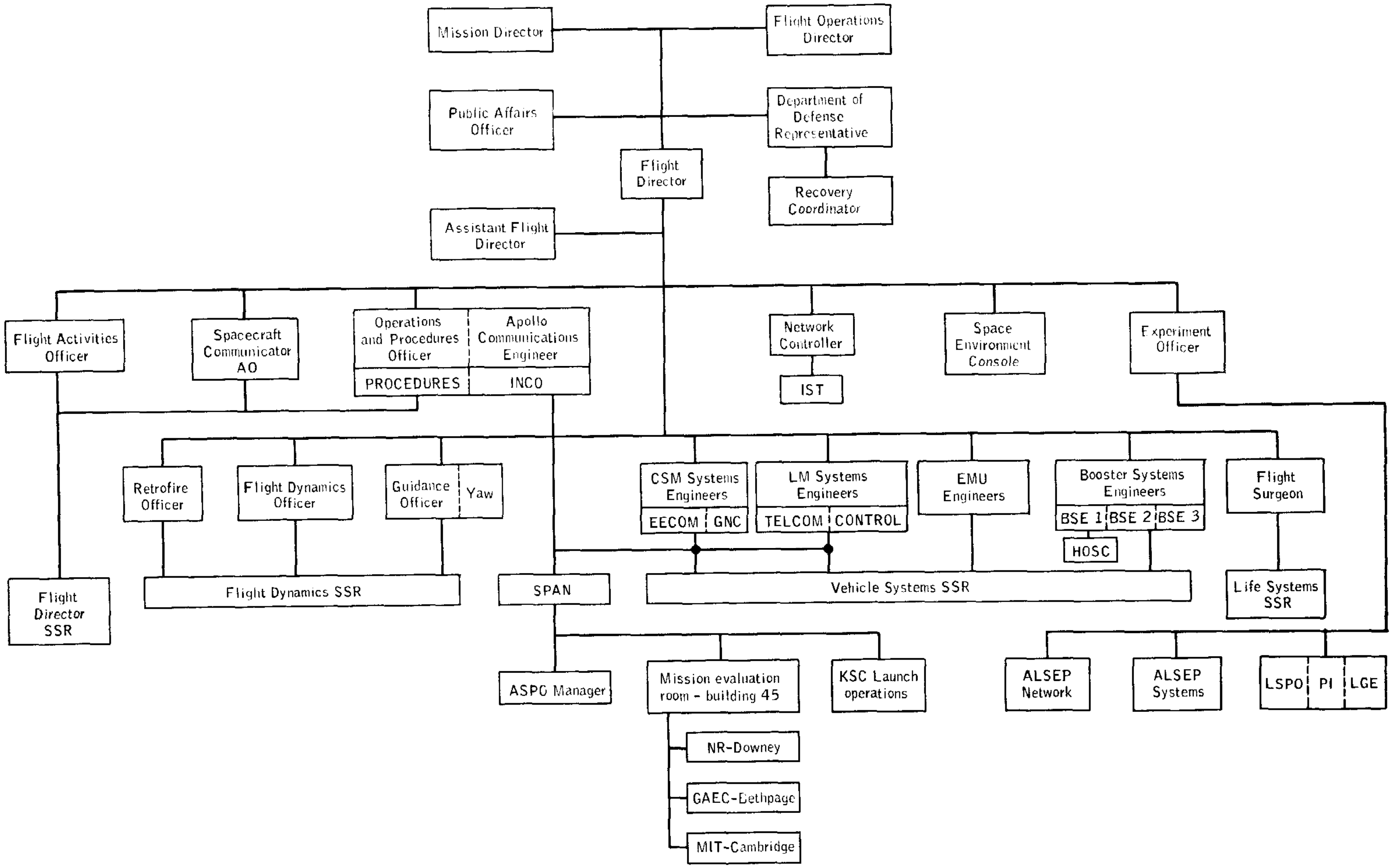


Figure A4-4.- MOCR and SSR organizational structure.

MISSION OPERATIONS CONTROL ROOM

The MOCR was the center for mission control operations. The prime control positions were stationed in this area. The MOCR was broken down into three operations groups. Responsibilities of the groups were as follows:

a. <u>Mission Command and Control Group</u>

(1) Mission Director (MD)
The MD was responsible for overall conduct of the mission.

(2) Flight Operations Director (FOD)
The FOD was responsible for the interface between the Flight Director and management.

(3) Flight Director (FD)
The FD was responsible for MOCR decisions and actions concerning vehicle systems, vehicle dynamics, and MCC/MSFN operations.

(4) Assistant Flight Director (AFD)
The AFD was responsible for assisting the Flight Director in the performance of his assigned duties.

(5) Flight Activities Officer (FAO)
The FAO was responsible for developing and coordinating the flight plan.

(6) Department of Defense Representative (DOD)
The DOD Representative was responsible for coordination and direction of all DOD mission support forces and sites.

(7) Assistant DOD Representative
The Assistant DOD Representative was responsible for assisting the DOD Representative in the performance of his task.

(8) Network Controller (NC) (NETWORK)
The Network Controller was responsible to the Flight Director for the detailed operational control and failure analysis of the MSFN.

(9) Assistant Network Controller
The Assistant Network Controller assisted the Network Controller in the performance of his duties and was responsible for all MCC equipment and its ability to support.

(10) Public Affairs Officer (PAO)
The PAO was responsible for keeping the public informed on the progress of the mission.

(11) Surgeon
The Flight Surgeon was responsible to the Flight Director for the analysis and evaluation of all medical activities concerned with the flight.

(12) Spacecraft Communicator (CAPCOM)
The Spacecraft Communicator was responsible to the Flight Director for all voice communications with the flight crew. The CAPCOM also served in conjunction with FAO as a crew procedures advisor. This position was manned by a member of the backup flight crew.

(13) Experiments Officer (EO) (EXPO)
The primary function of the EO was to provide overall operational coordination and control for the Apollo Lunar Surface Experiment Package (ALSEP), and the Lunar Geology Experiment (LGE). The coordination was with the various MOCR operational positions and the ALSEP SSR; the Principal Investigators, Management, the Program Officer, Goddard, and the Manned Space Flight Network. The EO was also responsible to the Flight Director for providing ALSEP and LGE status and any ALSEP or LGE activities that could have an effect on the Apollo mission.

b. Systems Operations Group (MOCR)

(1) Environmental, Electrical, and Communications (EECOM)
The CSM EECOM Engineer was responsible to the FD for monitoring and troubleshooting the CSM environmental, electrical, and sequential systems.

(2) Guidance, Navigation, and Control (GNC)
The GNC Engineer was responsible to the Flight Director for monitoring and troubleshooting the CSM guidance, navigation, control, and propulsion systems.

(3) TELCOM
The LM Environmental and Electrical Engineer was responsible to the FD for monitoring and troubleshooting the LM environmental, electrical, and sequential systems.

(4) CONTROL
The LM Guidance, Navigation, and Control Engineer was responsible to the Flight Director for monitoring and troubleshooting the LM guidance, navigation, control, and propulsion systems.

(5) Booster Systems Engineer (BSE)
The Booster Systems Engineers' responsibilities were delegated as follows:

(a) BSE 1 had overall responsibility for the launch vehicle including command capability. In addition, BSE 1 was responsible for all S-IC and S-II stage functions.

(b) BSE 2 had prime responsibility for all S-IVB stage functions with the exception of command.

(c) BSE 3 had prime responsibility for all instrument unit (IU) functions with the exception of command.

(6) Apollo Communications Engineer (ACE) (INCO) and Operations and Procedures Officer (O&P) (PROCEDURES)
The INCO and O&P shared a console and responsibility. The INCO's prime responsibility to the Flight Director was for monitoring and troubleshooting the CSM, LM, TV, PLSS, and erectable antenna communication systems. He was also responsible for execution of all commands associated with the communication systems. The O&P's prime responsibility to the Flight Director was for the detailed implementation of the MCC/MSFN/GSFC/KSC mission control interface procedures. The O&P was also responsible for scheduling and directing all telemetry and DSE voice playbacks. He also developed all communication inputs and changes to the ground support timeline.

c. Flight Dynamics Group

(1) Flight Dynamics Officer (FIDO)
The Flight Dynamics Officer participated in prelaunch checkout designed to insure system readiness, monitored powered flight events and trajectories from the standpoint of mission feasibility; monitored reentry events and trajectories, and updated impact point estimates as required.

(2) Retrofire Officer (RETRO)
The Retrofire Officer participated in prelaunch checkout designed to insure system readiness and maintained an updated reentry plan throughout the mission.

(3) Guidance Officer (GUIDO) and YAW
The Guidance Officer participated in prelaunch checkout designed to insure system readiness and performed the guidance monitor functions during power flight and spacecraft initialization. The GUIDO was also responsible for CSM and LM display keyboards (DSKY) as well as CMC and LGC command updates. The second Guidance Officer (YAW) had the same duties except that he was not responsible for command functions.

MCC SUPPORT ROOMS

Each MOCR group had a staff support room (SSR) to support all activities required by each MOCR position. These SSR's were strategically located in areas surrounding the MOCR's and were manned by the various personnel of a given activity.

a. <u>Staff Support Room</u>

(1) Flight Dynamics SSR
The Flight Dynamics SSR was responsible to the Flight Dynamics Group in the MOCR for providing detailed analysis of launch and reentry parameters, maneuver requirements, and orbital trajectories. It also, with the assistance of the Mission Planning and Analysis Division (MPAD), provided real-time support in the areas of trajectory and guidance to the MOCR Flight Dynamics team on trajectory and guidance matters. An additional service required provided interface between the MOCR Flight Dynamics team and parties normally outside the Flight Control team such as Program Office representatives, spacecraft contractor representatives, et cetera.

(2) Flight Director's SSR
The Flight Director's SSR was responsible for staff support to the Flight Director, AFD, Data Management Officer, and FAO. This SSR was also responsible to the Apollo Communications Engineer in the MOCR for monitoring the detailed status of the communication systems. The SSR was also responsible for two TV channel displays: Ground Timeline and Flight Plan.

(3) Vehicle Systems SSR
The Vehicle Systems SSR was responsible to the Systems Operations Group in the MOCR for monitoring the detailed status and trends of the flight systems; avoiding, correcting, and circumventing vehicle equipment failures; and detecting and isolating vehicle malfunctions. After the S-IVB was deactivated, the portable life support system engineer and the Experiments Officer occupied the two booster consoles in the Vehicle Systems SSR.

(4) Life Systems SSR
The Life Systems SSR was responsible to the Life Systems Officer for providing detailed monitoring of the physiological and environmental data from the spacecraft concerning the flight crew and their environment.

(5) Spaceflight Meteorological Room
The Spaceflight Meteorological Room was responsible to the Mission Command and Control Group for meteorological and space radiation information.

(6) Space Environment Console (SEC) (RADIATION)
The Space Environment Console was manned jointly by a Space Environment Officer (SEO) from the Flight Control Division and a Space Environment Specialist from the Space Physics Division. During mission support, the SEO was responsible for the console position, the proper operation of the console, and the completion of all necessary activities and procedures. The SEC was the central collecting and coordinating point at MSC for space radiation environment data during mission periods.

(7) Spacecraft Planning and Analysis (SPAN) Room
The SPAN Room was the liaison interface between the MOCR, the data analysis team, vehicle manufacturers, and KSC Launch Operations. During countdown and real-time operations, the SPAN team leader initiated the appropriate action necessary for the analysis of spacecraft anomalies.

(8) Recovery Operations Control Room (ROCR)
The Recovery Operations Control Room was responsible for the recovery phase of the mission and for keeping the Flight Director informed of the current status of the recovery operations. Additionally, the Recovery Operations Control Room provided an interface between the DOD Representative and the recovery forces.

(9) ALSEP SSR
The ALSEP SSR was responsible to the Experiments Officer, Lunar Surface Program Office, and Principal Investigators for providing detailed monitoring of ALSEP central station and experiments data. The SSR was also responsible for all scheduling of activities, commanding, and data distribution to appropriate users.

MISSION SUPPORT AREAS

The two primary support areas for the MOCR flight control team were the CCATS area and the RTCC area located on the first floor of the MCC. These two areas of support and their operational positions interfaced with the MOCR flight control team.

Communications, Command, and Telemetry System (CCATS)

The CCATS was the interface between the MCC and MSFN sites. CCATS was a hardware/software configuration (Univac 494 computer) having the capability to provide for the reception, transmission, routing, processing, display and control of incoming, outgoing, and internally generated data in the areas of telemetry, command, tracking, and administrative information. The CCATS consoles were augmented with various high-speed printers (HSP) and TTY receive-only (RO) printers adjacent to the consoles. Figure A4-5 illustrates the CCATS operational organization. CCATS personnel interfaced with the MOCR flight control team were as follows:

a. Command Support Console
This console was a three-position support element whose operators were concerned with the total command data flow from the generation and transfer of command loads from the RTCC to the verification of space vehicle acceptance following uplink command execution. The three command positions were:

(1) Real-Time Command Controller (RTC)

(2) Command Load Controller (LOAD CONTROL)

(3) CCATS Command Controller (CCATS CMD)

b. <u>Telemetry Instrumentation Control Console</u>

This console was a two-position support element whose operators were concerned with the telemetry control of incoming data from the MSFN. Certain telemetry program control was exercised on the incoming data. The two telemetry positions were:

(1) Telemetry Instrumentation Controller (TIC)

(2) CCATS Telemetry Controller (CCATS TM)

c. <u>Instrumentation Tracking Controller Console</u>

This console was a two-position support element whose operators were concerned with the tracking radar support involving the spacecraft and ground systems operations and configurations. The two tracking positions were:

(1) Instrumentation Tracking Controller (TRK)

(2) USB Controller

d. <u>Central Processor Control Console</u>

This console was a two-position support element and provided the facilities for monitoring and controlling selected software and hardware functions applicable to the configuration of the CCATS computer complex. The two positions were:

(1) Central Processor Controller (CPC)

(2) Central Processor Maintenance and Operations (M&O)

e. <u>Communications Controller Console</u>

The operators of this console provided overall communications management between MCC and MSFN elements.

Real-Time Computer Complex (RTCC)

The RTCC provided the data processing support for the MCC. It accomplished the telemetry processing, storage and limit sensing, trajectory and ephemeris calculations, command load generation, display generation, and many other necessary logic processing and calculations. The RTCC supported both MOCR's and as such had two divisions known as computer controller complexes, each capable of supporting one MOCR. Each complex was supported by two IBM 360 computers, known as the mission operations computer (MOC) and the dynamic standby computer (DSC). The DSC served as backup to the MOC. Figure A4-6 illustrates the RTCC operational organization for each complex. A brief description of the RTCC positions follows.

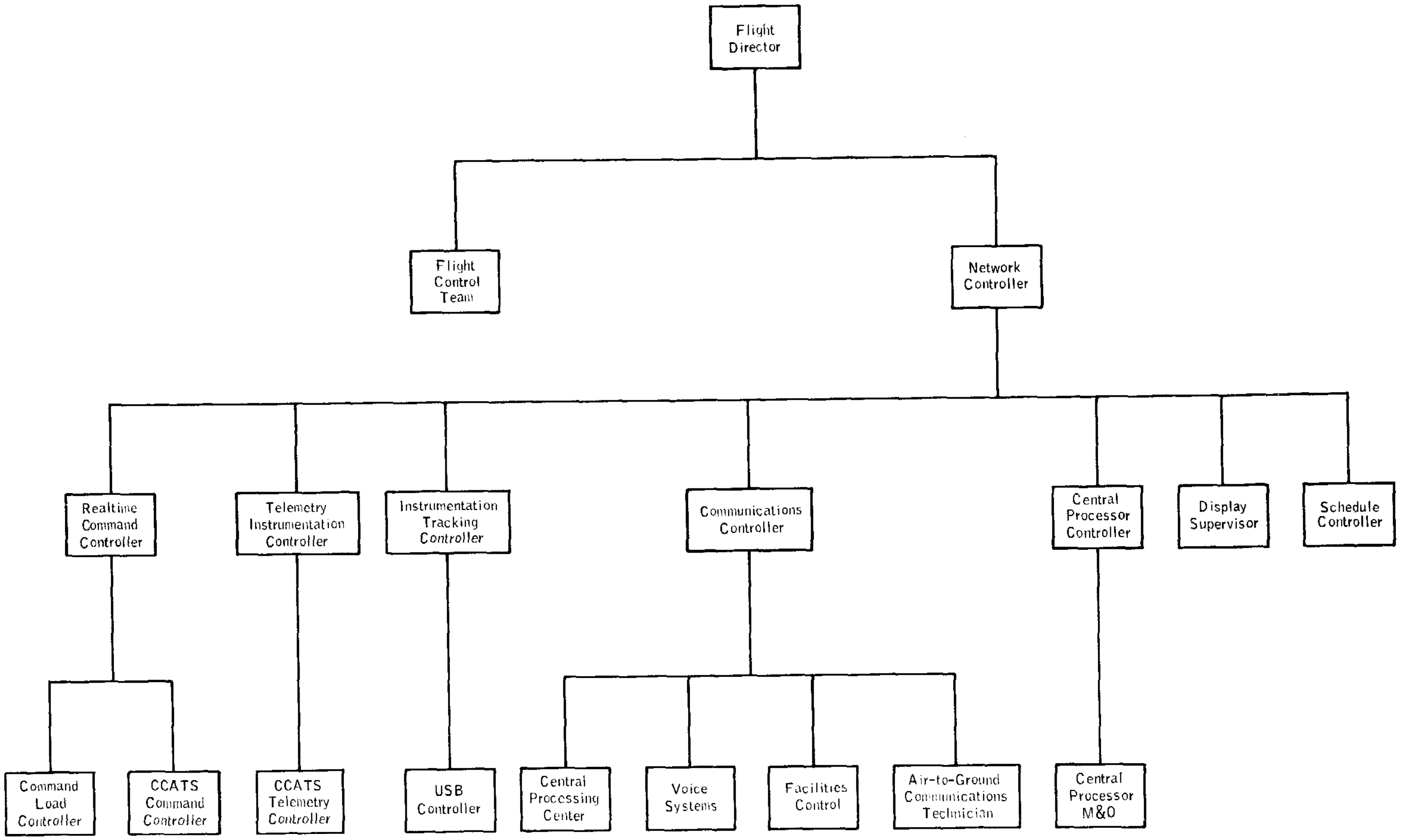


Figure A4-5.- CCATS operational organization.

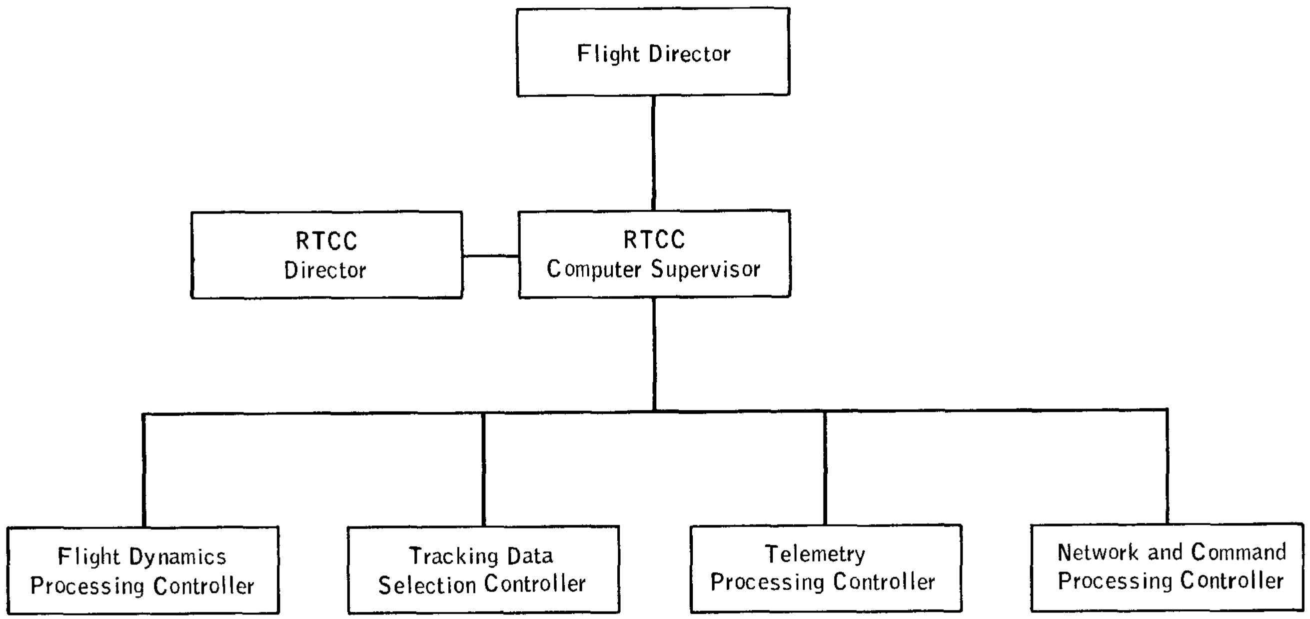


Figure A4-6.- RTCC operational organization.

a. RTCC Director

Controlled and coordinated the activities of the two computer complexes.

b. RTCC Computer Supervisor (Computer Sup)

Responsible for the operational control of the complex.

c. Tracking Data Selection Controller (Data Select)

Monitored the tracking data being processed in the RTCC and insured the data used as input to the MOCR and SSR displays was the best obtainable. Evaluated the quality of tracking data received during the launch phase and selected the source of data. Evaluated the trajectory determinations and was responsible for the various related displays. Informed the MOCR Flight Dynamics Officer concerning the quality and status of the data.

d. Flight Dynamics Processing Controller (Computer Dynamics)

Controlled and monitored all trajectory computing requirements requested by MOCR flight dynamics personnel and MOCR recovery activities. Performed evaluation and analysis of the predicted trajectory quantities as they related to the mission plan.

e. Network and Command Processing Controller (Computer Command)

Coordinated with MOCR personnel who had command responsibility and directed the generation, review, and transfer of requested command loads.

f. Telemetry Processing Controller (Computer TM)

This position had access to all telemetry data entering and leaving the RTCC and interfaced with the MOCR and SSR positions using telemetry data. Duties included monitoring telemetry input data, coordinating input requests, monitoring computer generated telemetry displays, and keeping the MOCR aware of the telemetry processing status.

NOTE

From ALSEP deployment to splashdown TRK and TIC will be responsible for scheduling sites to support the scientific package. This will include calling up of sites and data/command handling to MCC.

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PART A5

EXCERPTS FROM APOLLO FUEL CELL AND

CRYOGENIC GAS STORAGE SYSTEM FLIGHT SUPPORT HANDBOOK

The information contained in this part was extracted from the Apollo Fuel Cell and Cryogenic Gas Storage System Flight Support Handbook, dated February 18, 1970. It was prepared by the Propulsion and Power Division of the Manned Spacecraft Center. The text was taken from Section 2.0 Fuel Cell Operation and Performance, Section 3.0 Cryogenic Gas Storage System Operation and Performance, Section 4.0 Instrumentation and Caution and Warning, Section 5.0 Fuel Cell/Cryogenic Subsystem Malfunction Procedures, Section 7.0 Fuel Cell/Cryogenic Subsystem Hardware Description.

2.0 FUEL CELL OPERATION AND PERFORMANCE

The fuel cell operation and performance are described by nominal system performance and operational data for both ground and flight environments and fuel cell response to a variety of component malfunctions.

Nominal system performance and operational data are presented in curve and table format to assist in rapid reference. The data include procedures and curves for making rough estimates of radiator performance. Apollo 10 and 11 flight data were used to generate a portion of the curves used for evaluating radiator performance.

Fuel cell response of measured parameters (temperature, voltage, etc.) to specific component malfunctions make up the remainder of the data presented. The curves are adequately noted to allow application without written procedures.

The fuel cell operation and performance data assist the user in evaluating fuel cell performance, identification of flight anomalies and provide a basis for developing corrective actions.

The sources of the data were the original "NASA Apollo Block II Fuel Cell, Cryogenic Gas Storage System, and Flight Batteries Flight Support Handbook," dated September 1968, NASA-MSC, North American Rockwell, Pratt and Whitney, Beech Aircraft and Boeing-Houston. These data were reviewed and found to be accurate as of December 1969.

2.1 FUEL CELL SYSTEM OPERATIONAL PARAMETERS SUMMARY (Continued)

NOMINAL FUEL CELL PRESSURIZED SYSTEM VOLUMES

Hydrogen Loop	250 in^3	
Oxygen Loop	88 in^3	
Nitrogen Loop	3098 in^3	
Glycol Loop (Fuel Cell)	107 in^3	
Glycol Accumulator (Fuel Cell)	30 in^3	
Net Fuel Cell Glycol Volume	117 in^3	(20 in^3 water glycol removed from accumulator)
Average NR Glycol Plumbing and Radiator Volume	66 in^3	
Estimated Fuel Cell Glycol Loop Volume	183 in^3	= 0.79 gallons

TOTAL SYSTEM SPEC LEAKAGE INTO BAY IV

Hydrogen System, Oxygen System, and Fuel Cells (3)

5.3×10^{-3} scc/sec of Helium

Fuel Cell (3) nitrogen system

1.6×10^{-4} scc/sec of Helium

SYSTEM PRESSURE SUMMARY

SUPPLY PRESSURES

	SUPPLY PRESSURES (PSIA)		REGULATED PRESSURES S/N 650769 AND ON		
	NOMINAL	MINIMUM	ABSOLUTE PSIA	ABOVE NITROGEN PRESSURE PSI	DEAD BAND PSI
Hydrogen	245 ± 15	100	57.90 - 67.60	6.20 - 11.35	.2-.4
Oxygen	900 ± 35	150	57.90 - 67.95	6.20 - 11.7	.5-.7
Nitrogen	1500	165	50.20 - 57.75	---	2.0-2.15

DELIVERY PRESSURE

Water 62 psia

PRESSURE LIMITS

Maximum water system discharge back pressure 59.55 psia
Maximum reactant vent back pressure 16 psia

2.1 FUEL CELL SYSTEM OPERATIONAL PARAMETERS SUMMARY (Continued)

ENVIRONMENTAL CONTROL SYSTEM WATER SYSTEM PRESSURES

Potable Water Tank	25 psia ± 2, Plus cabin pressure
Water Relief Valve	5.5 psid ± 1
Water Tank Vent Valve	44 psia ± 4
Cabin Relief Valve	$6.0^{+.2}_{-.4}$

FUEL CELL GROUND HEATER POWER SETTINGS

STARTUP HEAT SCHEDULE

ZONE	AMPERES
1	2.8 - 3.2
2	38.0 - 42.0
3	2.8 - 3.2

NORMAL OPERATION HEAT SCHEDULE

ZONE	SEA LEVEL OPERATION	VACUUM OPERATION
1	1.2 - 1.6 amperes	0 amperes
2	8.0 - 12.0 amperes	0 amperes
3	1.2 - 1.6 amperes	0 amperes

DRYOUT HEAT SCHEDULE

ZONE	SEA LEVEL OPERATION	VACUUM OPERATION
1	1.75 - 2.05 amperes	1.5 - 1.65 amperes
2	As required to maintain 460°F to 485°F skin temperature. Approximately 23.9 amps.	21.0 - 22.5 amperes
3	1.75 - 2.05 amperes	1.5 - 1.65 amperes

2.1 FUEL CELL SYSTEM OPERATIONAL PARAMETERS SUMMARY (Continued)

FUEL CELL DISCONNECT OVERLOAD DATA

OVERLOAD CURRENT DATA

Load (amps/ cell)	Required Disconnect Delay (sec)	Test Delay (sec)	Transfer Time (sec)
75	100 minimum	No transfer	
112	25 - 300	80	0.046
150	8 - 150	38	0.046
300	2 - 8	5.81	0.046
450	1 - 2	1.07	0.046
600	0.62 - 1.2	0.776	0.046
750	0.42 - 0.76	0.572	0.046
1000	0.24 - 0.55	0.470	0.046

FUEL CELL DISCONNECT REVERSE CURRENT DATA

REVERSE CURRENT DATA

Load (amps/ cell)	Required Disconnect Delay (sec)	Test Delay (sec)	Transfer Time (sec)
4	No trip	No transfer	
20	1 - 10	2.10	0.046
30	1 - 1.3	1.22	0.046
50	1 - 1.3	1.11	0.046

2.1 FUEL CELL SYSTEM OPERATIONAL PARAMETERS SUMMARY (Continued)

REACTANT CONSUMPTION AND WATER PRODUCTION

LOAD AMPS	O_2 lb/hr	H_2 lb/hr	H_2O lb/hrs	H_2O cc/hr
0.5	0.0102	.001285	.01149	5.21
1	0.0204	.002570	.02297	10.42
2	0.0408	.005140	.04594	20.84
3	0.0612	.007710	.06891	31.26
4	0.0816	.010280	.09188	41.68
5	0.1020	.012850	.11485	52.10
6	0.1224	.015420	.13782	62.52
7	0.1428	.017990	.16079	72.94
8	0.1632	.020560	.18376	83.36
9	0.1836	.023130	.20673	93.78
10	0.2040	.025700	.2297	104.20
15	0.3060	.038550	.34455	156.30
20	0.4080	.051400	.45940	208.40
25	0.5100	.064250	.57425	260.50
30	0.6120	.077100	.68910	312.60
35	0.7140	.089950	.80395	364.70
40	0.8160	.10280	.91880	416.80
45	0.9180	.11565	1.03365	468.90
50	1.0200	.12850	1.1485	521.00
55	1.1220	.14135	1.26335	573.10
60	1.2240	.15420	1.3782	625.20
65	1.3260	.16705	1.49305	677.30
70	1.4280	.17990	1.6079	729.40
75	1.5300	.19275	1.72275	781.50
80	1.6320	.20560	1.83760	833.60
85	1.7340	.21845	1.95245	885.70
90	1.8360	.23130	2.06730	937.90
95	1.9380	.24415	2.18215	989.90
100	2.0400	.25700	2.2970	1042.00

FORMULAS:

$O_2 = 2.04 \times 10^{-2}\ I$

$H_2 = 2.57 \times 10^{-3}\ I$

$H_2O = 10.42$ cc/Amp Hr

$H_2O = 2.297 \times 10^{-2}$ lb/Amp Hr

3.0 CRYOGENIC GAS STORAGE SYSTEM OPERATION AND PERFORMANCE

The cryogenic system operation and performance are described by nominal system performance and operational data for both ground and flight environments.

Nominal system performance and operational data are presented in curve and table format to assist in rapid reference. The curves, with the exception of those used for heat leaks and pressure change rates, are adequately noted to allow application without written procedures. The data include formulas, methods, and curves for calculating cryogenic tank heat leaks and pressure change rates for both equilibrium and non-equilibrium (stratified) conditions. Apollo 7 and 8 flight data were used to provide a comparison of equilibrium (calculated) tank pressure cycle time to actual flight pressure cycle time for a variety of tank quantities.

The fuel cell operation and performance data assist the user in evaluating cryogenic system performance, identification of flight anomalies, and provide a basis for developing corrective actions.

The sources of the data were the original "NASA Apollo Block II Fuel Cell, Cryogenic Gas Storage System, and Flight Batteries Flight Support Handbook," dated September 1968, NASA-MSC, North American Rockwell, Pratt and Whitney, Beech Aircraft and Boeing-Houston. These data were reviewed and found to be accurate as of December 1969.

3.1 CRYOGENIC SYSTEM OPERATIONAL PARAMETERS SUMMARY

	Hydrogen	Oxygen
TANK WEIGHT (PER TANK)		
Empty (Approx.)	80.00 lb.	90.82 lb.
Usable Fluid	28.15 lb.	323.45 lb.
Stored Fluid (100% indication)	29.31 lb.	330.1 lb.
Residual	4%	2%
Maximum Fill Quantity	30.03 lb.	337.9 lb.
TANK VOLUME (PER TANK)	6.80 FT^3	4.75 FT^3
TANK FLOW RATE (PER TANK)		
Max. for 10 Minutes	1.02 lbs/hr	4.03 lbs/hr
Max. for 1/2 hour	———	10.40 lbs/hr
Relief Valve Max Flow	6 lbs/hr @ 130°F	26 lbs/hr @ 130°F
TANK PRESSURIZATION		
Heaters (2 elements per tank)		
Flight		
Resistance	78.4 ohms per element	10.12 ohms per element
Maximum Voltage	28 V DC	28 V DC
Power	10 watts per element*	77.5 watts per element*
Total Heater Heat Input Per Tank (2 Elements)	68.2 BTU/Hr	528.6 BTU/Hr
Ground		
Resistance	78.4 ohms per element	10.12 ohms per element
Maximum Voltage	65.0 V DC	65.0 V DC
Power	54.0 watts per element*	417.5 watts per element*
Total Heater Heat Input Per Tank (2 Elements)	368 BTU/Hr	2848 BTU/Hr

* Conversion Factor: 1 watt = 3.41 BTU/Hr

3.1 CRYOGENIC SYSTEM OPERATIONAL PARAMETERS SUMMARY

		Hydrogen	Oxygen
Pressure Switch			
Open Pressure	Max.	260 psia	935 psia
Close Pressure	Min.	225 psia	865 psia
Deadband	Min.	10 psia	30 psia
Destratification Motors (2 Motors Per Tank)			
Voltage		115/200 V 400 cps	115/200 V 400 cps
Power - Average		3.5 watts per motor*	26.4 watts per motor*
Total Average Motor Heat Input Per Tank		23.8 BTU/Hr	180 BTU/Hr
SYSTEM PRESSURES			
Normal Operating		245 ±15 psia	900 ±35 psia
Spec Min. Dead Band of Pressure Switches		10 psi	30 psi
Relief Valve Note: Relief Valves are Referenced to Environmental Pressure, therefore Pressure at Sea Level (psig) will be same value in vacuum (psia)			
Crack	Min.	273 psig	983 psig
Full Flow	Max.	285 psig	1010 psig
Reseat	Min.	268 psig	965 psig
Outer Tank Shell Burst Disc			
Nominal Burst Pressure		90^{+10}_{-20} psid	75 ± 7.5 psid
SYSTEM TEMPERATURES			
Stored Fluid		-425 to 80°F	-300°F to 80°F
Heater Thermostat (Over Temp. Protection)		N.A. for 113 and Subs.	N.A. for 114 and Subs.
Open	Max.	80°F ± 10	80°F ± 10
Close	Min.	-200°F	-75°F

* Conversion Factor: 1 watt = 3.41 BTU/Hr

3.1 CRYOGENIC SYSTEM OPERATIONAL PARAMETERS SUMMARY

	Hydrogen	Oxygen
TANK HEAT LEAK (SPEC PER TANK)		
Operating (dQ/dM @ $140^{o}F$)	7.25 BTU/HR (.0725 #/hr)	27.7 BTU/HR (.79 #/hr)
VALVE MODULE LEAKAGE RATES		
External	400 scc H_2/HR/ Valve	400 scc O_2/HR/ Valve
	0.736×10^{-6} lbs H_2/HR/Valve	9.2×10^{-6} lbs O_2/HR/Valve
LIFE	600 HRS @ Cryogenic Temps. and operating pressure -225 psia	600 HRS @ Cryogenic Temps. and operating pressure -865 psia

4.0 INSTRUMENTATION AND CAUTION AND WARNING

The tabular data presented in Tables 4.1 and 4.2 list instrumentation measurements and specify instrumentation range, accuracy and bit value, if applicable. All of the data in Tables 4.1 and 4.2 can be used for system monitoring during ground checkout. Table 4.1 lists data displayed to the crew and telemetered from the vehicle to the Manned Space Flight Network (MSFN) during missions. Table 4.2 lists data available only for system monitoring during ground checkout. Event indications displayed to crew during flight are noted in Table 4.2.

The instrumentation sensor location, with the exception of voltage and current data, can be found by referring to the fuel cell/cryogenic schematics located in Section 7.0. Voltage and current readout and schematic locations can be obtained by referring to North American Rockwell drawings V37-700001, Systems Instrumentation, and V34-900101, Integrated System Schematics Apollo CSM, respectively.

The Caution and Warning System monitors the most critical fuel cell/cryogenic measurements and alerts the flight crew to abnormal system operation. The data presented in Table 4.1 are specification nominal caution and warning limits for the applicable measurements. Malfunctions procedures, Section 5.0, are provided for problem isolation as a result of a caution and warning alarm.

The source of the data was North American Rockwell Measurement Systems End-to-End Calibrated Accuracy Tolerances, TDR68-079, dated January 10, 1969 and the original Flight Support Handbook.

TABLE 4.1
INSTRUMENTATION/CAUTION AND WARNING SUMMARY

MEASUREMENT NUMBER *	MEASUREMENT NAME	RANGE	ACCURACY		BIT VALUE	CAUTION AND WARNING SETTINGS	
			PERCENT	ACTUAL		LOW	HIGH
CC0206V CC0207V	DC Bus Voltage A DC Bus Voltage B	0-45 volts	±0.94	±0.42V	0.178	26.25V	—
SC2113C SC2114C SC2115C	FC 1 Current FC 2 Current FC 3 Current	0-100 amps	±1.07	±1.07 a	0.395	—	—
SC2060P SC2061P SC2062P	FC 1 N_2 Press FC 2 N_2 Press FC 3 N_2 Press	0-75 psia	±4.30	±3.22 psia	0.295	—	—
SC2066P SC2067P SC2068P	FC 1 O_2 Press FC 2 O_2 Press FC 3 O_2 Press	0-75 psia	±4.30	±3.22 psia	0.295	—	—
SC2069P SC2070P SC2071P	FC 1 H_2 Press FC 2 H_2 Press FC 3 H_2 Press	0-75 psia	±4.30	±3.22 psia	0.295	—	—

* See note, page 4-11

TABLE 4.1
INSTRUMENTATION/CAUTION AND WARNING SUMMARY (Continued)

MEASUREMENT NUMBER *	MEASUREMENT NAME	RANGE	ACCURACY		BIT VALUE	CAUTION AND WARNING SETTINGS	
			PERCENT	ACTUAL		LOW	HIGH
SC2081T	FC 1 Cond Ex Temp	145-250°F	±2.18	+2.29°F	0.417	150°F	175°F
SC2082T	FC 2 Cond Ex Temp						
SC2083T	FC 3 Cond Ex Temp						
SC2084T	FC 1 Skin Temp	80-550°F	±1.15	±5.40°F	1.94	360°F	500°F
SC2085T	FC 2 Skin Temp						
SC2086T	FC 3 Skin Temp						
SC2087T	FC 1 Rad Out Temp	-50 to +300°F	±1.71	5.98°F	1.38	-30°F	—
SC2088T	FC 2 Rad Out Temp						
SC2089T	FC 3 Rad Out Temp						
SC2090T	FC 1 Rad In Temp	-50 to +300°F	±1.71	±5.98°F	1.38	—	—
SC2091T	FC 2 Rad In Temp						
SC2092T	FC 3 Rad In Temp						
SC2139R	FC 1 H_2 Flow Rate	0-0.2 lb/hr	±10.0	±0.020 lb/hr	0.00079	0.0	0.16
SC2140R	FC 2 H_2 Flow Rate						
SC2141R	FC 3 H_2 Flow Rate						

* See note, page 4-11

TABLE 4.1
INSTRUMENTATION/CAUTION AND WARNING SUMMARY (Continued)

MEASUREMENT NUMBER *	MEASUREMENT NAME	RANGE	ACCURACY		BIT VALUE	CAUTION AND WARNING SETTINGS	
			PERCENT	ACTUAL		LOW	HIGH
SC2142R SC2143R SC2144R	FC 1 O_2 Flow Rate FC 2 O_2 Flow Rate FC 3 O_2 Flow Rate	0-1.6 lb/hr	±10.0	±0.160 lb/hr	0.0063	0.0	1.27
SC0030Q SC0031Q	H_2 Tank 1 Qty H_2 Tank 2 Qty	0-100%	±2.68	2.68%	0.4%	—	—
SC0032Q SC0033Q	O_2 Tank 1 Qty O_2 Tank 2 Qty	0-100%	±2.68	2.68%	0.4%	—	—
SC0037P SC0038P	O_2 Tank 1 Press O_2 Tank 2 Press	50-1050 psia	±2.68	±26.8 psia	4.23	800	950
SC0039P SC0040P	H_2 Tank 1 Press H_2 Tank 2 Press	0-350 psia	±2.68	±9.38 psia	1.48	220	270
SC0041T SC0042T	O_2 Tank 1 Temp O_2 Tank 2 Temp	-320 to +80°F	±2.68	±10.85°F	1.57	—	—
SC0043T SC0044T	H_2 Tank 1 Temp H_2 Tank 2 Temp	-420 to -200°F	±2.68	±6.03°F	0.867	—	—

* See note, page 4-11

TABLE 4.1
INSTRUMENTATION/CAUTION AND WARNING SUMMARY (Continued)

MEASUREMENT NUMBER *	MEASUREMENT NAME	RANGE	ACCURACY		BIT VALUE	CAUTION AND WARNING SETTINGS	
			PERCENT	ACTUAL		LOW	HIGH
SC2160X	FC1 pH High	Normal - High	—	—	Event	—	—
SC2161X	FC2 pH High	Normal - High	—	—	Event	—	—
SC2162X	FC3 pH High	Normal - High	—	—	Event	—	—
**SC0050Q	H_2 Tank 3 Qty	0-100%					
**SC0051Q	O_2 Tank 3 Qty	0-100%					
**SC0052P	H_2 Tank 3 Press.	0-350 psia					
**SC0053P	O_2 Tank 3 Press.	50-1050 psia					

* See note, page A-160
** CSM 112 through 115 only