7. Dr. Von Braun - Since there is concern over the effect on LM thermal protection from the SM/RCS during extraction and subsequent operations, is short duration pulsing of the RCS really going to be effective in reducing degradation of the thermal coating?

ANSWER - The condition is still under study; however, the limited total duration of RCS firing is not expected to result in significant degradation.

NASA-S-66-5241 JUN

CREW PERFORMANCE REQUIREMENTS

- ABORT INITIATION
- FLIGHT CONTROL
- SYSTEM MANAGEMENT
- NAVIGATION
- ONBOARD MISSION MANAGEMENT

Figure 1

NASA-S-66-5236 JUN

CREW ORGANIZATION

- CREW POSITION
  - COMMAND PILOT
  - SENIOR PILOT
  - PILOT
- CROSS TRAINED IN ALL FUNCTIONS
- TRAINED AS A TEAM

Figure 2

NASA-S-66-5239 JUN

TYPES OF CREW TRAINING

- SYSTEMS FAMILIARIZATION
- SPECIFIC TASK TRAINING
- MISSION SEGMENT TRAINING
- SPECIFIC MISSION TRAINING
- EXPERIMENT ACTIVITY TRAINING

Figure 3

NASA-S-66-5238 JUN

ELEMENTS OF CREW TRAINING

- NORMAL MODE CREW ACTIVITY
- MALFUNCTION RECOGNITION AND RESPONSE
- EMERGENCY MODE CREW ACTIVITY
- CREW INTEGRATION

Figure 4

NASA-S-66-5237 JUN

SUBSYSTEMS

- LAUNCH ESCAPE
- GUIDANCE & NAVIGATION
- STABILIZATION & CONTROL
- REACTION CONTROL
- PROPULSION
  - SERVICE PROPULSION
  - DESCENT PROPULSION
  - ASCENT PROPULSION
- ENVIRONMENTAL CONTROL
- ELECTRICAL POWER
- COMMUNICATION
- RADAR
- SEQUENTIAL EVENTS
- EARTH LANDING
- EXTRAVEHICULAR MOBILITY UNIT

Figure 5

NASA-S-66-5240 JUN

TRAINING FACILITIES

- SYSTEMS TRAINERS
- PART TASK TRAINERS
  - MOCKUPS
  - DYNAMIC CREW PROCEDURES TRAINER
  - TRANSLATION AND DOCKING TRAINER
  - LUNAR LANDING TRAINING VEHICLE
  - EGRESS TRAINER
- MISSION SIMULATORS
  - COMMAND & SERVICE MODULE
  - LUNAR MODULE
- SPECIAL FACILITIES
  - CENTRIFUGE
  - AIR BEARING TRAINER
  - ZERO 'G' AND 1/6 'G' AIRCRAFT FLIGHTS
  - ENGINEERING SIMULATORS

Figure 6

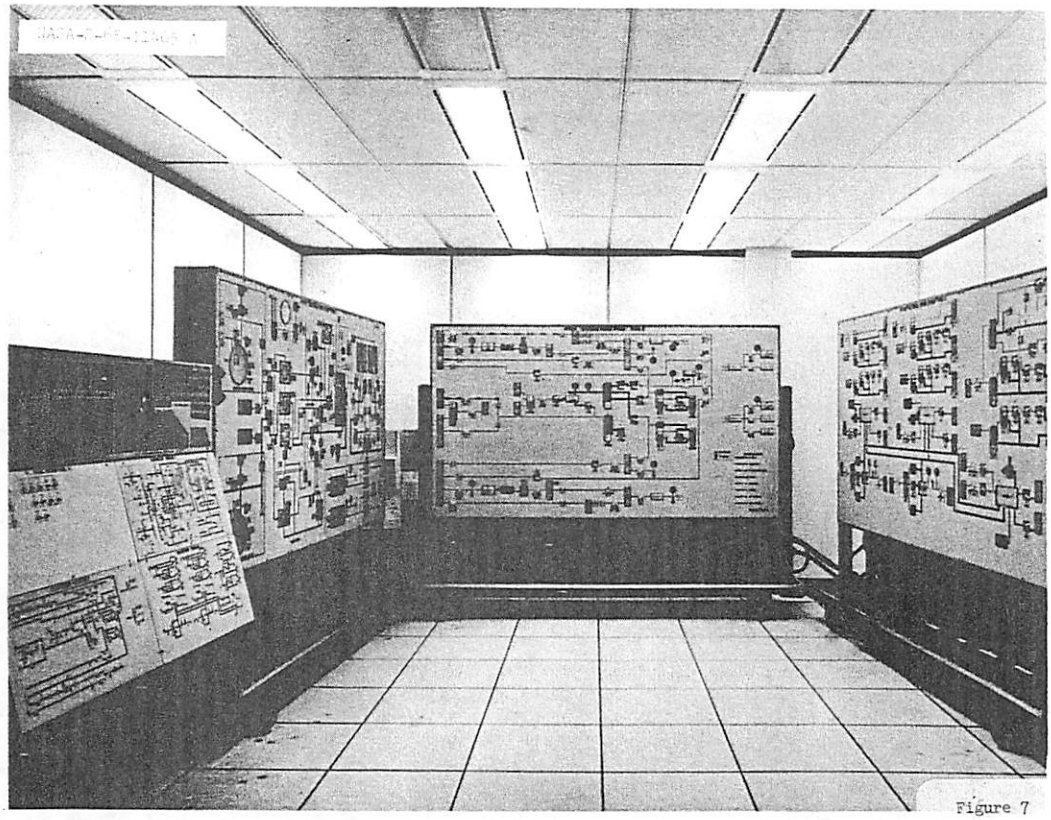


Figure 7

NASA-S-65-5753 APRIL 28, 1965

APOLLO BLOCK II MOCKUP

COMMAND MODULE BLOCK II MOCKUP - INTERIOR CONFIGURATION ONLY - SHOWN ON TRANSPORTATION DOLLY

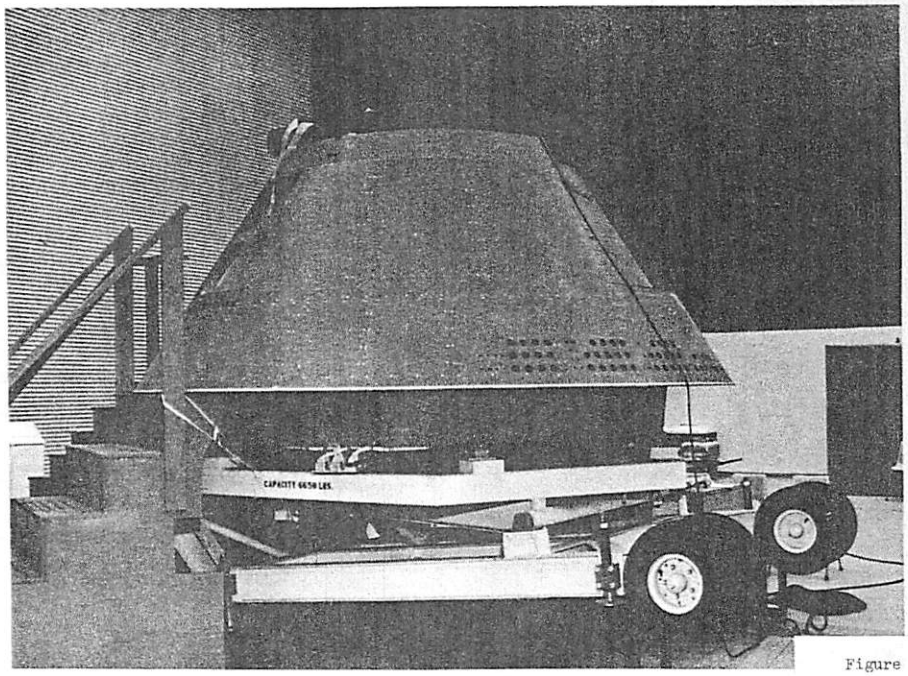


Figure 8

NASA-S-66-6147 JUNE

LM MOCKUP

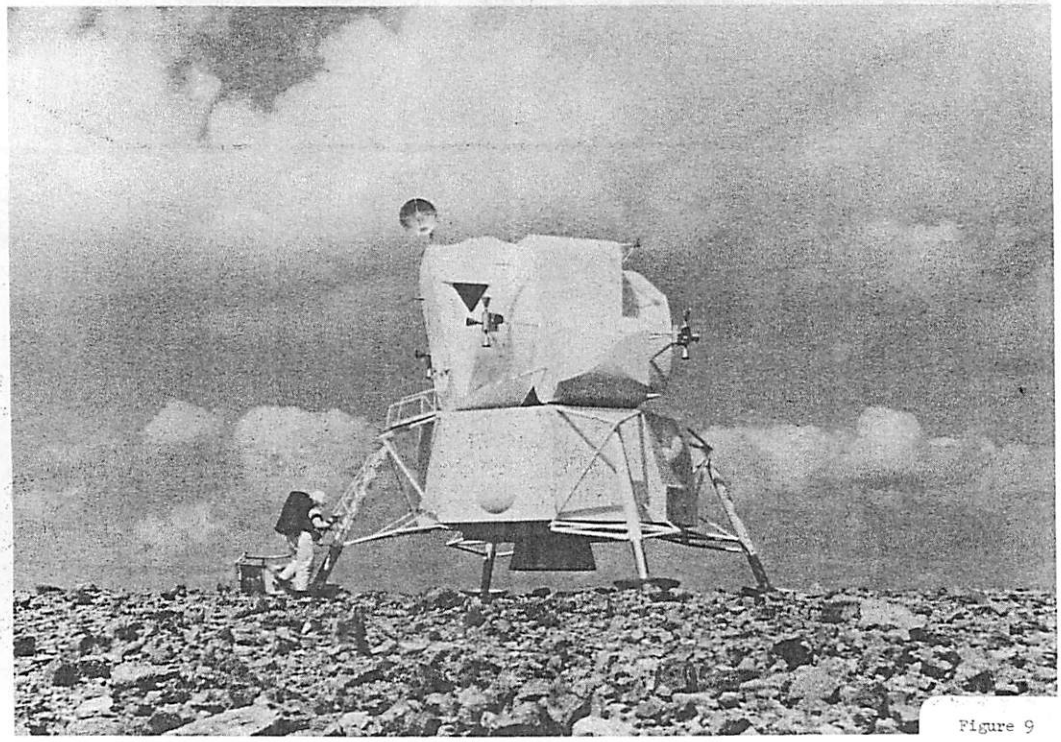


Figure 9

NASA-S-66-5247 JUN

DYNAMIC CREW
PROCEDURES
TRAINER
CM CONFIGURATION

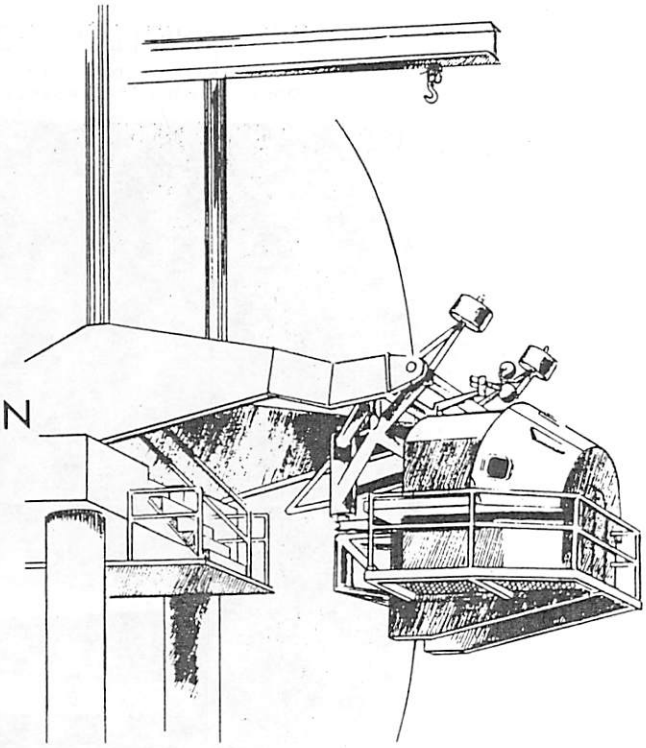


Figure 10

NASA-S-66-5246 JUN

DYNAMIC CREW
PROCEDURES
TRAINER
LM CONFIGURATION

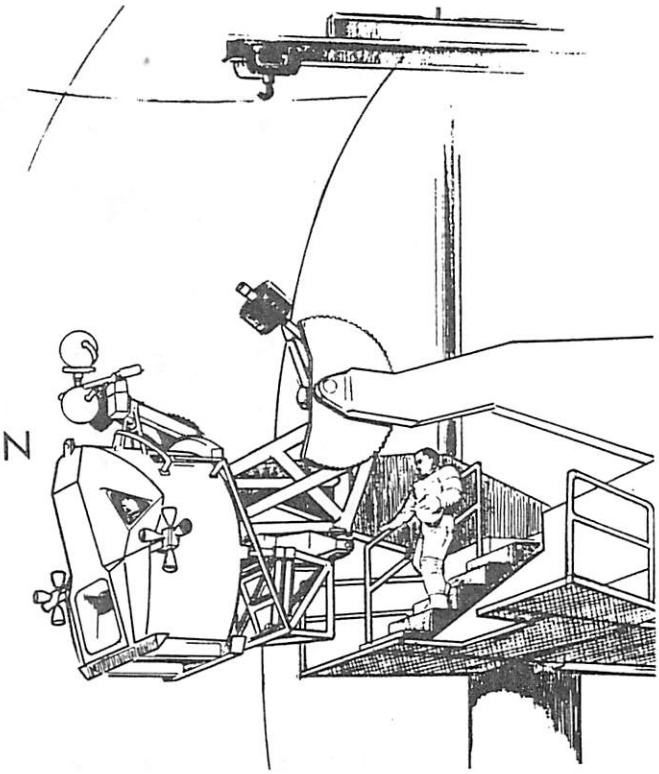


Figure 11

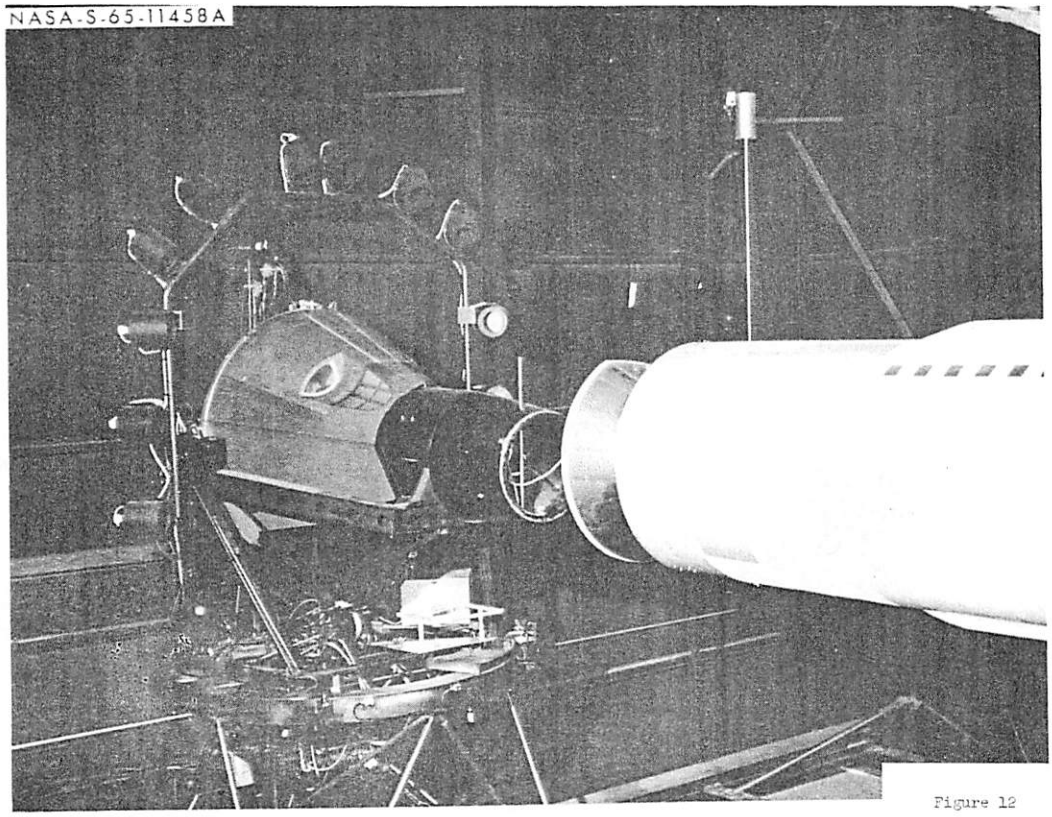


Figure 12

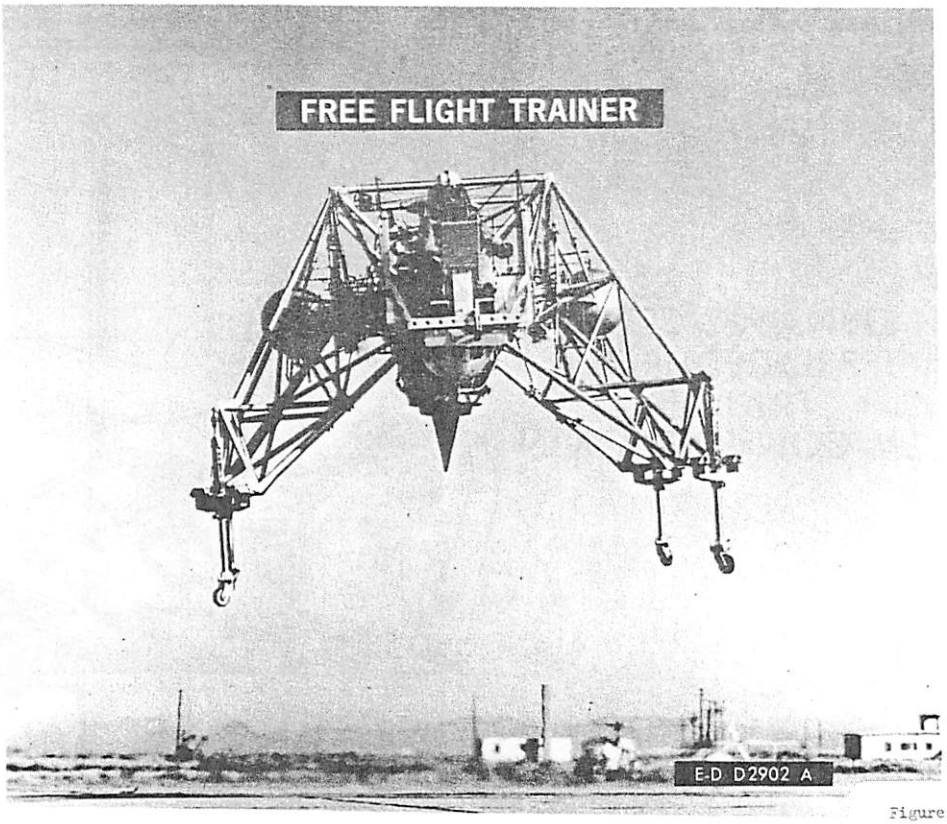


Figure 13

NASA-S-66-6382 JUNE

EGRESS TRAINER

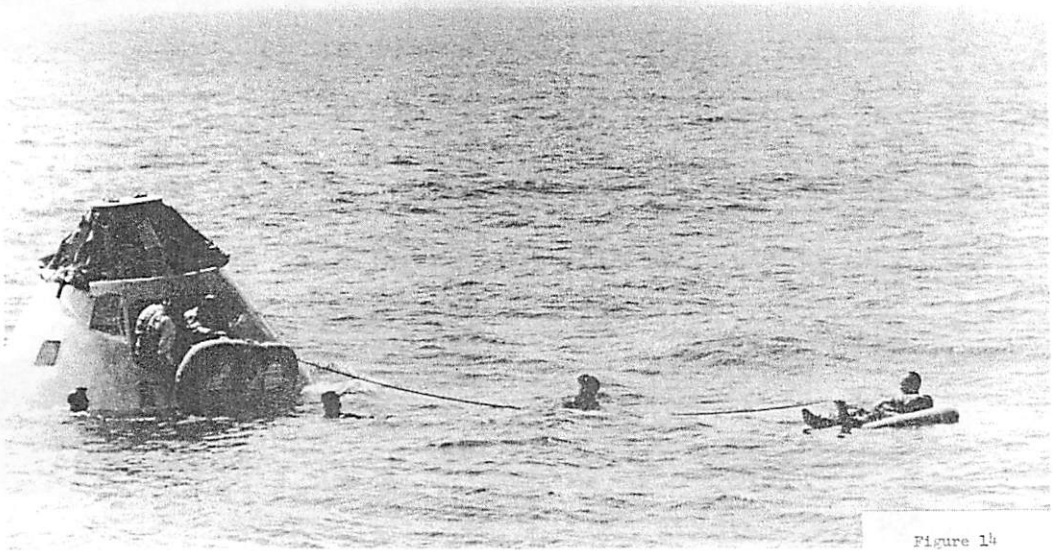


Figure 14

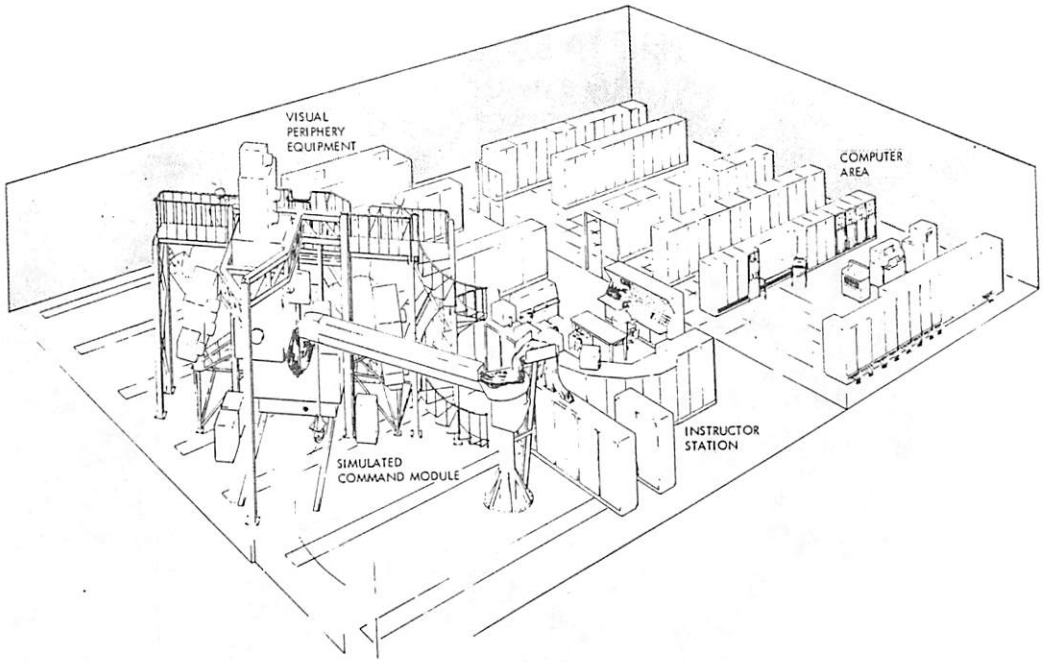


Figure 15

NASA-S-66-5231 JUN

LM MISSION SIMULATOR

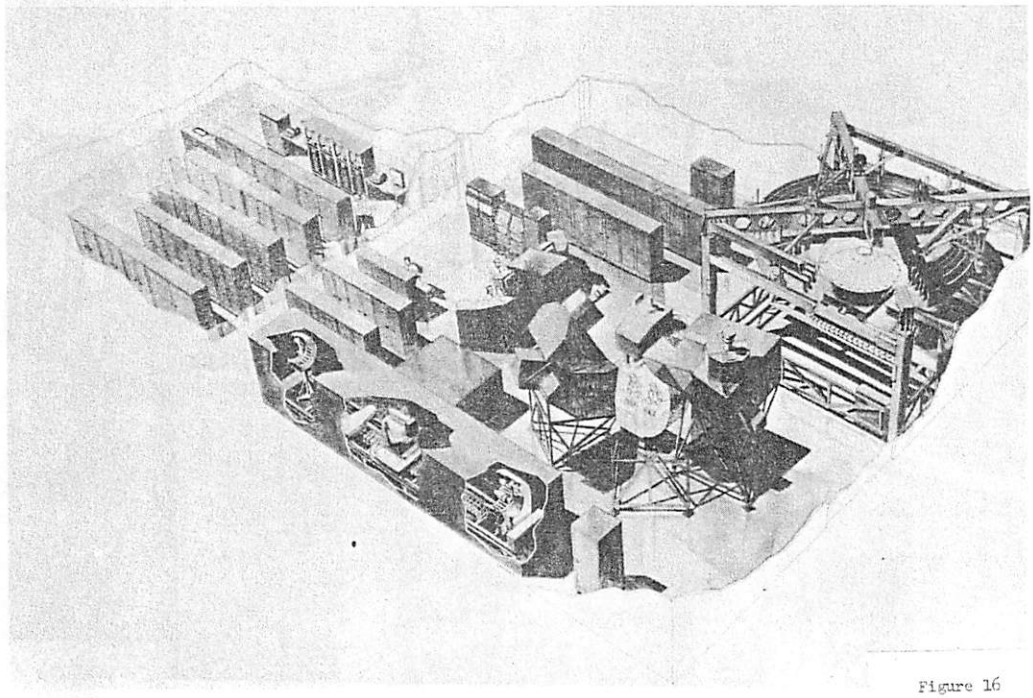


Figure 16

NASA-S-66-4240 APR 26

FLIGHT ACCELERATION FACILITY

THREE MAN GIMBLING GONDOLA

SIMULATES ACCELERATION UP TO 30 'G'

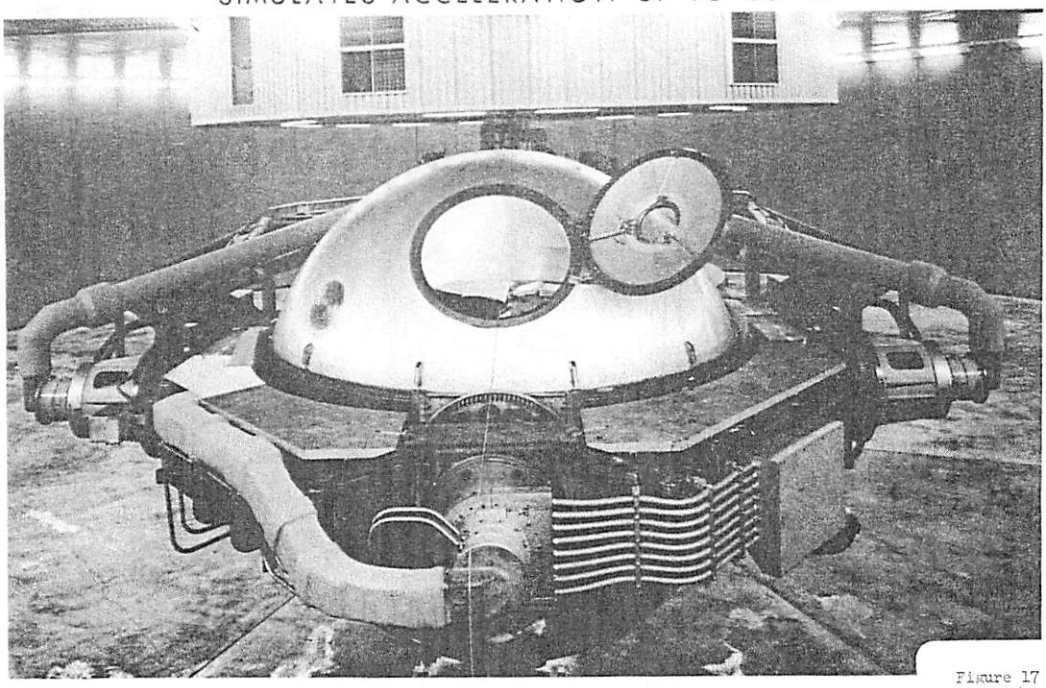


Figure 17

Figure 18

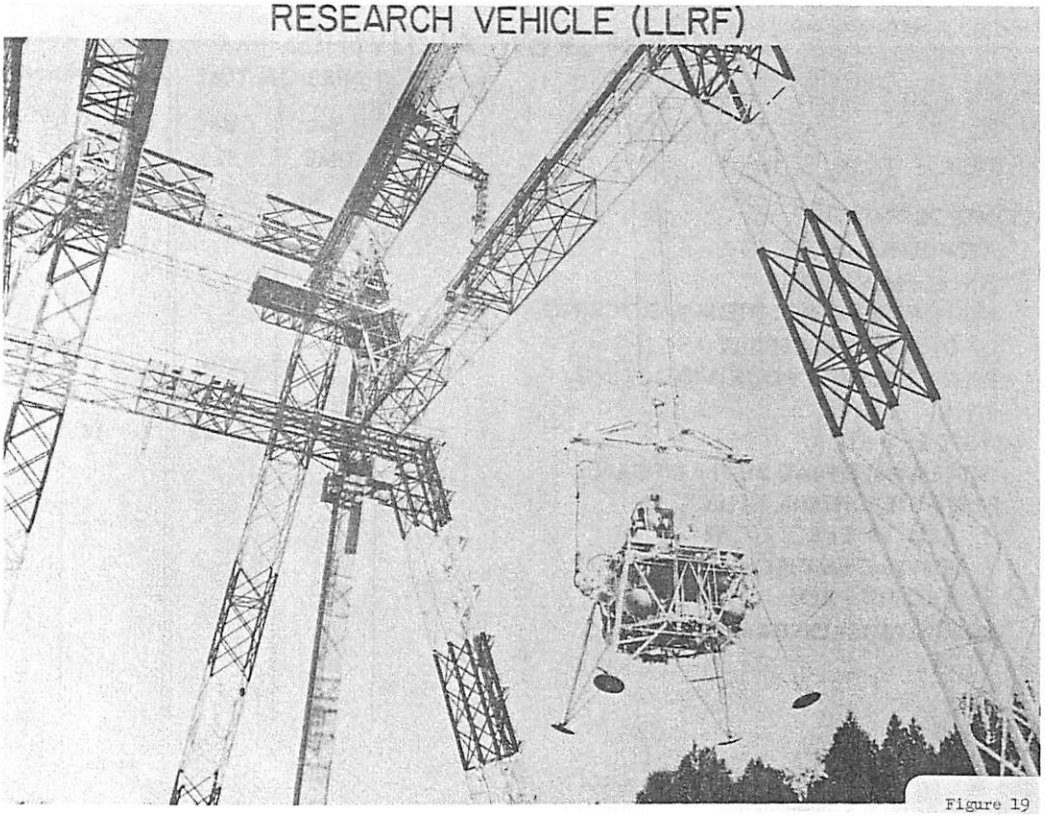


Figure 19

NASA-S-66-3885 JUN

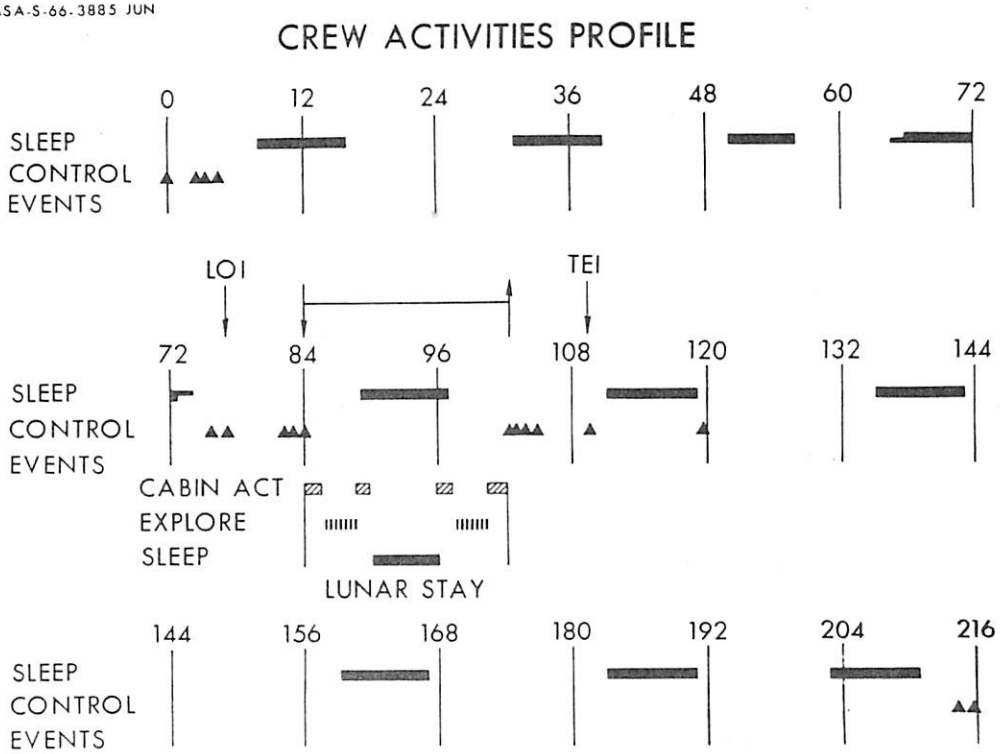


Figure 20

NASA-S-66-6075 JUN

CREW ACTIVITIES

TASK	MISSION TIME % TIME	MISSION TIME CUM %	CREW MANHOURS % TIME	CREW MANHOURS CUM %
CONTROL	01	01	01	01
ATTITUDE				
ΔV BURNS				
TRANSPOSITION & DOCKING				
LM DESCENT & ASCENT				
RENDEZVOUS & DOCKING				
ENTRY				
MONITOR	12	13	04	05
GENERAL DISPLAY SCAN				
PERIODIC CHECK				
ELECTRICAL				
ENVIRONMENTAL				
PROPULSION				
SUBSYSTEM MONITORING				

Figure 21

NASA-S-66-6076 JUN

CREW ACTIVITIES (CONT)

TASK	MISSION TIME % TIME	MISSION TIME CUM %	CREW MANHOURS % TIME	CREW MANHOURS CUM %
SYSTEM MAINTENANCE	03	16	01	06
LiOH CANNISTER CHANGE				
FUEL CELL H_2 PURGE				
FUEL CELL O_2 PURGE				
BATTERY CHARGE				
PLSS RECHARGE				
GUIDANCE & NAVIGATION	03	19	02	08
RADAR TRACKING				
OPTICAL TRACKING				
COMMUNICATION	03	22	02	10
SCHEDULED VOICE REPORTS				
DATA RECORDING				
DATA DUMP				
BIO-MED TRANSMIT				
CHECKOUT	02	24	02	12
LM PRE-SEPARATION				
LM PRE-LAUNCH				

Figure 22

NASA-S-66-6077 JUN

CREW ACTIVITIES (CONT)

TASK	MISSION TIME % TIME	MISSION TIME CUM %	CREW MANHOURS % TIME	CREW MANHOURS CUM %
FUNCTIONAL TASKS	03	27	03	15
STATION CHANGES				
SUIT DON & DOFF				
EQUIPMENT REMOVAL				
EQUIPMENT STOWAGE				
MAKING HARD DOCK				
CLEAR TUNNEL				
SECURE TUNNEL				
CREW TRANSFER				
EQUIPMENT TRANSFER				

Figure 23

NASA-S-66-6078 JUN

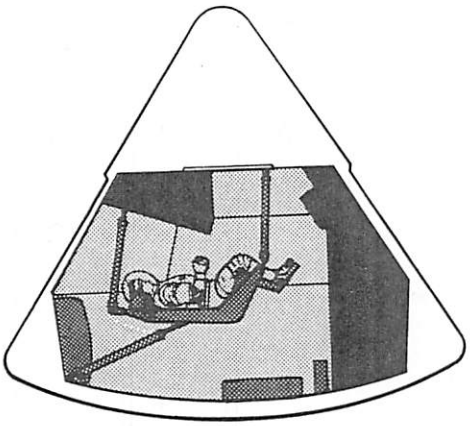
CREW ACTIVITIES (CONT)

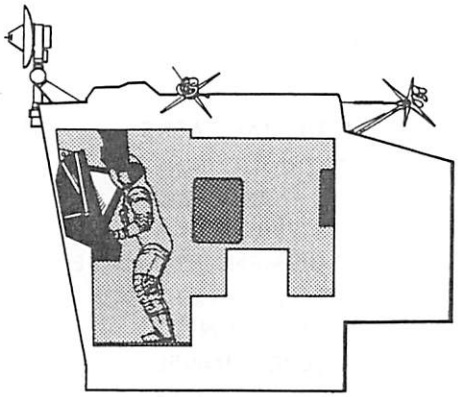
TASK	MISSION TIME % TIME	MISSION TIME CUM %	CREW MANHOURS % TIME	CREW MANHOURS CUM %
EXPLORATION	02	29	02	17
PHOTOGRAPHY				
SCIENTIFIC EQUIPMENT SETUP				
SAMPLE GATHERING				
VEHICLE INSPECTION				
SURFACE INSPECTION				
LIFE SUPPORT	07	36	04	21
FOOD PREPARATION & EATING				
BODY FUNCTIONS				
HYGIENE				
SLEEP	33	69	33	54
NO SCHEDULED ACTIVITY (INFLIGHT EXPERIMENTS WILL CONSUME A PORTION OF THIS TIME)	31	100	46	100
TOTAL HOURS		216		648

Figure 24

NASA-S-66-6131-JUN

VEHICLE VOLUMES





TOTAL PRESSURIZED VOLUME	- 306 FT^3	TOTAL PRESSURIZED VOLUME	- 235 FT^3
CREW COMPARTMENT VOLUME	- 245 FT^3	CREW COMPARTMENT VOLUME	- 218 FT^3
EFFECTIVE FREE VOLUME	- 210 FT^3	EFFECTIVE FREE VOLUME	- 190 FT^3

Figure 25

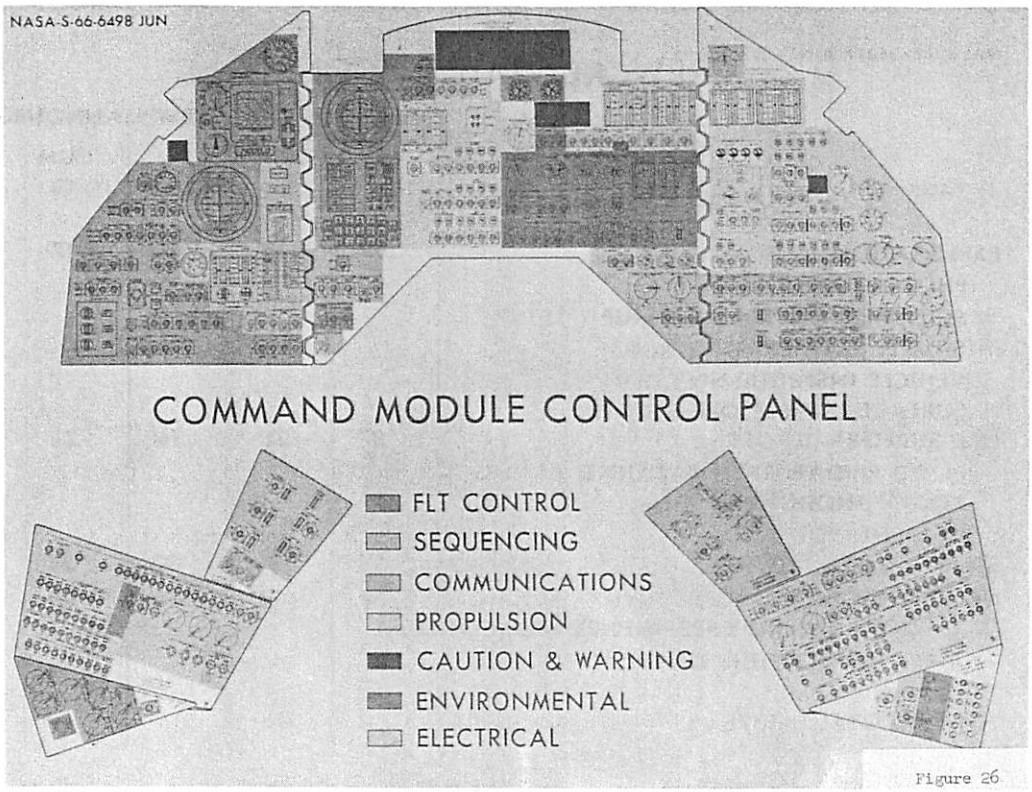


Figure 26

NASA-S-66-6438 JUN

LAUNCH

- MONITOR LAUNCH VEHICLE PERFORMANCE
  - ATTITUDE-ATTITUDE RATE
  - STAGING SEQUENCES
  - THRUST LEVELS
  - TANK PRESSURES
- MONITOR GUIDANCE
- MONITOR MISSION SEQUENCES
- MONITOR SPACECRAFT SYSTEMS
- MONITOR COMMUNICATION MODES

Figure 27

NASA-S-66-6139-JUN

LAUNCH CONFIGURATION

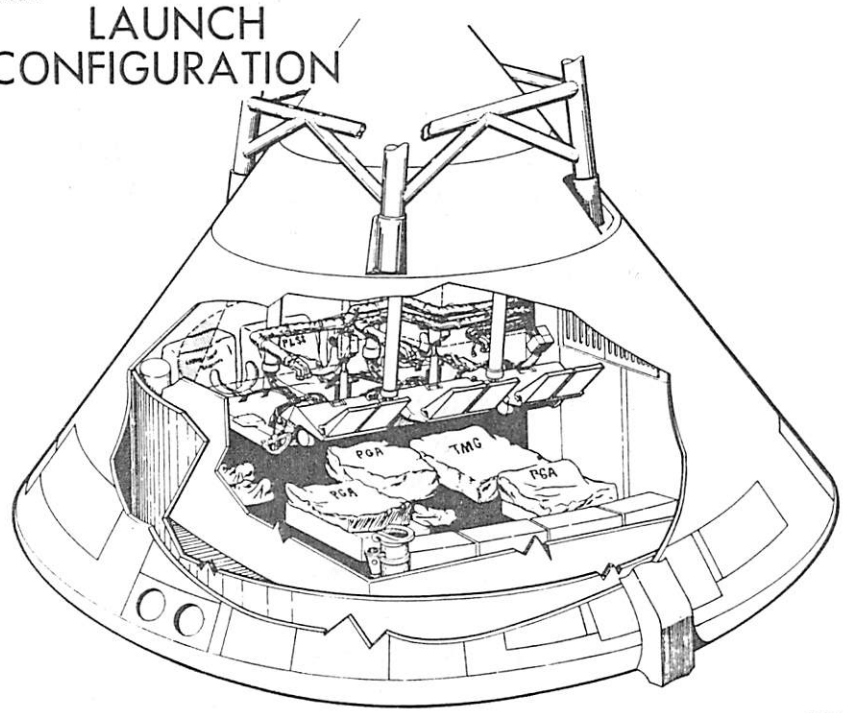


Figure 28

NASA-S-66-6824 JUN

ABORT AFTER 61 SEC

1 ABORT DECISION
2 TRANSLATION HAND CONTROLLER (ROTATE CCW)
3 EVENT TIMER "CHECK"
4 LES MOTOR FIRE
5 CM RCS PRESSURIZED ?
6 CANARDS DEPLOY ?
7 ELS LOGIC CIRCUIT ARMED ?
8 LES TOWER JETT ?
9 APEX COVER JETT ?
10 DROGUE CHUTES DEPLOYED ?
11 ALTIMETER - MONITOR CHUTES DEPLOY
12 MAIN CHUTES DEPLOYED ?
13 CABIN PRESS RELIEF VALVES "CLOSE"
14 CM PROP JETT DUMP SW "DUMP"
15 PROP JETT PURGE SW "PURGE"
16 RELEASE MAIN CHUTE - *AFTER LANDING*

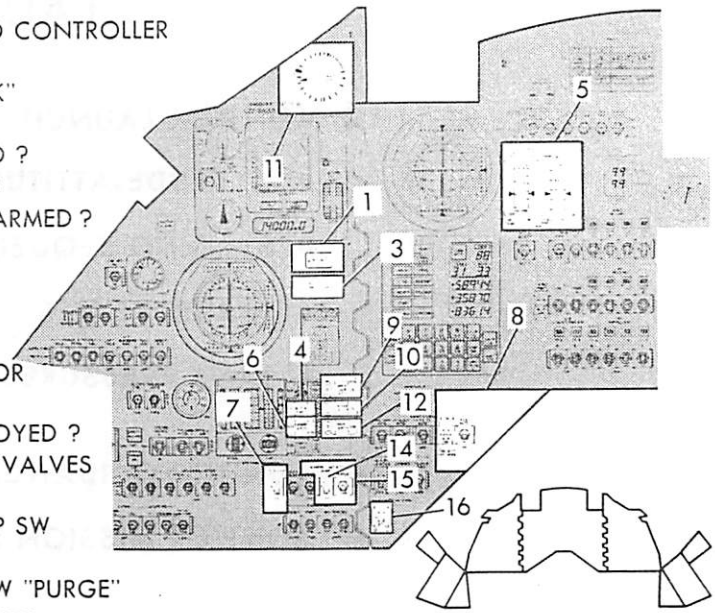


Figure 29

NASA-S-66-6590 JUN

EARTH ORBIT

- ORIENT VEHICLE FOR IMU ALIGNMENT
- ORIENT FOR LANDMARK TRACKING
- EXTEND AND SECURE DOCKING PROBE
- ORIENT FOR IMU ALIGNMENT
- ORIENT FOR TLI

- ENTER LEB
- ALIGN IMU
- TRACK LANDMARKS
- ALIGN IMU

- CHARGE BATTERY
- TRANSMIT HI BIT RATE PCM
- VERIFY CAUTION & WARNING & SPACECRAFT SYSTEM STATUS

Figure 30

NASA-S-66-6154 JUNE

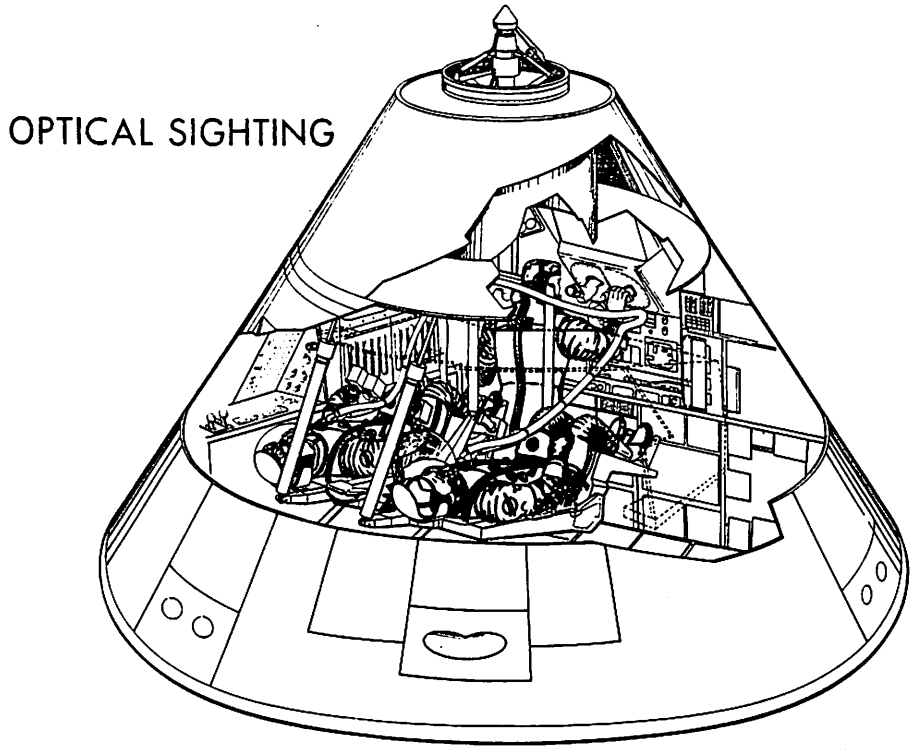


Figure 31

NASA-S-66-6592 JUN

TRANSLUNAR INJECTION

- ORIENT FOR ALIGNMENT
- MONITOR IMU ALIGNMENT
- CAGE BODY MOUNTED GYROS
- COUNTDOWN
- MONITOR SIVB

- PERFORM IMU FINE ALIGNMENT
- MONITOR SYSTEMS

- PURGE FUEL CELLS
- CHARGE BATTERIES
- PREPARE FOR PEAK POWER
- MONITOR SYSTEMS

Figure 32

NASA-S-66-6451 JUN

TRANSPOSITION DOCKING

- PREPARE FOR CSM SEPARATION
- SEPARATE CSM-LM FROM S-IV-B
- PERFORM SEPARATION PITCHOVER AND CLOSING MANEUVER
- ALIGN AND EXECUTE DOCKING

- CONFIRM MSFN TRAJECTORY
- MONITOR STATE VECTOR UPDATE
- PRESSURIZE TUNNEL AND LM
- REMOVE HATCHES
- SET DOCKING LATCHES
- RESTORE TUNNEL AREA

- SHIFT COUCHES TO DOCKING POSITION
- POWER DOWN EPS AND CHANGE BATTERIES
- ALIGN HIGH GAIN ANTENNA

Figure 33

NASA-S-66-6825 JUN

TRANSLUNAR TRANSPOSITION AND DOCKING

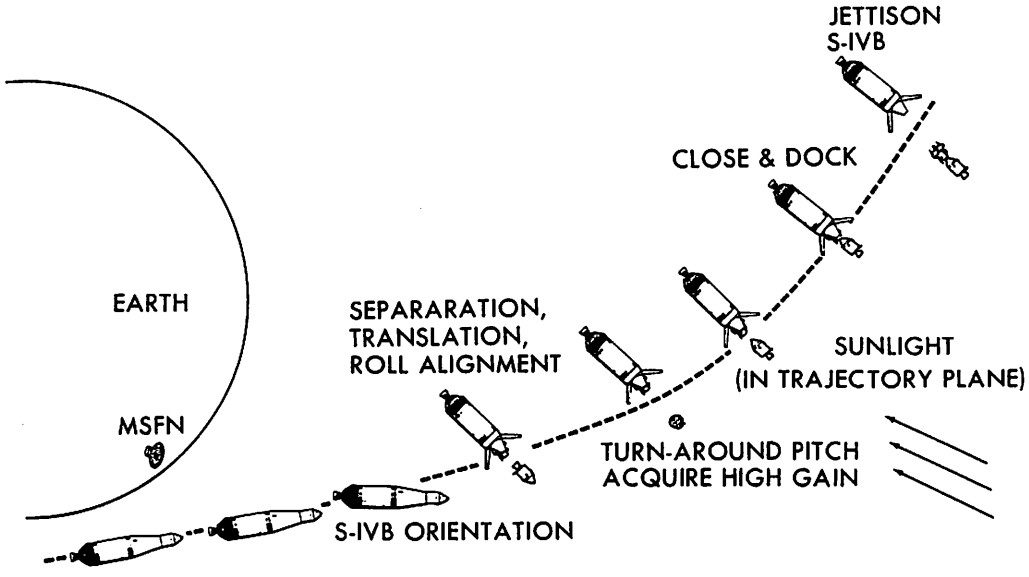


Figure 34

NASA-S-66-6132-JUN

DOCKING AND FLIGHT CONFIGURATION

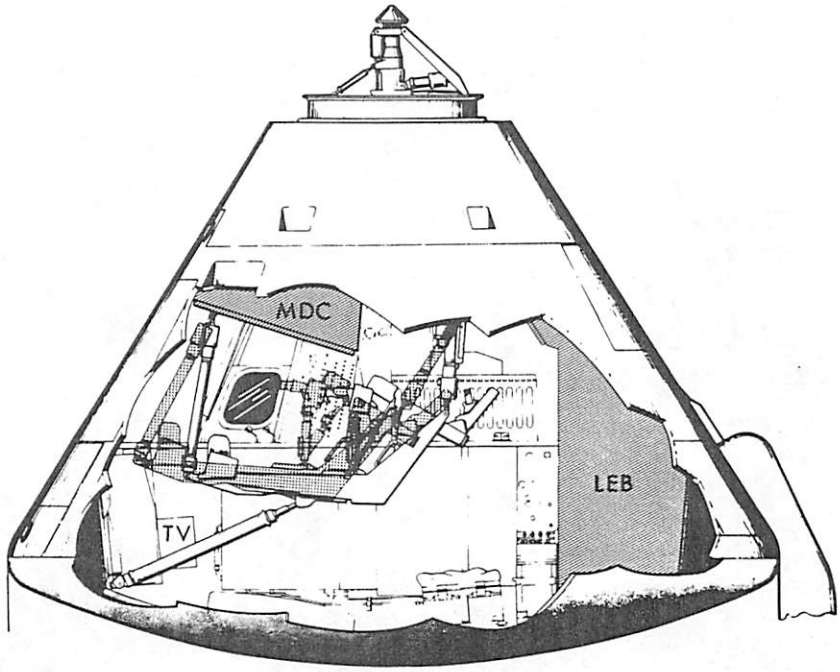


Figure 35

NASA-S-66-6137-JUN

TRANSPOSITION DOCKING

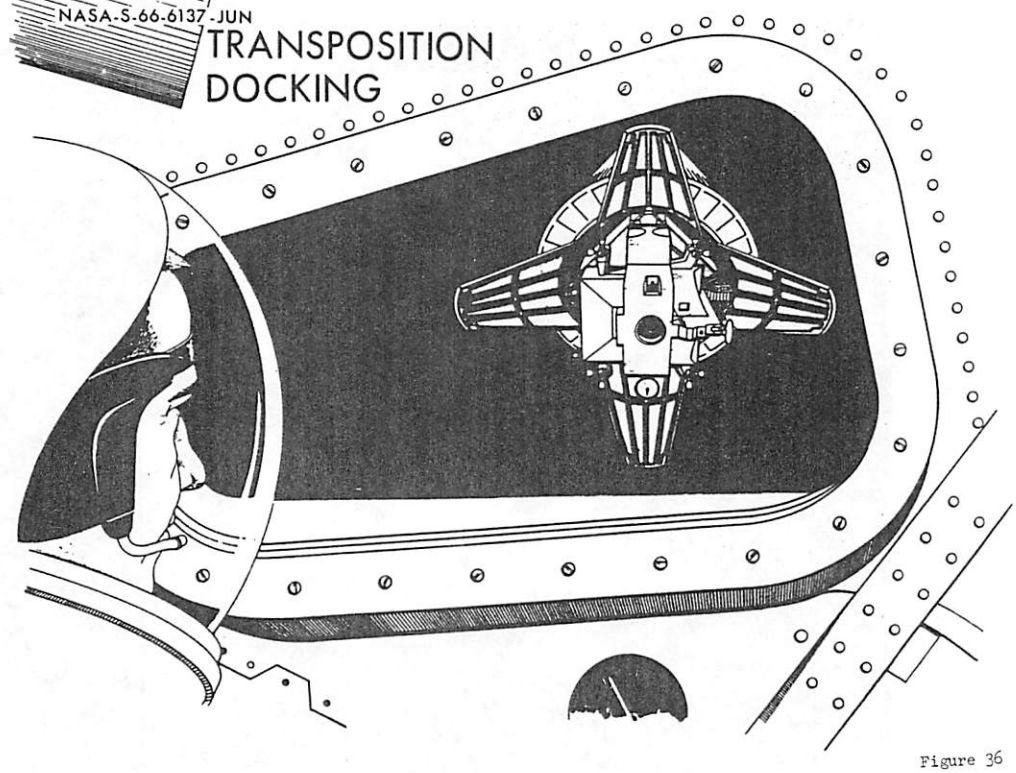


Figure 36

NASA
S-65-17771

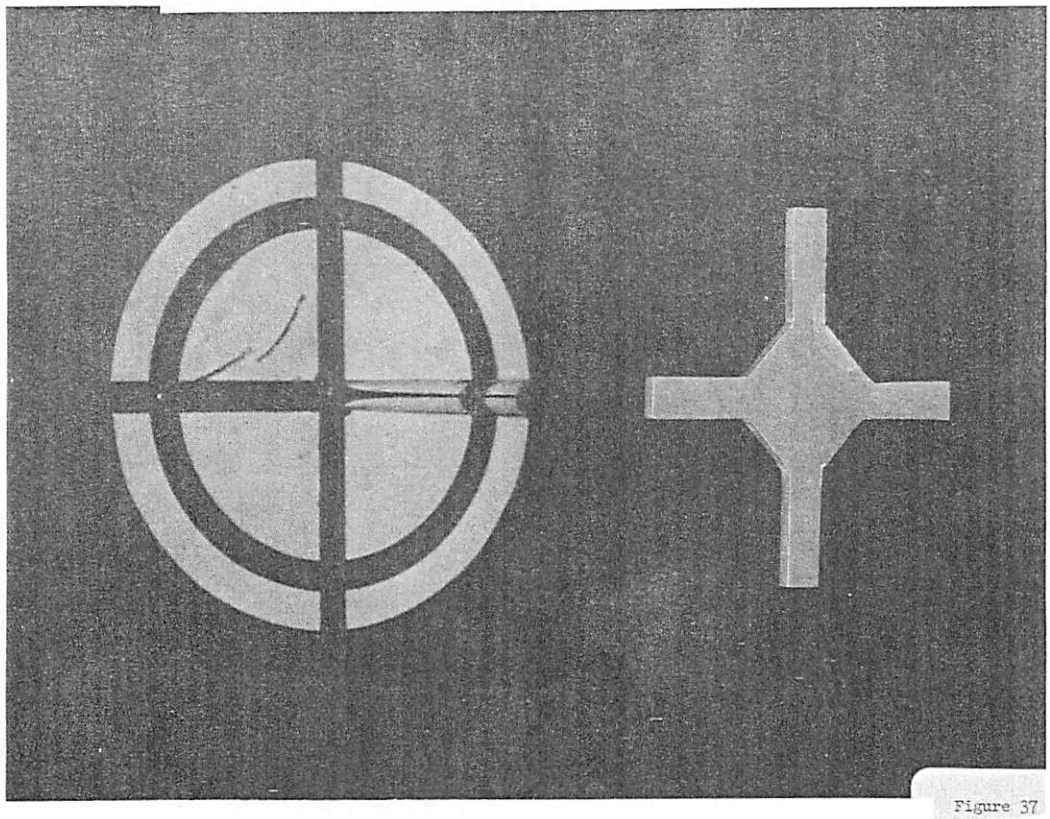


Figure 37

NASA
S-65-17774

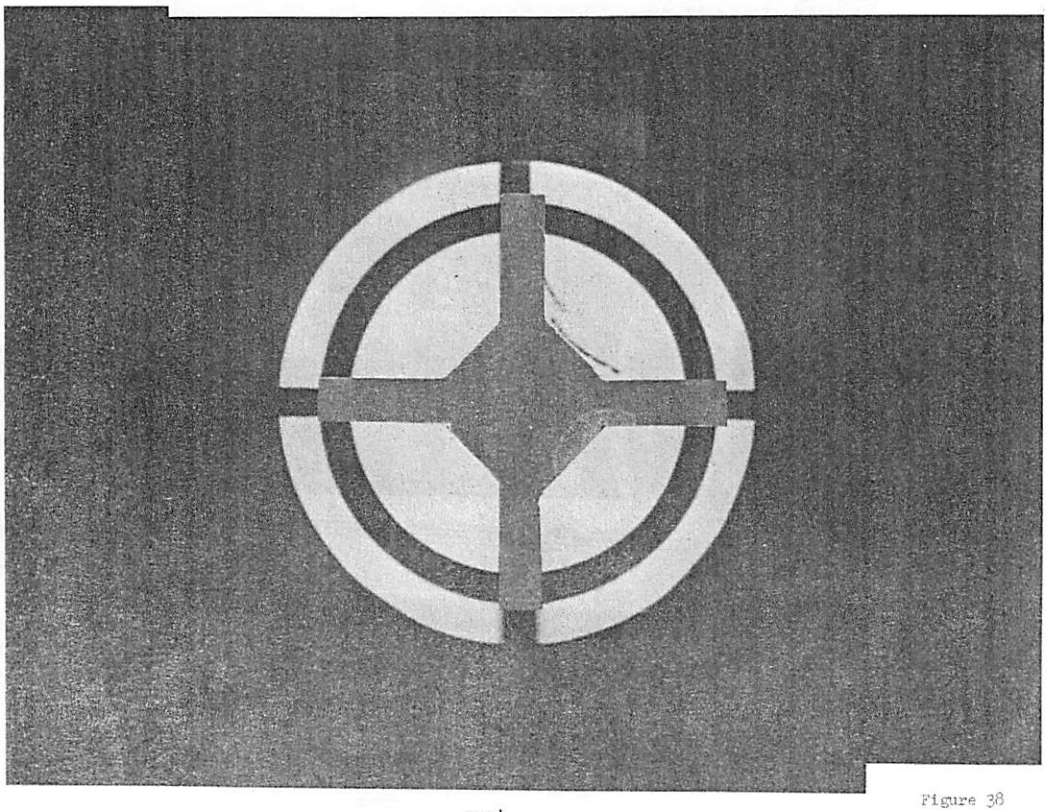


Figure 38

NASA-S-66-6136-JUN

HARD-DOCK LATCHING

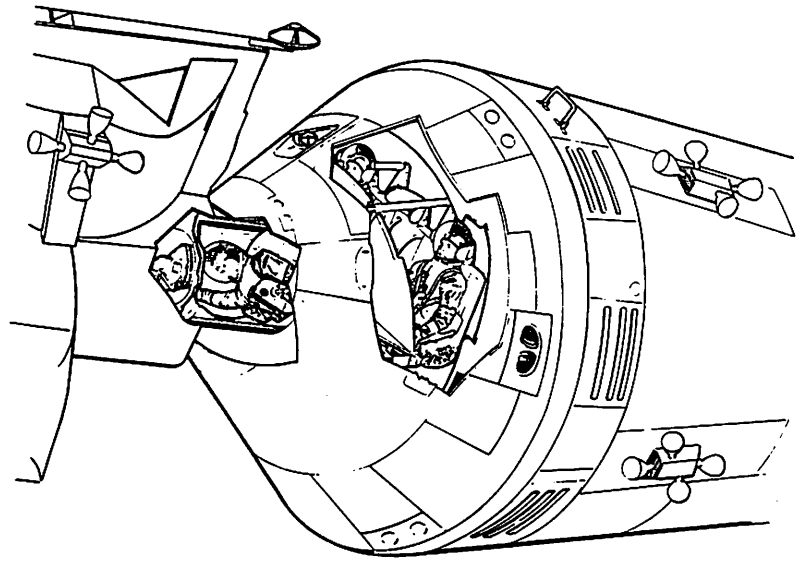


Figure 39

NASA-S-66-6489 JUN

TRANSLUNAR COAST

- MIDCOURSE CORRECTIONS
- PERIODIC CHECKS
- PERIODIC MAINTENANCE
- SLEEP

Figure 40

NASA-S-66-6845 JUNE

STOWAGE COMPARTMENTS

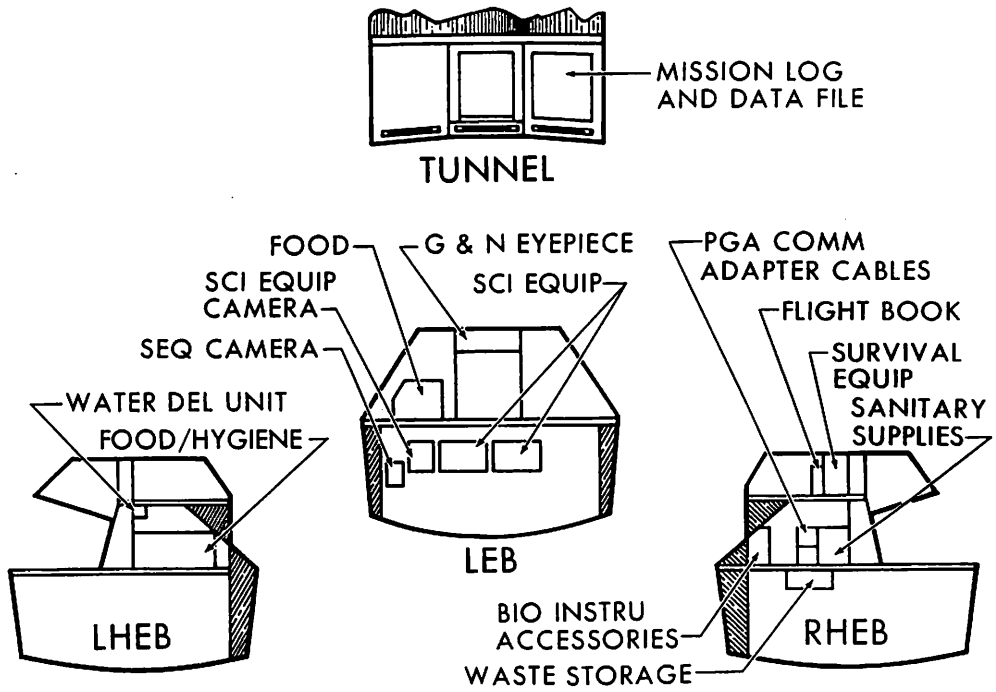


Figure 41

NASA-S-66-6861 JUN

BLOCK II STOWAGE ITEMS

		UNITS	TOTAL OPERATIONS (ALL UNITS)
A	EMU HARDWARE & CONTAINERS	28	160
B	TV & SEQUENCE CAMERA & ACCESSORIES	22	109
C	HYGIENE EQUIPMENT	105	218
D	MEDICAL EQUIPMENT	108	253
E	RADIATION MONITORING EQUIPMENT	22	87
F	CREW CARRY-ON ACCESSORIES	27	289
G	SURVIVAL EQUIPMENT	6	9
H	DOCKING & EXTRAVEHICULAR TRANSFER EQUIPMENT	8	23
I	G&N LOOSE EQUIPMENT	7	65
J	LOOSE SPACECRAFT SUPPORT HARDWARE	34	812
K	FOOD PACKS	168	168
L	LiOH CANISTER	56	117
M	EXPERIMENT HARDWARE, TYPICAL	9	90
		600	2400

Figure 42

NASA-S-66-6153 JUNE

SLEEP STATIONS

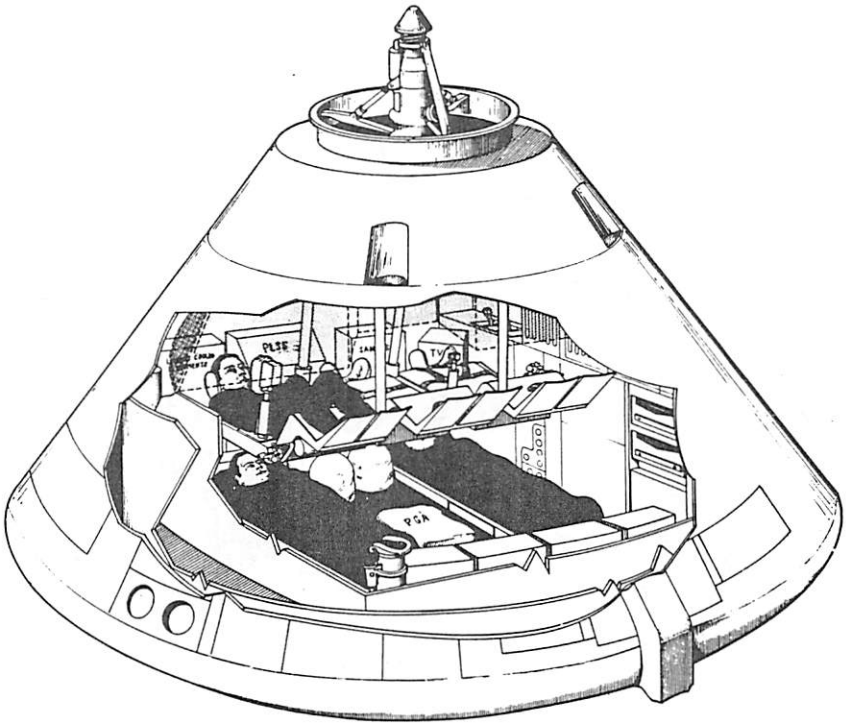


Figure 43

NASA-S-66-6148 JUNE

FOOD PREPARATION

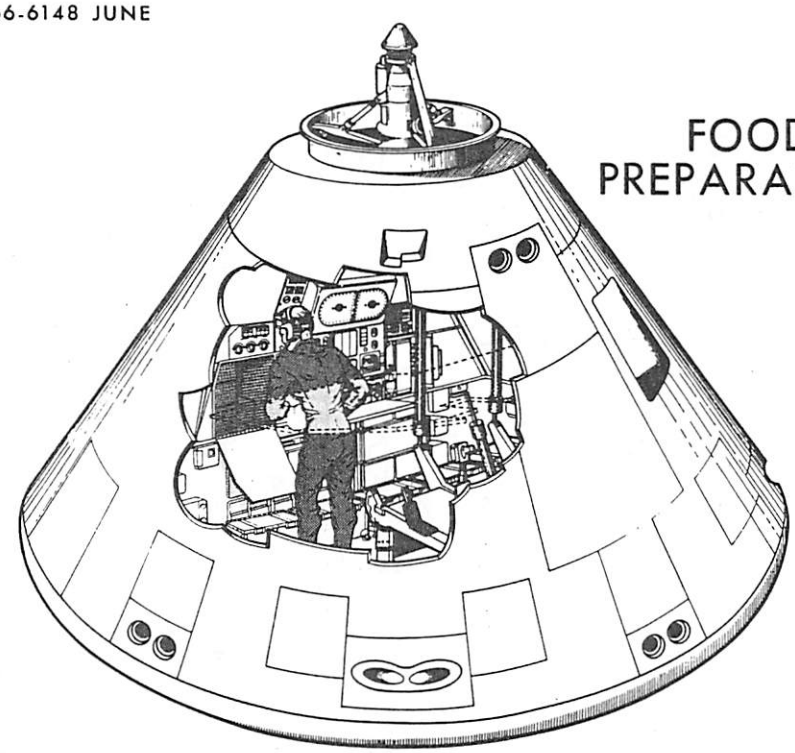


Figure 44

NASA-S-66-6138-JUN

LiOH CANISTER CHANGE

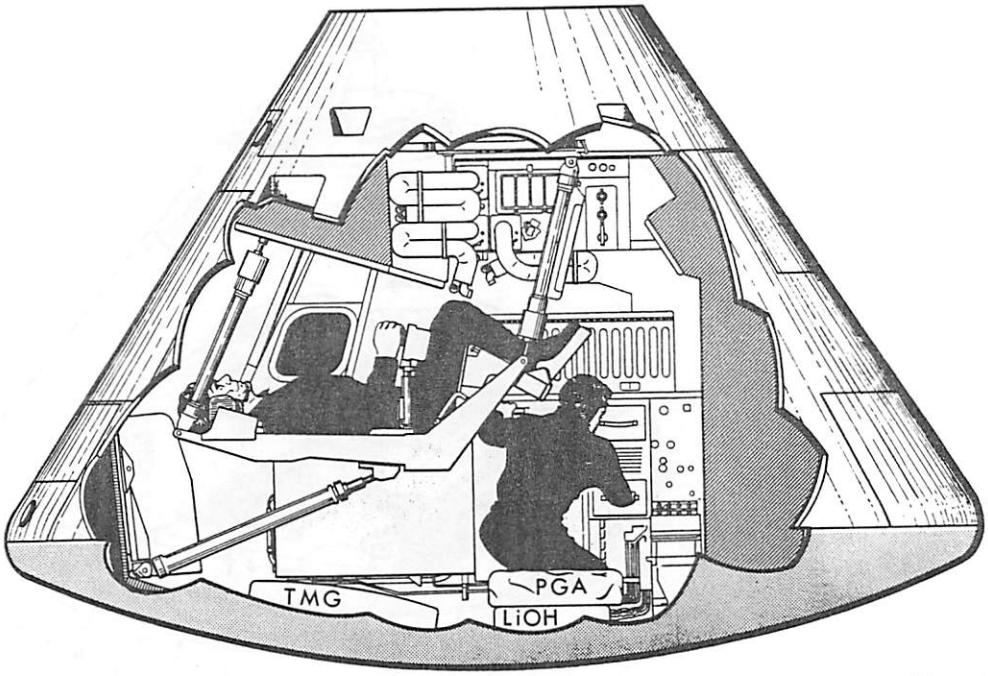


Figure 45

NASA-S-66-6823 JUN

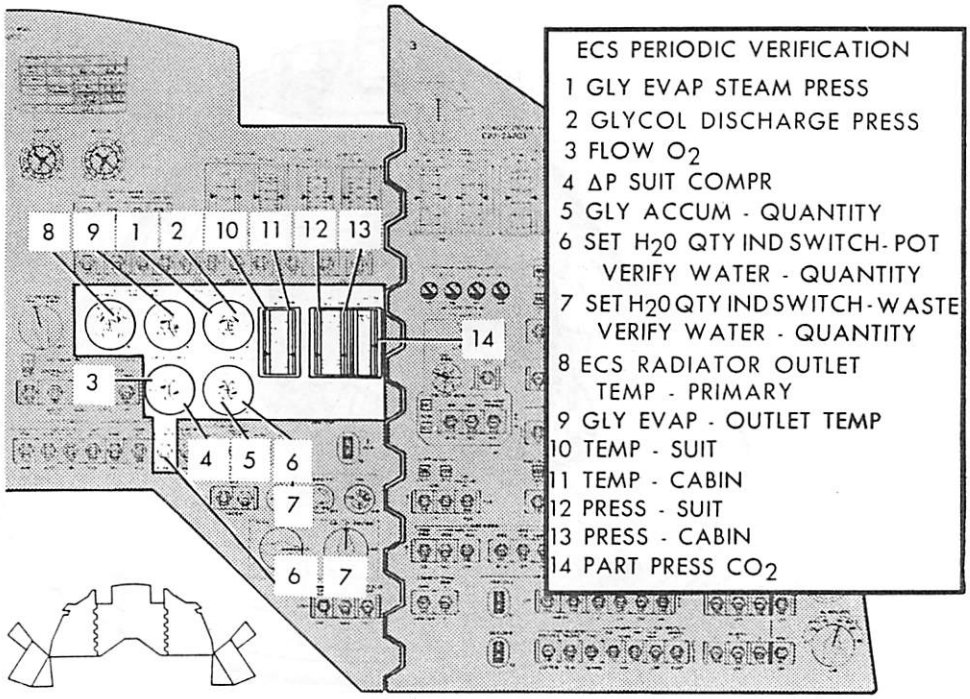


Figure 46

NASA-S-66-6149 JUNE

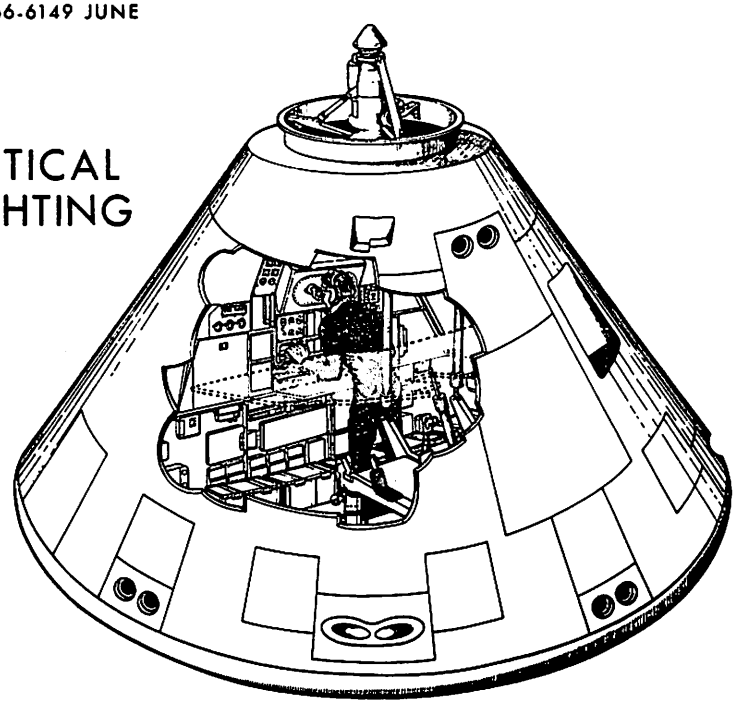


Figure 47

NASA-S-66-6445 JUN

LM CHECKOUT

- PRESSURIZE TUNNEL AND LM
- REMOVE PRESSURE HATCH, ABLATIVE HATCH, PROBE, & DROGUE
- ENTER LM - CHECK CONTROL SYSTEMS

- ENTER LM
- CHECK ELECTRICAL AND ENVIRONMENTAL SYSTEMS
- ALIGN IMU

- STOW DOCKING EQUIPMENT
- MONITOR CSM SYSTEMS

Figure 48

NASA-S-66-6152 JUNE

PREPARATION FOR TRANSFER

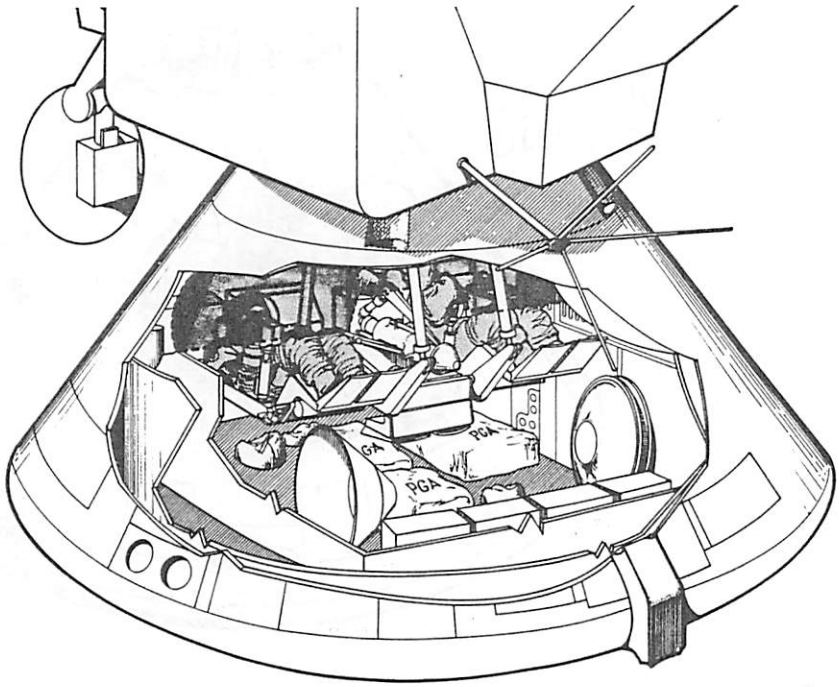


Figure 49

NASA-S-66-6150 JUNE

CREW TRANSFER

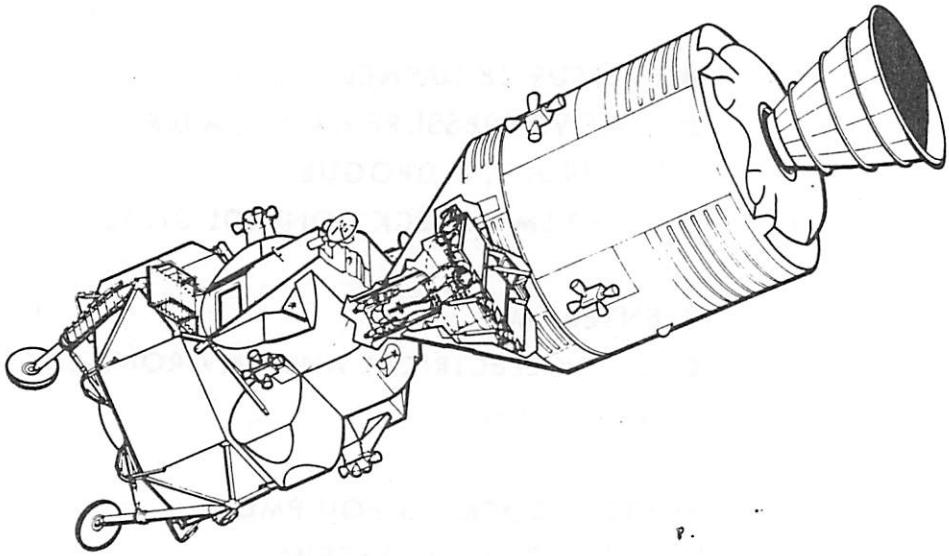


Figure 50

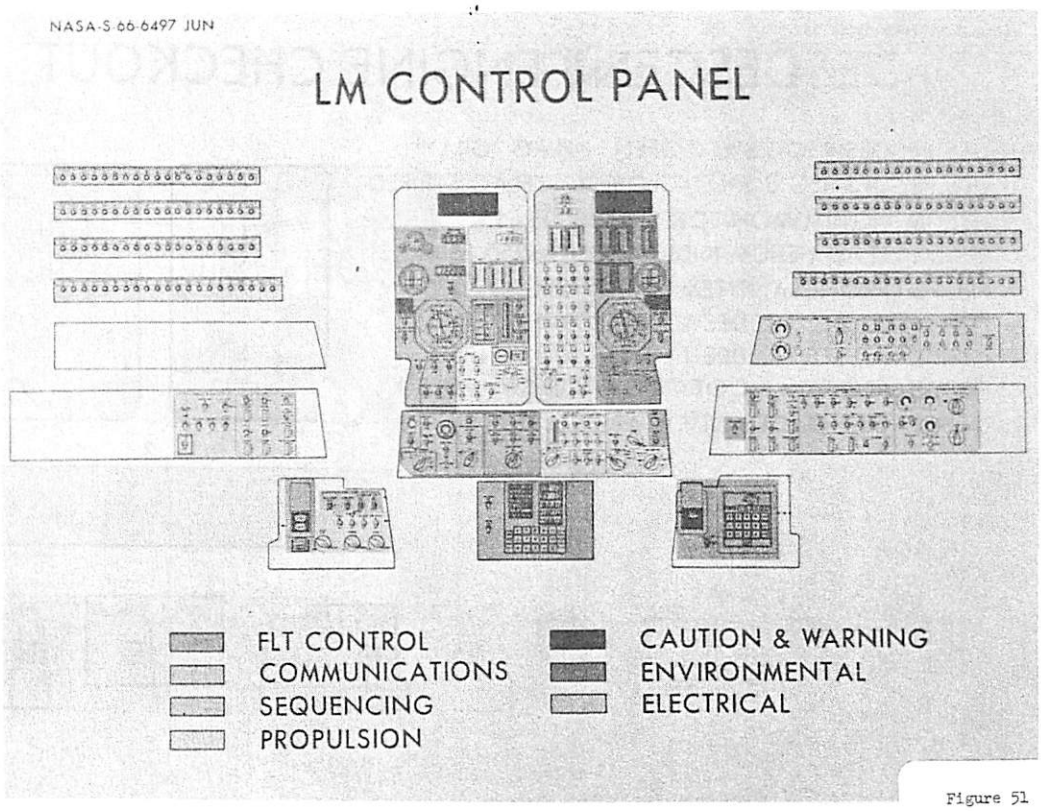


Figure 51

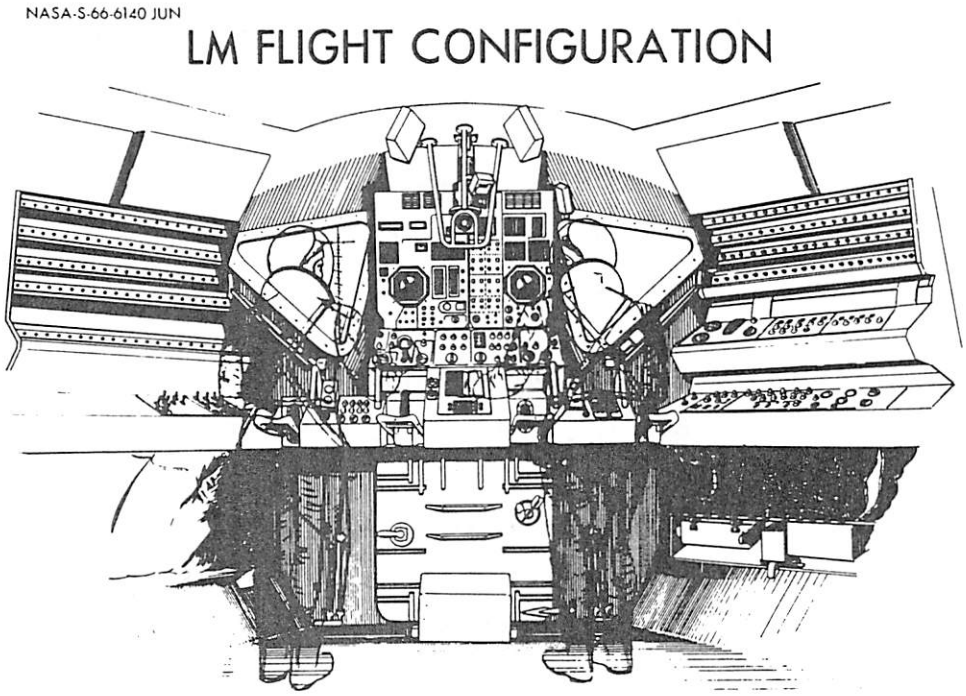
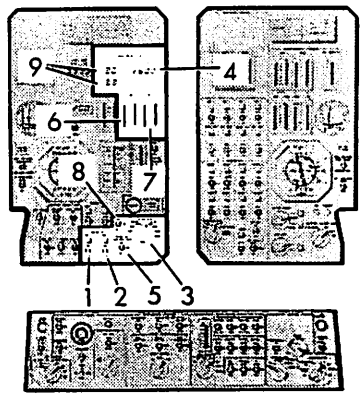


Figure 52

NASA-S-66-6822 JUN

DESCENT ENGINE CHECKOUT

1 DES REG 1 SW - "OPEN" - FLAG "GRAY"
2 DES REG 2 SW - "CLOSED" - "FLAG STRIPED"
3 HELIUM MONITOR SW "DES PRESS"
4 READ HELIUM INDICATION <1250 PSIA
5 PROPELLANT TEMP/PRESS SW TO "DES 1"
6 FUEL/OXID DES 1 TEMP - 70°F± 20°F
7 FUEL/OXID DES 1 PRESS - 175 ±55 PSIA
8 PROPELLANT QTY MONITOR SW - "DES 1"
9 QTY GAGES AT OR ABOVE 95%



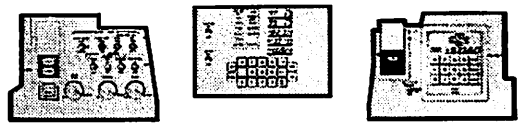


Figure 53

NASA-S-66-6484 JUN

LUNAR ORBIT INSERTION

- ORIENT CSM/LM FOR MANEUVER
- COUNTDOWN AND MONITOR THRUSTING
- ASSESS RESULTS OF THRUSTING
- ORIENT FOR ATTITUDE HOLD

- ALIGN IMU FOR THRUSTING
- REALIGN IMU FOR LOCAL ATTITUDE HOLD

- PREPARE EPS FOR PEAK POWER
- MONITOR SPS PROPELLENT RATIOS & QUANTITIES
- CHARGE BATTERIES

Figure 54

NASA-S-66-6869 JUNE

LUNAR ORBIT INSERTION

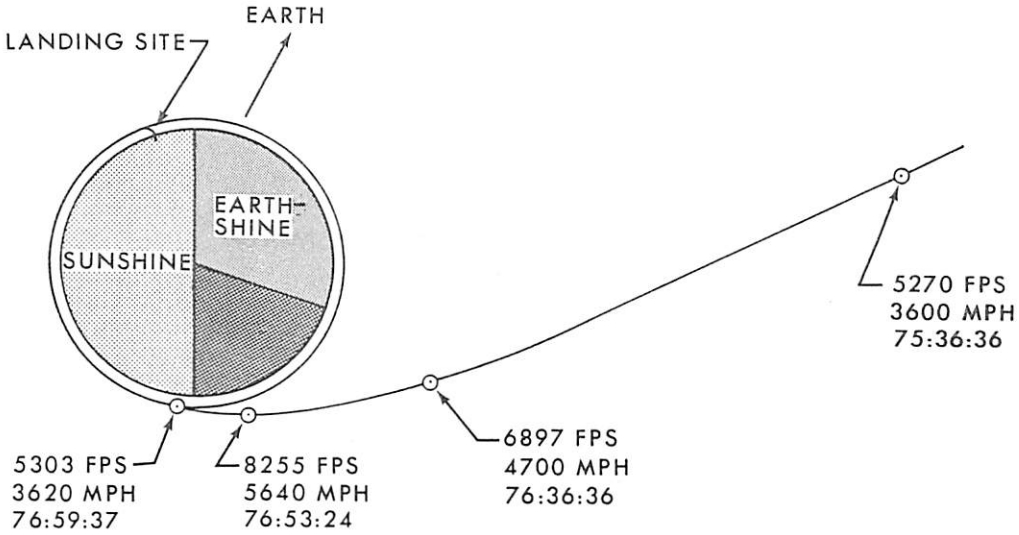


Figure 55

NASA-S-66-6593 JUN

APPARENT SIZE OF MOON

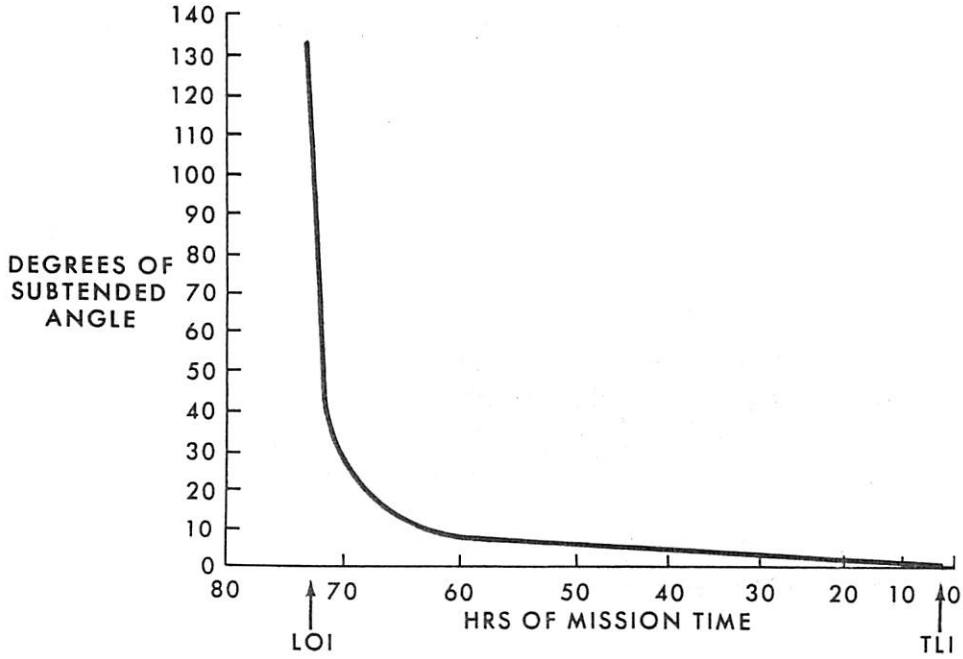


Figure 56

NASA-S-66-6146 JUNE

TRANSFER OF EQUIPMENT

(TRANSLUNAR)

TO LM

- 1 PLSS
- 2 EOS
- 1 PAIR EV GLOVES
- 1 TMG (LESS BOOTS)
- 1 RADIATION SURVEY METER
- 1 TV CAMERA
- 1 LM FLIGHT PLAN
- 1 EVCT DEVICE
- 2 EV VISORS
- 2 HELMET STORAGE CONTAINERS (CONTAINING VISORS)

TO CSM

- 2 LM ELECTRICAL UMBILICALS

Figure 57

NASA-S-66-6151 JUNE

TRANSFER OF EQUIPMENT

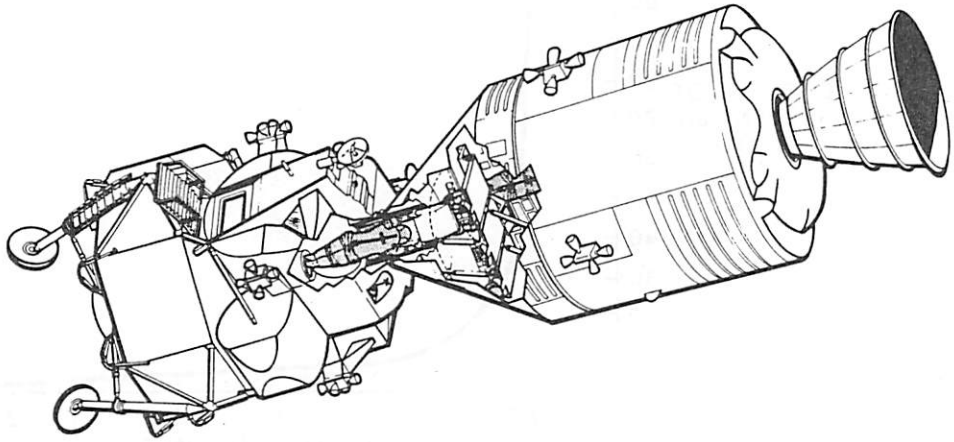


Figure 58

NASA-S-66-6447 JUN

LUNAR DESCENT

- MONITOR DESCENT ENGINE IGNITION AND ENGINE GIMBAL ALIGNMENT
- MONITOR PROPULSION QUANTITIES
- PREPARE FOR PGNCS/AGS DIFFERENCE CHECK
- COMPARE RANGE RATE WITH GUIDANCE BOUNDARIES AT CHECK TIME
- DETERMINE THAT LANDING RADAR DATA ARE AVAILABLE
- COMPARE LANDING RADAR ALTITUDE WITH GUIDANCE BOUNDARIES AT CHECK TIME
- CHECK STATUS OF RCS AND ASCENT PROPULSION PRIOR TO FINAL APPROACH
- MONITOR PROGRAMMED PITCH ATTITUDE CHANGE AT HI-GATE
- MONITOR THRUST INDICATOR FOR THRUST REDUCTION TO ABOUT 60 PC
- ACTIVATE DSKY DISPLAY OF LANDING AREA ELEVATION AND COMMUNICATE DISPLAYED VALUES
- EVALUATE LANDING AREA FOR ACCEPTANCE OR REJECTION
- NULL ALL RATES EXCEPT DESCENT FOR TOUCHDOWN

Figure 59

NASA-S-66-6140 JUN

LM FLIGHT CONFIGURATION

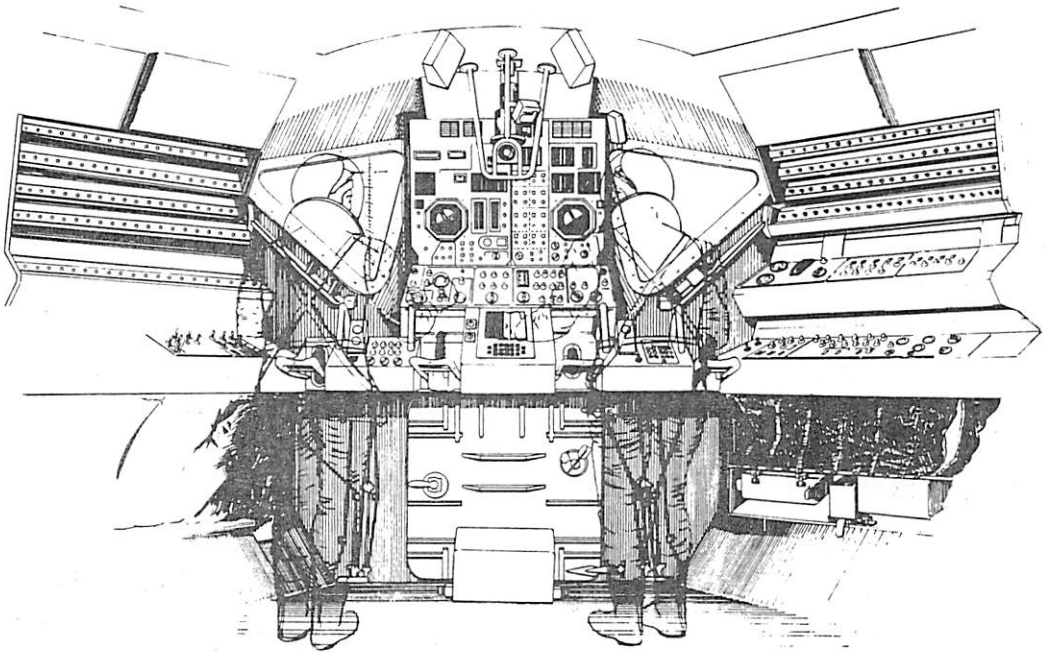


Figure 60

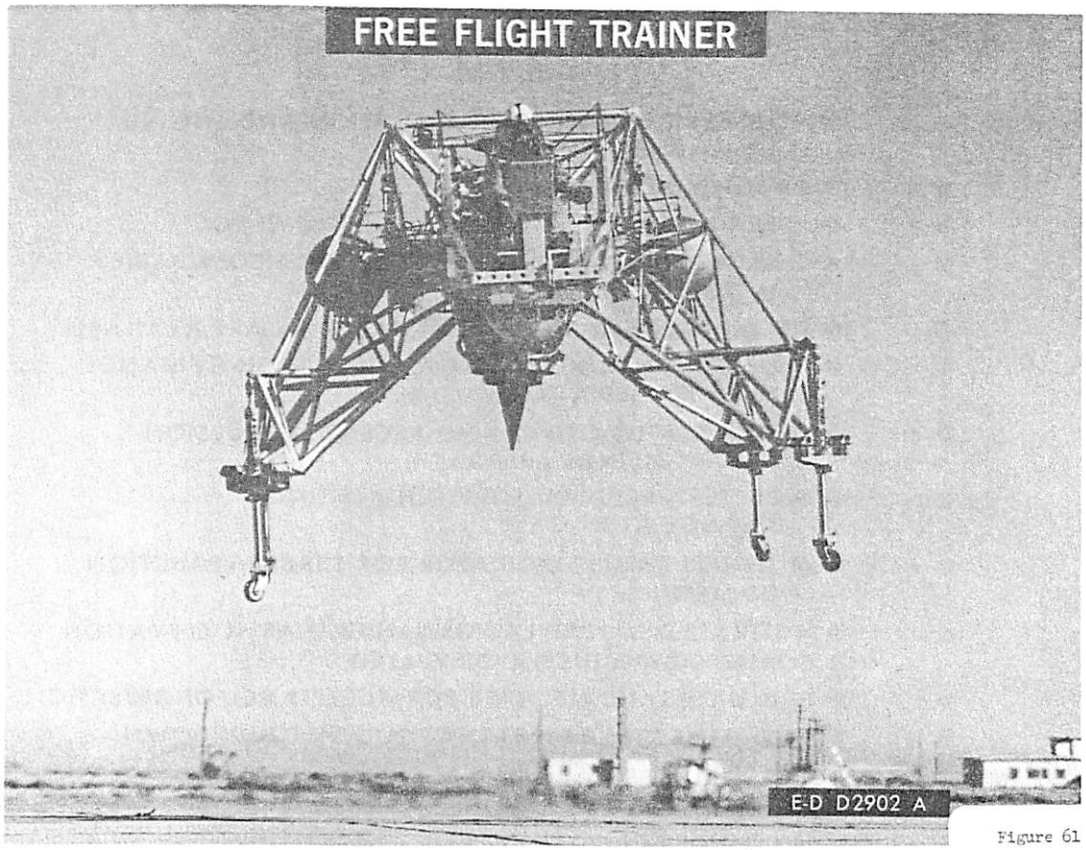


Figure 61

NASA-S-66-5166 JUN

PROPOSED LUNAR STAY

(18 HOURS 22 MINUTES)

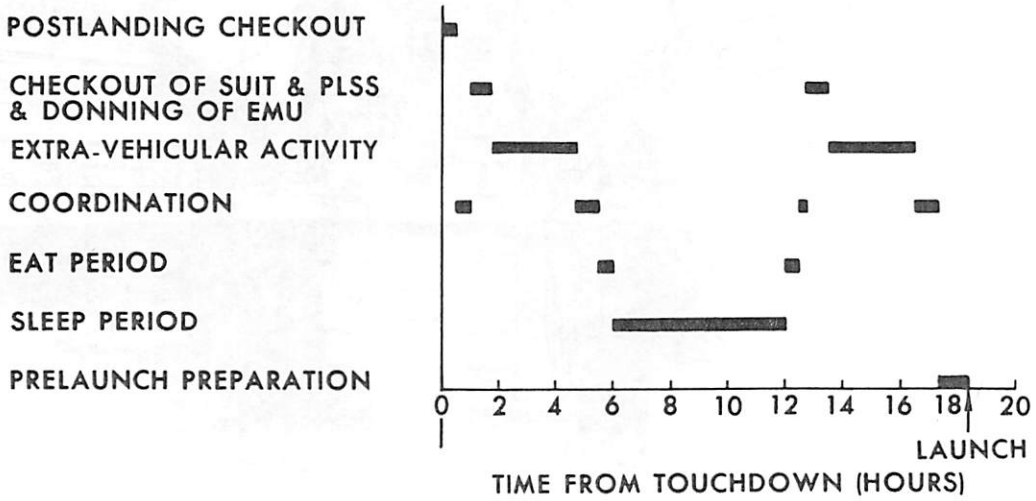


Figure 62

NASA-S-66-5073 JUN 3

LUNAR STAY

CREW ACTIVITY SUMMARY

ACTIVITY	HR	MIN	% TIME
POSTLANDING CHECKOUT		33	03
DON EMU & CHECKOUT	1	22	08
EXPLORATION	6	07	33
CABIN ACTIVITY	2	23	13
MONITOR SYSTEMS			
EVALUATE EXPLORATION			
COMMUNICATE W/MSFN			
RECHARGE PLSS			
UNSTOW & STOW EQUIPMENT			
PREPARE FOOD & EAT		55	05
SLEEP & REST	6	07	33
PRELAUNCH PREPARATIONS		55	05
TOTAL STAY TIME	18	22	100

Figure 63

NASA-S-66-6143-JUN

PLSS DONNING

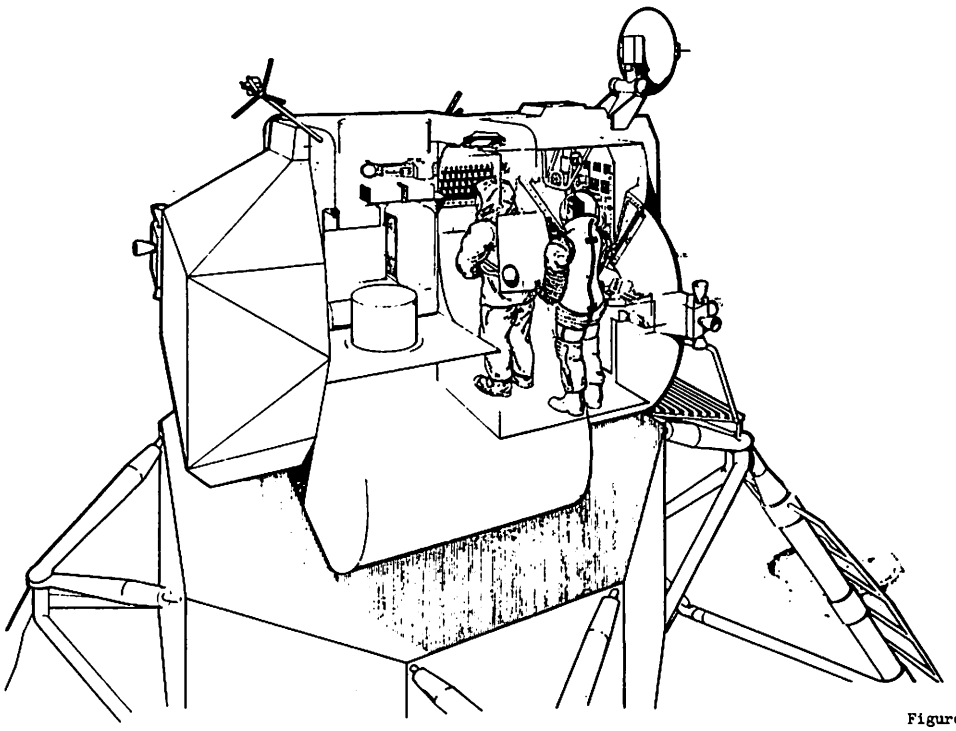


Figure 64

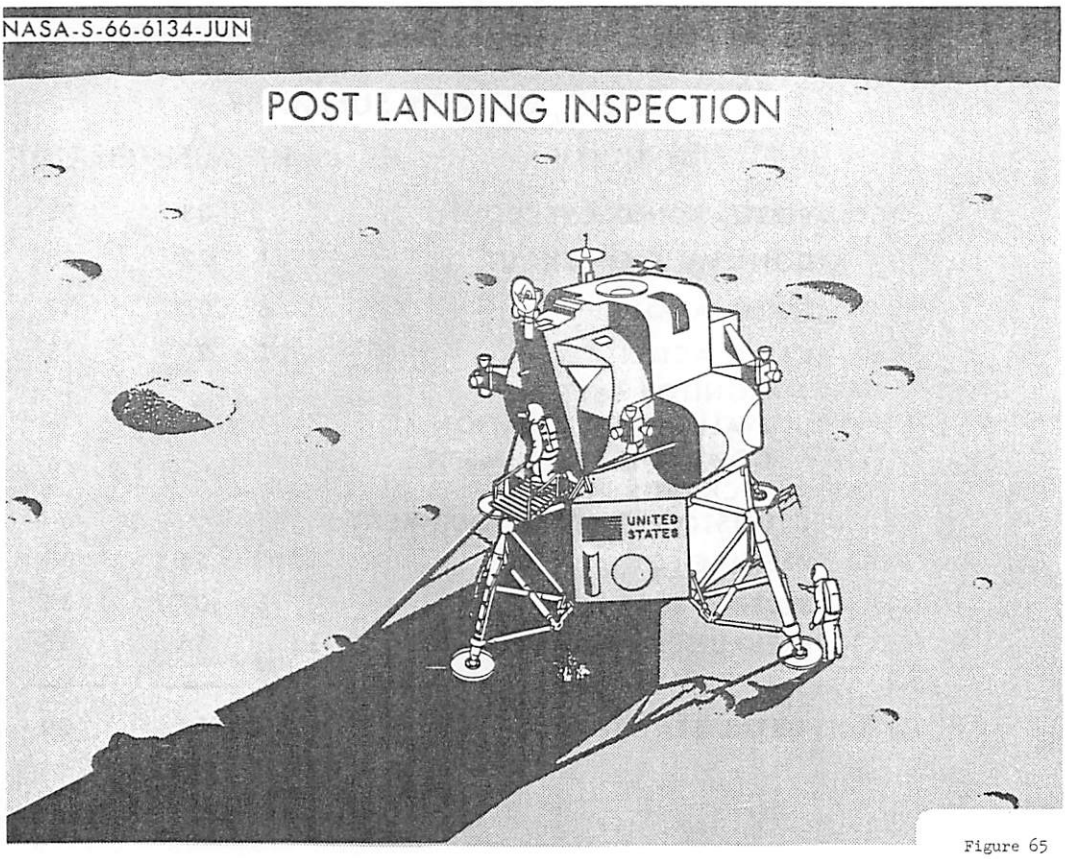


Figure 65

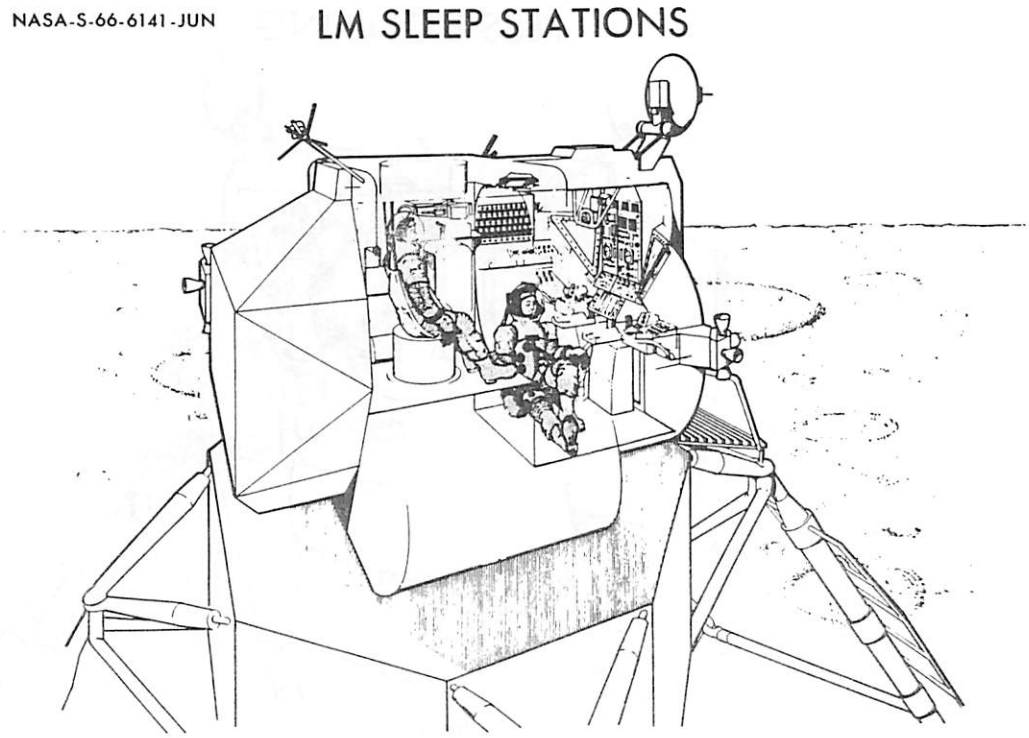


Figure 66

Figure 67

Figure 68

Figure 69

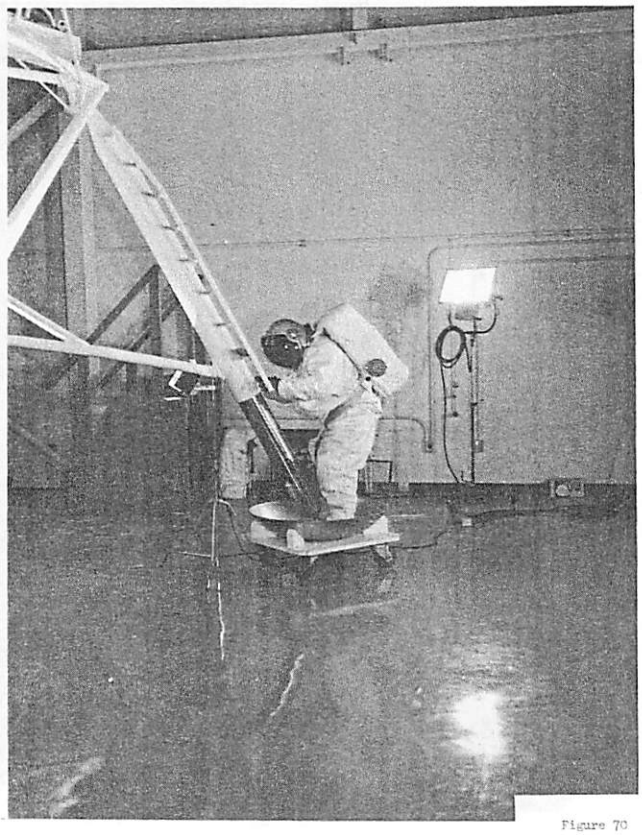


Figure 70

Figure 71

NASA-S-66-6145 JUNE

DISCARDED LUNAR SURFACE

- 5 LiOH CANISTERS*
- 4 PLSS BATTERIES
- 1 BAG PLSS CONDENSATE (TREATED)*
- 1 BAG URINE (TREATED)*
  SEALED FECAL CONTAINERS (TREATED)*
- 1 PLSS
- 1 STILL CAMERA
- 1 SEQUENCE CAMERA
- 2 PAIR EV BOOTS
- ? USED FOOD CONTAINERS

*STORED WITHIN DESCENT STAGE

Figure 72

NASA-S-66-6595 JUN

LUNAR ASCENT

- COUNTDOWN TO LAUNCH WINDOW
- MONITOR ASCENT PROFILE AND VELOCITY
- CONFIRM ORBIT WITH MSFN

- ALIGN IMU
- VERIFY DATA WITH MSFN
- ACTIVATE RENDEZVOUS RADAR
- CLOSE RCS/ASCENT INTER-CONNECT

- ORIENT FOR RADAR TRANSPONDER AND LM OPTICAL TRACKING

Figure 73

NASA-S-S-66-6383 JUNE

AOT SIGHTING

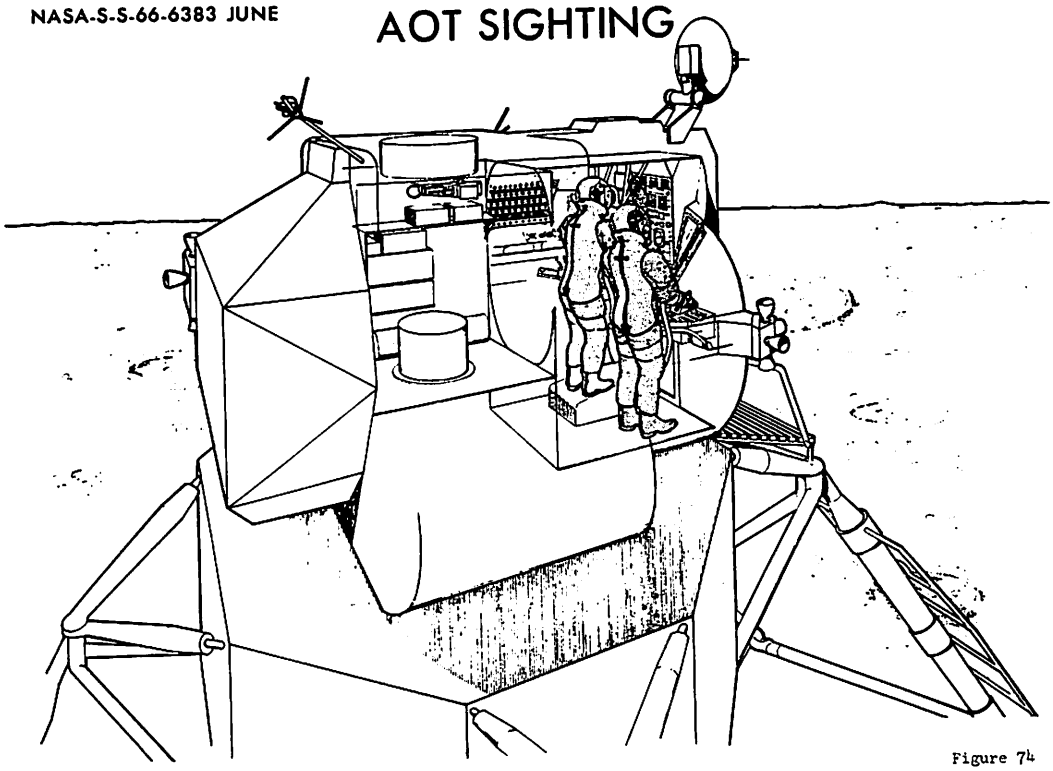


Figure 74

NASA-S-66-6591 JUN

RENDEZVOUS AND DOCKING

- CONFIRM TRAJECTORY PARAMETERS WITH CSM
- MONITOR RENDEZVOUS GATE MANEUVER BURNS
- MANEUVER TO DOCKING

- CONFIRM DELTA-V AND TIME TO GO WITH MSFN
- CHECK SUBSYSTEM STATUS

- ALIGN IMU
- ORIENT FOR ATTITUDE HOLD

Figure 75

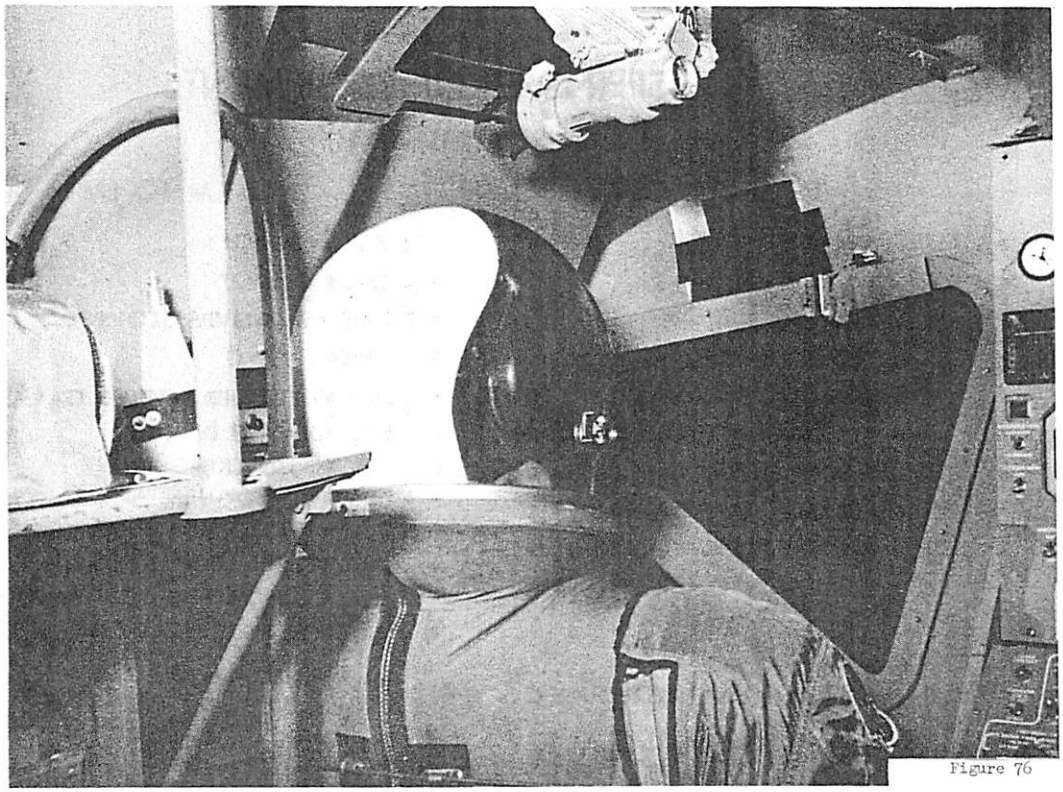


Figure 76

NASA-S-66-6142-JUN

ASCENT DOCKING

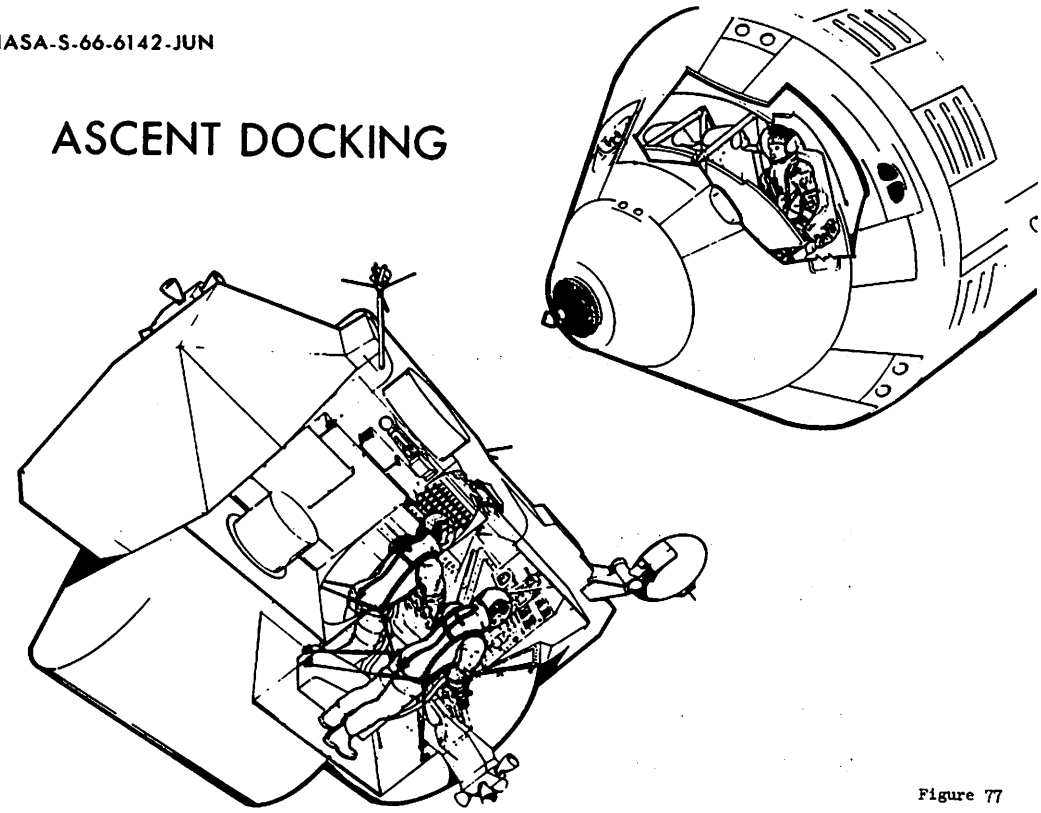


Figure 77

NASA-S-66-6144 JUNE

TRANSFER OF EQUIPMENT

(TRANSEARTH)

TO CSM

- 1 PLSS
- 1 PAIR EV GLOVES
- 1 TV CAMERA
- 1 LM FLIGHT PLAN
- 2 HELMET STORAGE CONTAINERS
- 2 SAMPLE RETURN CONTAINERS
- 1 SEQUENCE CAMERA FILM CONTAINER
- 1 FILM & TAPE CONTAINER
- 1 DATA STORAGE ELECTRONIC ASSEMBLY
- 1 RADIATION SURVEY METER

TO LM

- 2 EOS*
- 2 TMG*
- 1 PAIR EV GLOVES*
- 3 CWG
- 2 LIQUID COOLED GARMENTS
- 1 EVCT DEVICE*
- 1 DOCKING PROBE
- 1 DROGUE*
- 2 ELECTRICAL UMBILICALS
- 2 EV VISORS*
- USED FOOD CONTAINERS
- SEALED FECAL CONTAINERS

*LEFT IN LM UNLESS REQUIRED FOR EVT

Figure 78

NASA-S-66-6506 JUN

EVCT

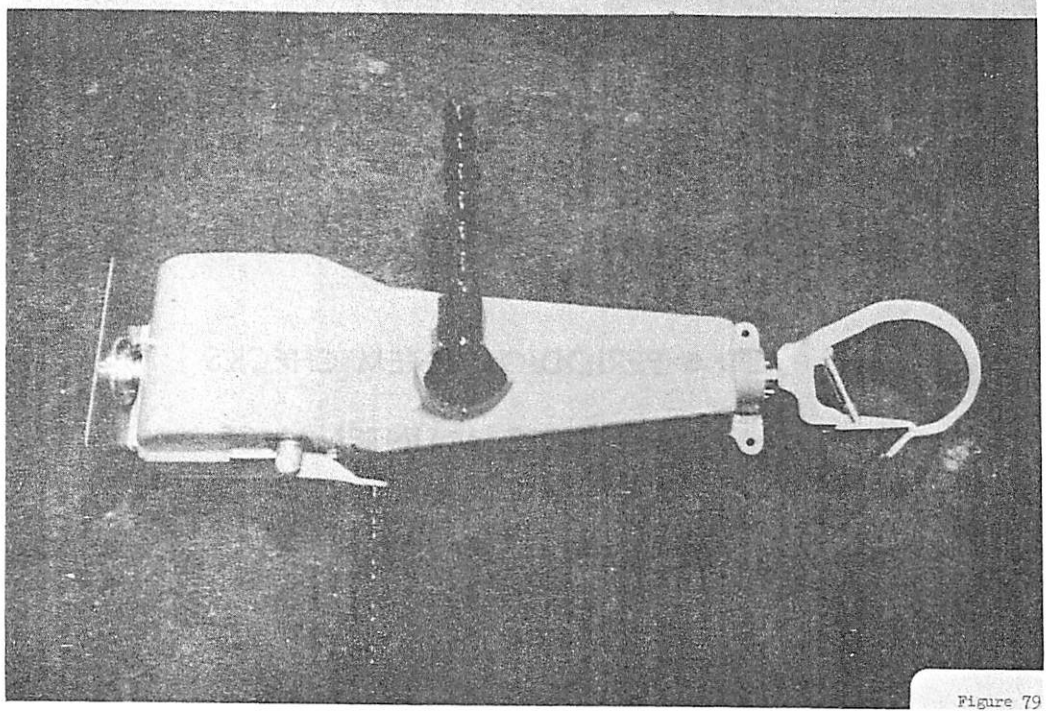


Figure 79

NASA-S-66-6130-JUN

CSM LUNAR ORBIT

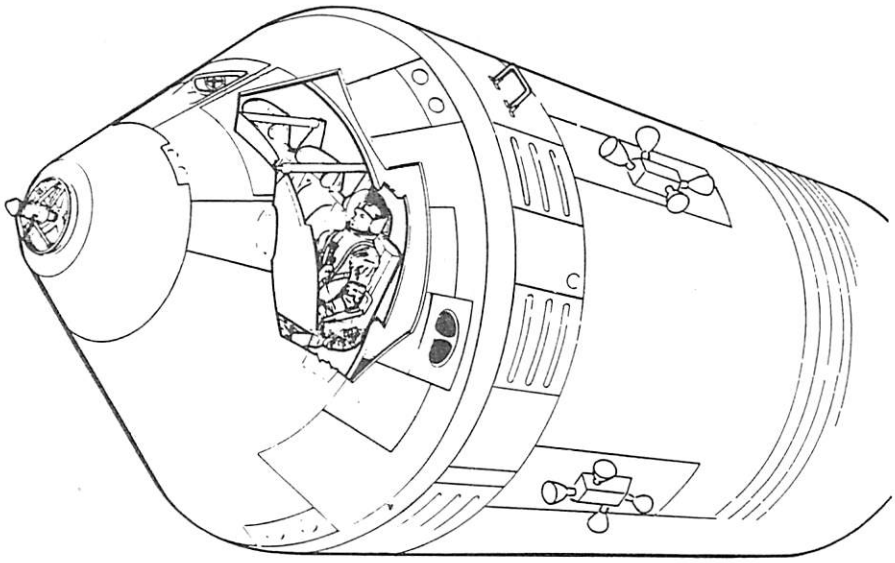


Figure 80

NASA-S-66-6594 JUN

TRANSEARTH

- MIDCOURSE CORRECTIONS
- PERIODIC SYSTEM CHECKS
- PERIODIC MAINTENANCE
- SLEEP

Figure 81

NASA-S-66-6860 JUN

ENTRY

- INITIATE SEPARATION
- USE ROTATIONAL CONTROL FOR LIFT VECTOR
- DUMP RCS PROPELLANT
- ENGAGE ELS

- CONFIRM SEQUENCING
- MONITOR ATTITUDE
- CONFIRM DESCENT WITH MSFN
- UNLOCK COUCHES

- ENTRY BATTERIES ON BUS
- DEACTIVATE FUEL CELLS
- MONITOR CHUTE DEPLOY

Figure 82

NASA-S-65-1414

TYPICAL ENTRY TRAJECTORY

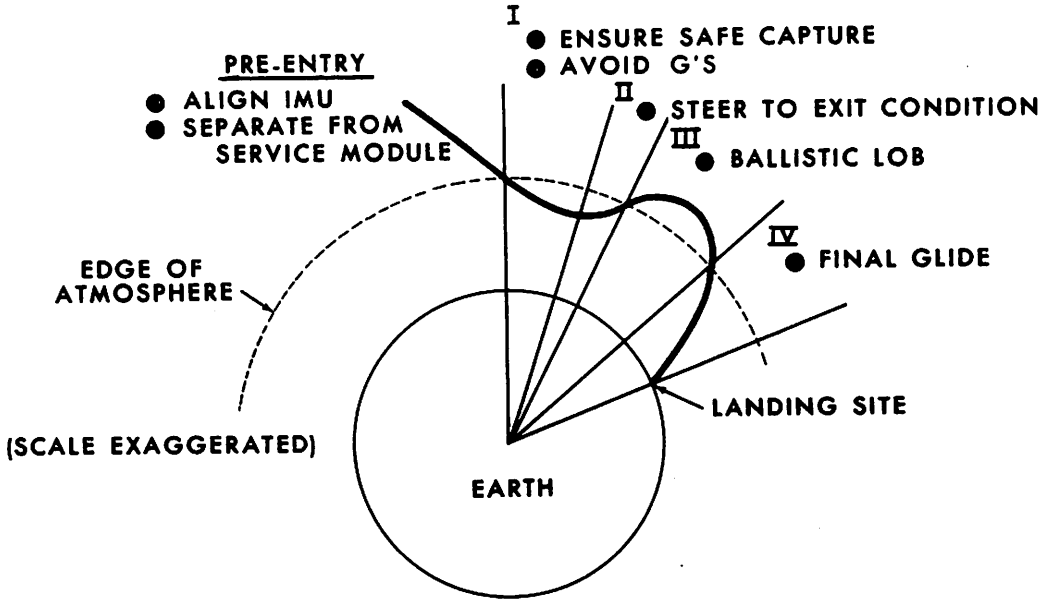


FIGURE 8

Figure 83

EXTRAVEHICULAR MOBILITY UNIT OPERATIONS

by

William C. Kincaide

EXTRAVEHICULAR MOBILITY UNIT OPERATIONS

The Extravehicular Mobility Unit (EMU) is in reality a spacecraft module in itself, operating completely independent of the other modules while on the lunar surface. The EMU has its own communications, electrical power, and environmental control system. Its guidance and navigation, propulsion, and reaction control systems are the astronaut working in conjunction with the EMU.

The EMU consists of seven major subsystems (figure 1): a liquid cooled undergarment, a pressure garment assembly, a portable life support system, a thermal-meteoroid garment, lunar boots, gloves, and protective over visor.

In addition to the lunar exploration capabilities, the EMU will allow the crew to perform free space extravehicular transfer from the Command Module to the Lunar Module or vice versa in event of a docking system malfunction. And as in both Projects Mercury and Gemini, the space suit provides a backup for unscheduled loss of cabin pressure. In the event of a noncatastrophic cabin depressurization, the suit is capable of being donned prior to the cabin reaching an unsafe pressure level. This capability allows the crew to remove the suits for a good share of the mission if they so choose.

Specific EMU requirements for the lunar mission are: To allow explorations of the lunar surface for distances of at least one-half nautical mile; provide up to four hours of continuous separation time from the spacecraft for each excursion and a total capability of 24 hours by multiple excursions; permit two crewmen to be extravehicular simultaneously; and permit recharge of the EMU within one hour for rapid turn around. The four hour separation period has been further defined to be three hours of nominal mission and one hour contingency. The twenty-four hour total exploration time is attained by eight excursions of four per EMU.

The design requirements of the portable life support system, PLSS, are shown in figure 4. The main function of the PLSS is to control and replenish the atmosphere within the space suit. The Unit, which weighs 65 pounds fully charged, will provide oxygen and CO_2 control for respiration and cooling for average work rates up to 1600 Btu per hour. This is similar to a man walking at 4 to 5 miles per hour here on earth. The total capacity for cooling is 4800 Btu. The unit is also designed to accommodate high work rates of up to 2000 Btu per hour for periods of up to ten minutes. In actuality, tests have shown

that the unit will handle short peaks of 3000 to 4000 Btu per hour, however, expendables will be consumed at an accelerated rate, thereby shortening the mission time available. The PLSS also has the capacity to handle external heat leaks into the system of up to 250 Btu per hour.

The basic system schematic is shown in figure 5. Thermal control is achieved through a unique approach which does not rely upon crew sweating as the primary means of cooling as in the present conventional spacecraft environmental control systems. This is accomplished by circulating cool water at a rate of four pounds per minute from the PLSS through tubes in direct contact with the skin so that metabolic heat is conducted away. Thus, the problems of astronaut dehydration, sweat in the eyes, skin maceration, etc., are minimized.

The basic gas ventilation loop is still required to replenish oxygen, remove carbon dioxide and moisture, and control total pressure. However, flow rates are reduced to a total flow of 6 cfm to the helmet, as compared to 15 to 20 cubic feet per minute which would be required without water cooling.

A typical maximum integrated metabolic profile is shown in figure 6. Profiles like this are being used primarily to test the PLSS, however, they are based upon a reasonable estimate of lunar excursion. This profile is based upon a three hour excursion at an average metabolic rate of 1600 Btu's per hour, which is the maximum design point for the PLSS. Periods of heavy work such as egress from the spacecraft, and walking are assumed to require about 2000 Btu's per hour. Moderate tasks such as setting up experiments rates will require around 1600 Btu's per hour.

Obviously, an actual metabolic profile for a lunar excursion will be a series of sharp peaks and valleys, many of which will exceed 2000 Btu's per hour for short periods.

The EMU will maintain the astronaut in a thermally comfortable condition, however, at these sustained high metabolic rates he will undoubtedly become tired and may require periodic rest periods.

The PLSS also houses a redundant two-way simultaneous voice communications unit and a seven channel telemetry unit for system and biomedical data transmission. The data which will be available is shown in figure 7. Information available to earth will include: Total suit pressure, status of PLSS consumables, such as cooling water quantity, primary oxygen remaining, battery use rate, thermal performance of the PLSS, and electrocardiogram. From this data, it will be possible to assess the metabolic rates associated with lunar tasks.

The astronaut will be able to monitor his suit pressure, coolant water quantity remaining, and primary oxygen quantity. Audible warning tones will also alert the astronaut to low suit pressure and high oxygen use rates.

One of the most difficult EMU design problems to date has been the location of PLSS controls, figure 8. It is difficult to make switches and valves readily accessible without degrading mobility.

Many approaches have been evaluated from over the shoulder cables to side arm extensions. The concept finally chosen was a behind the back-fingertip operation as being the least complex insofar as PLSS design and operational usage. Electrical and communications switches are located on the left lower corner of the PLSS. Manual water and oxygen valves are located on the other corner. As seen in figure 8, the corners are easily accessible and, with training, the controls can be operated quickly and accurately. All controls will be operated at start-up; however, only the water garment inlet temperature control and communications switch require operation on the lunar surface.

An independent emergency oxygen system is also available to the astronaut. This 3.5 pound unit contains 0.2 of a pound of oxygen stored at 7500 psi. The system is actuated by pulling a "green apple" which provides regulated oxygen directly to the helmet. The emergency system will provide from 5 to 38 minutes of additional time, depending upon the point in time at which the failure occurs. The system is not rechargeable. Figure 9 typifies the progress made in the EMU program toward compacting hardware. The system on the left is the emergency oxygen system as of about two years ago, which weighed over 5.5 pounds. The volume improvement speaks for itself.

The pressure garment assembly, shown in figure 11, consists of a basic torso enclosure, intravehicular helmet, boots, and gloves. The suit provides pressure protection with sufficient mobility to accomplish the lunar mission. Unlike its predecessors, the Apollo suit uses convoluted bellows to allow flexure of joints by maintaining a constant volume in the suit thus reducing the effort required to compress the gas. Joints are located at the shoulders, elbows, wrists, thighs, knees, and ankles. Bearings are located in the upper arms and wrists to allow the arm and hand to be rotated. Entry into the suit is made through a dual zippered opening in the back identical to the Gemini suit. The Gemini zipper has proved to be exceptionally reliable by comparison to past closure designs. In fact, Gemini space suit technology, operational experience and components are being used to fullest extent possible in the Apollo program.

Figures 12 through 14 depict some of the basic movements that can be performed with the Apollo suit. The lunar explorer will be able

to walk, kneel, crawl on all fours, get up from a prone position either from the side, front, or back, bend down at the waist, squat and reach most frontal and side areas of his suit.

A major factor contributing to the capabilities of the suit is familiarization and training on the part of the wearer. For example, many arm positions are more easily attained by a combination of motions rather than a direct movement to that position. Proper use of the helmet tie down can make sitting and other similar operations which require bending at the waist much easier.

The helmet has a fixed visor with no neck bearing, which allows the wearer to turn his head without having to move the helmet with him. This gives the crewman a greater field of vision and eliminates the torque required to move a neck bearing. Downward vision is particularly important to the lunar mission since the astronaut must be able to see his feet to be able to select each step in rough terrain. Also, the crewman will be required to make and break his gas ventilation connections within two minutes to transfer from vehicle to PLSS operation. The helmet is capable of being quickly donned without assistance, over a communications cap. The cap is also worn for "shirt sleeve" communications.

Visor fogging, which occurred during the GT-9 Gemini extravehicular experiment, has been and will continue to be given a great deal of consideration in the EMU test program.

Fogging is, of course, caused by condensation of the warm wet expired breath and ventilation gas on the relatively cold inner surface of the visor. Manned tests on an EMU at an altitude of 300,000 feet, with -300°F cold walls simulating lunar night conditions, showed that satisfactory clearing of the visor occurred at metabolic rates up to 2000 Btu per hour. The test subject could force a small patch of fogging by purposely blowing on the visor, however, the clouded area cleared itself within one to two seconds. Visor inside surface temperature was only slightly lower than the temperature of the ventilation flow, in spite of an outside surface temperature of 20°F. Low emissivity coatings will be provided on the visors to control visor temperatures and a wetting agent coating for the internal visor is being investigated to completely preclude fogging.

The Apollo visor is made of polycarbonate which was selected primaril for its impact strength. Quarter inch polycarbonate will withstand impact loads of 80 foot pounds or more depending upon the area and velocity of the object striking the visor. This energy level is very important in Apollo where the astronauts will be moving about on the lunar surface and inside the spacecraft exposing the helmet to knocks on bulkheads, brackets, etc. For comparison, Mercury and early Gemini visors were made of acrylic or plexiglass which break at energy levels of under 5 foot pounds. This was satisfactory because the crew did not leave the couch.

Tests were conducted in the 1/6 gravity aircraft with a mockup fiberglass visor, to determine the energy loads that could be expected for a fall on the lunar surface (figure 15). We would certainly expect this to be the worst case. During this series, energy levels of 135 foot pounds were recorded. The polycarbonate helmet and over visor combination will accommodate this type of blow without injuring the astronaut through its ability to deform and absorb energy. The helmet has been impacted with 130 foot pounds by dropping a 16 pound rod with a 2-inch diameter hemispherical tip without rupturing. Polycarbonates are relatively new and production process controls and fabrication techniques are not as yet quite developed to the point where a quality helmet visor with acceptable distortions and surface imperfections can be produced consistently. While this is still an existing problem several contractors are investigating forming processes and it is felt that an acceptable helmet will be qualified by January 1967.

Provisions are made to store body wastes within the suit. The urine collection bag is identical to the Gemini device, except for minor interface revisions. It can also be emptied in flight and reused if necessary. Fecal collection is not expected to be required during the planned pressurized suit modes, however, during an emergency return which could take up to 115 hours, provisions must be made to contain the feces. Numerous types of systems have been examined, however, to date none have been totally acceptable.

The liquid cooled garment (figure 16) is worn under the space suit, next to the skin. Unlike regular underwear the garment has 300 feet of polyvinyl chloride tubing sewn into it which directly contacts the skin of the wearer. The PLSS circulates cool water through the tubes in forty parallel paths to reduce pressure drop. An astronaut will have a choice of inlet temperature settings, from 45° to 85° F, depending upon his activity level. During a three hour manned mission profile in which metabolic load varied from 400 Btu/hr to 2000 Btu/hr for varying lengths of time, test subject comfort was maintained with only six changes in position of the control valve. The subject's skin temperature was maintained at a comfortable level while the average sweat rate was only 71.7 cc/hr for the test. The testing to date on this garment has been extensive. Subjects have worn the garment for several days without significant comfort problems.

The thermal-meteoroid garment (figure 18) is worn over the entire pressure garment to protect the space suit from cuts, abrasions, and meteoroid penetrations, and to provide passive thermal control. The garment is made up of an outer layer of reflective white dacron, seven layers of super insulation, and finally two layers of neoprene coated nylon. Insulation to limit conduction also has been added in areas which will routinely come into contact with hot or cold surfaces such as the hands, knees, and feet.

Mobility is not appreciably degraded with the addition of these layers over the suit, except for the gloves and boots. The thermal gloves have a fine woven stainless steel palm for durability backed by 16 layers of super insulation for conductive protection. The back side of the glove is identical to the thermal garment cross section. Flexibility is hampered by the relatively small diameter fingers compared to the material bulk and tactility is very difficult to retain, especially at the fingertips where the material comes together. This glove has recently been tested under vacuum conditions, in which a subject was able to grip a hot rod at 250° F for three minutes and a cold rod at -250° F for over thirteen minutes.

The lunar boot is not as problematic as the glove because gripping and tactility are not required, however, a flexible sole is desirable to avoid having to walk flat footed. The soles of the lunar boot have an outer surface of silicone rubber which holds up surprisingly well on sharp rough surfaces. The rubber is followed by 13 layers of super insulation and finally two layers of nomex felt. A current boot design has been successfully tested under the vacuum conditions in a hot plate at 250° F for over one hour.

Unmanned testing of thermal garments has been underway since early 1963, in an effort to obtain adequate protection without severely impairing mobility. The garment has been optimized from a 25 layer cross section to its present seven layers. Access flaps have been purposely left open during these tests to evaluate potential hot spot problems. The outer surface of the garment was purposely dusted with soil of the same absorptivity-reflectivity characteristics as the lunar surface to examine the thermal implications. The test data and computer analysis agreed that the heat flux in could increase by a factor of one. However, this flux is still within the capacity of the PLSS. Even with the minor GT-9 problem, the two Gemini EVA flights and ground tests have validated this concept of thermal protection.

A prototype extravehicular visor assembly, figure 22, will be worn over the primary helmet. The attachment concept is identical to that shown, however, the visor attenuation approach has been modified to the GT-4 concept. Two visors are provided which rely upon reflectance rather than absorption to attenuate infrared and visible light.

The test set-up for unmanned testing of the thermal-meteoroid garment in the Ling-Temco-Vought space simulator is shown in figure 23. In this series a quartz lamp cage was placed around the test specimen, in conjunction with the solar source and cold walls, to simulate the infrared heating expected from the lunar surface. The dummy is rotated about its longitudinal axis to examine transient situations and different view factor situations.

The worst thermal case tested to date simulated an explorer standing in a lunar plane with a sun at 90° from the vertical. The total heat leak reached about 135 Btu/hr. Further unmanned tests are planned to examine other critical thermal situations, such as the EMU working in a crater.

Tests have shown that the Apollo Block II pressure garment assembly is the most mobile soft space suit yet developed. The metabolic energy required to exercise the pressurized suit is small by comparison to the Mercury and Gemini suits and its range of motion significantly greater. Of course, neither of its predecessors were designed for walking, however, even in areas of comparable motion requirements, the Apollo suit is superior.

While the Apollo suit is the best available, it still requires a good deal of metabolic energy to operate. Figure 24 summarizes some of the results of manned treadmill tests conducted to date, with unpressurized and pressurized suits at both 1 g and 1/6 g. It appears that the metabolic expenditure for walking in the pressurized suit will require up to twice as much energy as that of the unpressurized suit in one g. This ground based data also indicates that metabolic expenditure for walking will be reduced up to 50%, due to the 1/6 gravity environment. From this data, we can expect that the astronaut should be able to travel up 2 or 3 miles per hour without any thermal stress depending upon the immediate terrain. To date, metabolic data has been collected primarily by exercising subjects on treadmills because it offers a convenient standard for comparison. More tests will be conducted, in fact this type of testing will be intensified to measure the metabolic penalty associated with a variety of surface conditions.

The MSC lunar crater area has been used periodically to evaluate, subjectively, the problems of terrain and 1/6 gravity as shown in figures 25 and 26. The 1/6 gravity simulator creates some problems itself because of the effort required by the subject to overcome its inertia. However, these tests have proved quite valuable in assessing the balance and stability problems.

Field trips have been made to sites in Oregon and Arizona where the terrain is believed to resemble that of the lunar surface. Subjects wearing full EMU's performed simulated traverses in deep sand and in rocky areas, up a variety of slopes and on flat surfaces, as seen in figures 27 and 28. Various tools, experiments, and walking aids were evaluated in conjunction with the EMU. Field simulation of this sort will continue throughout the program becoming more sophisticated as production hardware and detail on the lunar surface is available.

It has been very apparent from these field trips and the 1/6 gravity simulations in the MSC lunar crater that balance will be difficult to maintain and in fact may well be the constraint in determining the range of expolration. Subjects tended to walk carefully in these tests rather than bounding along, primarily because they have a great deal of difficulty in maintaining their balance and stopping quickly. They could make better time by loping along; however, because of these control problems, would probably only attempt this in an emergency.

EMU failure modes which constrain the lunar mission are primarily directly associated with expendables and therefore determine the time the crew has to return to the spacecraft. For example, one of the more critical failures is a fan malfunction which would require that the astronaut return to the spacecraft immediately. The remedial action for this case would be for the crewman to activate the emergency oxygen system and open a fixed orifice in the suit which causes a two pound per hour or 1.9 cfm in the helmet as the pressure regulators attempt to maintain the suit pressure. The resultant mission constraint is shown in figure 29. As the astronaut leaves the vehicle, he can walk up to a maximum of 26 minutes away before he has to start working his way back. Assuming nominal usage to this point, the amount of oxygen left in his tanks will just give him 26 minutes at 2 pounds per hour. After 26 minutes he will have to work his way back, always staying within this envelope, which is a function of the use rate, i.e., metabolic consumption and leakage. If he works harder or has a greater leakage to contend with, the maximum envelope is reduced. The specific leak rate for the EMU is 200 standard cubic centimeters per minute. A leakage check will be performed prior to egress however the check will be made by measuring pressure decay on a small mounted gage. The test, as such, will be relatively gross, assuring the crewman that all connections are properly made. Oxygen quantity trend information will be calculated on the ground to keep the astronaut informed as to his return status.

The EMU subsystems have completed critical design review. First article configuration inspections will be held during July 1966. In August, a subject wearing the full EMU will walk into a space simulator. This test will be the first real manned thermal test in a simulated environment, completely protected by the EMU subsystems.

Based upon the tests to date, we are confident that this unit will be adequate to perform a valuable lunar mission. When the program was initiated, the design requirements were based upon a relatively poor estimate of the lunar environment. The data which has been acquired since this time from pegases, surveyor, etc., has shown the original estimate to be conservative and as such adds to the confidence in the hardware.

Questions and Answers

EXTRAVEHICULAR MOBILITY UNIT OPERATIONS

Speaker: William C. Kincaide

1. Can the extravehicular astronaut walk sideways?

   ANSWER - Yes.

2. Why is the helmet red?

   ANSWER - Allows better observation of the EVA.

3. Which visor will be down during EVA?

   ANSWER - Normally the inner visor for night-time excursions and the gold visor for daytime excursions.

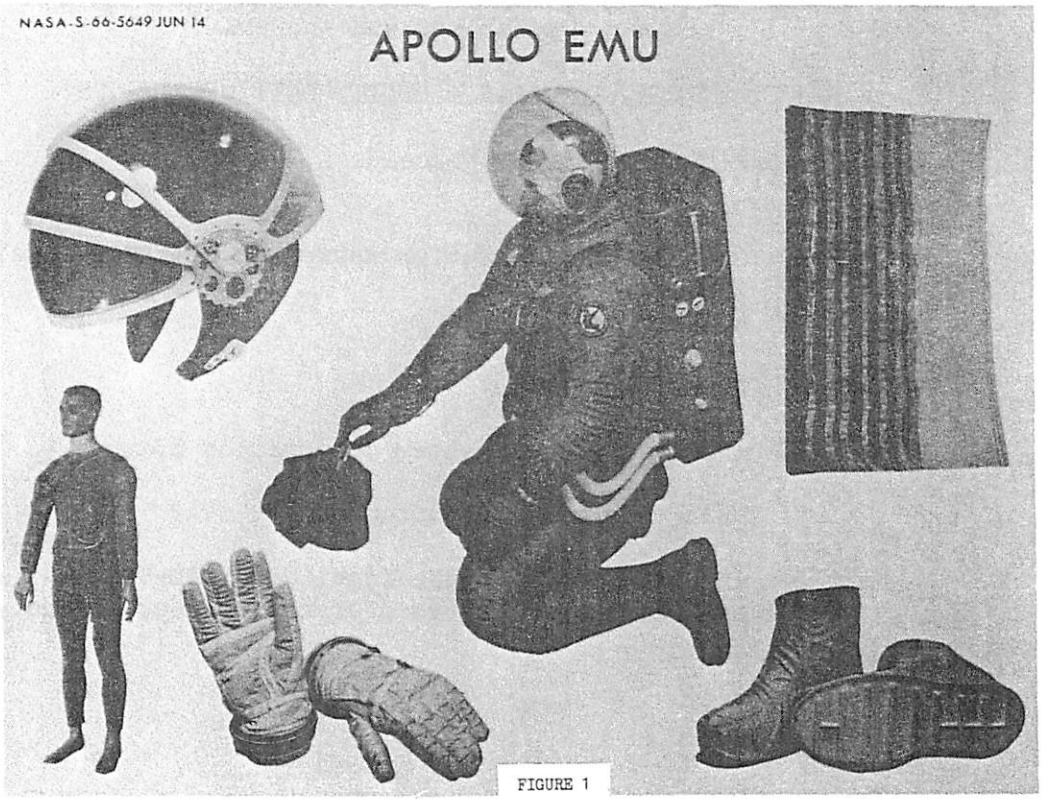


FIGURE 1

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EMU MISSION REQUIREMENTS

- PERMIT APOLLO CREWMEN TO LEAVE THE CM OR LM IN FREE SPACE TO ACCOMPLISH EXTRAVEHICULAR TRANSFER
- PERMIT APOLLO CREWMAN TO LEAVE THE LM ON THE LUNAR SURFACE TO EXPLORE & RETURN SAFELY TO THE LM
- PROVIDE BACKUP PROTECTION WITHIN THE SPACECRAFT IN THE EVENT OF UNSCHEDULED CABIN PRESSURE LOSS

FIGURE 2