R Ǝ N T R Y

AN ORBITAL SIMULATOR

APOLLO COMMAND MODULE

FLIGHT MANUAL

REENTRY

AN ORBITAL SIMULATOR
APOLLO COMMAND MODULE FLIGHT
MANUAL

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TABLE OF CONTENTS

I. INTRODUCTION

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1. ABOUT

Project Apollo for Reentry is one of the modules available for the space simulator "Reentry – An Orbital Simulator" by Wilhelmsen Studios. The module includes the Apollo Command Module spacecraft and the Lunar Module spacecraft. This document will cover the Apollo Command Module.

The goal of Project Apollo for Reentry is to create a gamified and immersive experience on how it was to be an Apollo astronaut, what procedures the real astronauts had to follow, and learn about the systems onboard.

The Command Module implementation in Project Apollo for Reentry is described in this manual and is modelled after the SM2A-03-BK-II APOLLO OPERATIONS HANDBOOK BLOCK II SPACECRAFT manual.

All the training needed to fly the spacecraft is available in this manual and in-game. If you want to study the spacecraft down to the lowest details, I highly recommended reading the manual by NASA.

NOTE

Not all of the components described in this document is simulated. Some might have been simplified or is a placeholder for a future update, while some will never be implemented. They are described because they are needed to complete the descriptions of systems and its operation, and for historical accuracy. This is a computer game meant for the general user, so simplifications have been made to make it better suited for a computer game.

GET THE GAME

The game can be purchased from https://reentrygame.com/buy - the Project Apollo for Reentry module is included in this package.

JOIN THE COMMUNITY

An important aspect of virtual space flight is the community – learning to operate these crafts yourself can be very complex. I recommend you join the official "Reentry – An Orbital Simulator" server on Discord, accessible from the in-game menus or http://discord.gg/reentrygame! Ask for help, find multiplayer sessions, get roles for your game progress, share clips, screenshots and meet fellow virtual astronauts and mission controllers.

WHAT IS THIS MANUAL?

This manual contains most of the information you need to successfully master the Command Module Spacecraft in Reentry. This manual is specific to the Command Module spacecraft. For generic Reentry information, please see the **Reentry – An Orbital Simulator: User Manual**.

DONATE TO SUPPORT THE DEVELOPMENT OF THE GAME

If you wish to support the development of this game, or if you enjoy playing it, please consider giving a small donation. Creating a game like this is a lot of fun, but also takes up a lot of my spare time and my limited resources to fund it.

Any donations will help me cover costs for development, assets, server hosting, and coffee for staying up late.

You can donate from the Main Menu of the game, or online using PayPal on the following page:
http://reentrygame.com/donate

From one space enthusiast to another, thank you again for considering giving a donation!

LEGAL

Images and information in the manual, as well as in the **Project Apollo for Reentry** module is based on information made public by NASA and related documents. Images and references from various NASA documents are used.

The images in this guide and game are using public domain images from NASA.
https://www.jsc.nasa.gov/policies.html#Guidelines

The information described here is tailored to the simulation and my implementation of the spacecraft for Reentry – An Orbital Simulator. Some systems are simplified or made differently due to being used in a computer software, and for gamifying the experience.

Both public documents released by NASA and Wikipedia have been used as a reference in my implementation of Project Apollo, as well as writing the education material for the game, including this manual, in-game academy, and mission flow.

This module is subject to change and/or removal at any time.

2. A BRIEF HISTORY

Project Apollo was the third space program of the United States. It started in 1960, with Apollo 7 as the first manned flight in 1968, and concluded with the last flight, Apollo 17, in 1972.

The main objective was to land a man on the Moon and returning him safely to the Earth.

It was the first program to send manned missions beyond low Earth orbit, and to another celestial body.

Apollo followed the success of Project Mercury and Project Gemini, building upon a lot of the learnings from these programs. From attaining orbits in Project Mercury, to maneuvering in orbit, EVAs, rendezvous and docking in Gemini, NASA had many of the tools needed to follow the plan to build the powerful Saturn V rocket, and the high-tech Command and Service Module acting as the Apollo Spacecraft.

Two spacecraft types were built. The first was Apollo Block I. Due to an issue with the design that unfortunately cost the lives of the entire Apollo 1 crew during a fire on the launch pad in 1967, another enhanced version was built. The Apollo Block II spacecraft was an enhanced version of Block I with many improvements and modifications. The first manned mission was flown in 1968 (Apollo 7), and was to orbit Earth and test the spacecraft.

The Apollo spacecraft was operated by three astronauts, the Commander, the Pilot, and the Lunar Module Pilot. Two of them landed on the Moon, while the Pilot operated the Command Module during lunar orbit.

3. MISSION PROFILES

There are two different types of missions for Project Apollo. The first is an orbital flight around Earth where the capsule is tested. The other is a Lunar mission profile where the spacecraft is sent to the Moon and back again, either just to Orbit the Moon or land on it.

Lunar Mission Profile

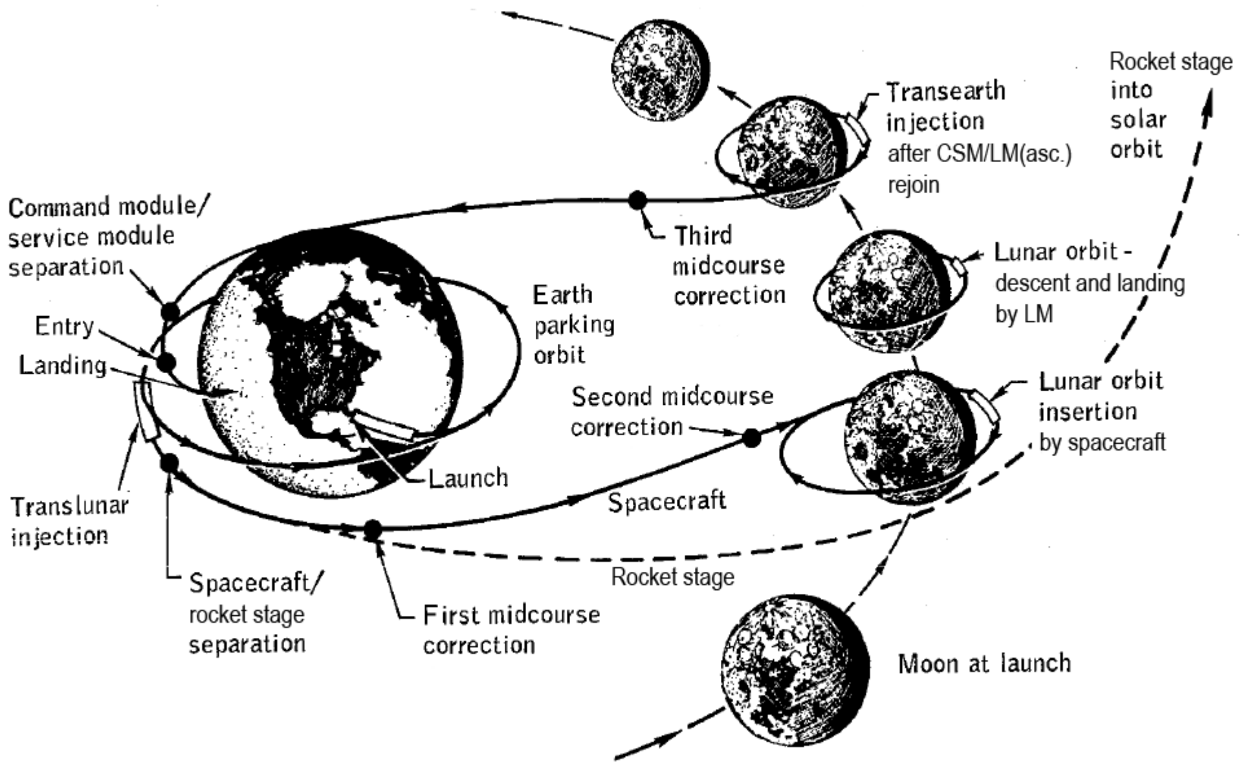


Fig 1.3.1 – Lunar Mission Profile, Apollo 8, NASA.

The Lunar Mission consists of a few key milestones

1) **Launch**
A Saturn V rocket takes the spacecraft and its payload (ballast or Lunar Module) into orbit after a 11+ minute long ascent, the orbit is usually a circular orbit around 100 nmi alt in size.

2) **Translunar Injection**
The Translunar Injection (TLI) is a burn that lasts for about 6 minutes, taking the spacecraft from Earth orbit to an orbit that will arrive at the Moon, ideally with a Pe of 60 nmi alt. The SIVB stage of the Saturn V performs the burn.

3) **Transposition and docking**
After the burn, the spacecraft separates itself from the Saturn V/SIVB launch vehicle. It then translates away from it before doing a 180-degree rotation. It will then dock with the Lunar Module that still sits in the SIVB stage. After docking, the Lunar Module is ejected from the SIVB and follow the Apollo Spacecraft until leaving the Moon.

4) **Lunar Orbit Insertion**
The Lunar Orbit Insertion (LOI) happens after a long coasting period from Earth to the Moon (midcourse corrections can happen during coasting). The bell-shaped engine on the spacecraft performs a burn that will slow down the spacecraft and enter the

Lunar orbit. A typical LOI burn will insert the spacecraft into an elliptical orbit of 170 nmi alt x 60 nmi alt. A later burn will circularize this orbit to a 60 nmi x 60 nmi alt orbit, and a later burn called the Descent Orbit Injection (DOI) will insert the spacecraft into an orbit designed to land the Lunar Modula at a specific location on the Moon. The DOI burn can be executed using the CSM or the LM.

5) **Powered descent**
The Lunar Module is then entered and separated from the spacecraft. This now becomes another spacecraft that will be used to land on the Moon after a powered descent.

6) **EVAs**
EVAs are performed on the surface of the Moon

7) **Ascent**
When done with the EVAs on the Moon, the Lunar Module will launch from the surface of the Moon using the ascent stage, and rendezvous and dock with the Command/Service Module again.

8) **Trans-Earth Injection**
After docking with the CM, the LM is jettisoned. The Trans-Earth Injection (TEI) use the main engine of the Service Module to bring it back to Earth.

9) **Reentry**
After arriving Earth, the SM is jettisoned and the CM is performing the last bit down to Earth, and land in the ocean.

10) **Recovery**
The crew is recovered

4. INTERACTING WITH THE COCKPIT

When you load an Apollo mission form the Main Menu, you will be seated inside the cockpit. To look around, you can use the mouse while holding in the middle mouse button/scroll wheel. You can use the arrow keys to move the camera around.

Use F5 to F12 to move the camera to predefined spots in the cockpit view. You can use F1 to switch to an external view and F3 to enter orbital view.

There are multiple controls you can interact with in the cockpit, as well as two joysticks to orient and translate the spacecraft. This section describes how you can use the mouse/keyboard to interact with these controls.

The Command Module consists of many panels, with hundreds of switches and controls.

Below are the main categories of controls used to interact with the cockpit.

Switch

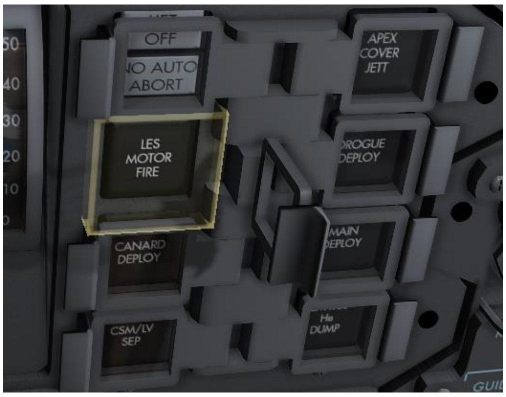
Multiple switches are used to configure various onboard systems. A label is usually describing the function of the switch and what positions it can be set to. A switch can either go in a vertical direction, or a horizontal direction.

Vertical switches are pushed upwards using a single left mouse click, and downwards using a single right click.

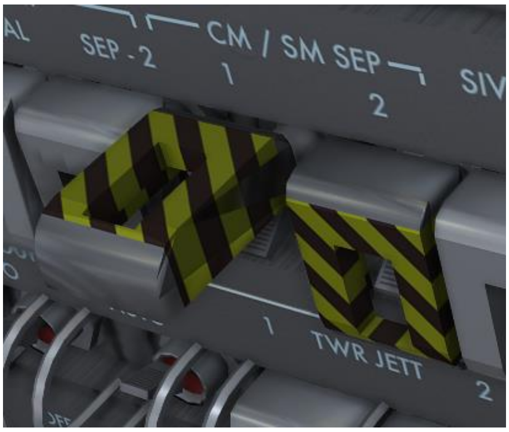
Horizontal switches are pushed left using the left mouse button, and right using the right mouse button.

A switch can have two or three positions. When a three-position switch occurs, the same logic applies.

Push Buttons
The push button can be clicked using the left mouse button to push it down. This will trigger the related action to the push button



Protected Button
Some push buttons are covered. To push this, open the cover using left click. Then push the button normally using another left click. The cover can be closed using the right mouse button.



Protected Switch
Some switches are covered for protection. Open the cover using left mouse button, close it using right mouse button. The switch works like a normal switch when the cover is open.

Circuit Breaker
Circuit breakers can be closed using left mouse button, and opened using the right mouse button. A closed circuit breaker (cb) means that the electrical loop is closed and functional. An open cb means the electrical loop is open and disabled. An open cb is identified by being further out then closed ones, as well as a white ring on the inner side.

Selector
A selector can be rotated to configure a system or select the source sensor an indicator will use.

If can rotate both left and right:

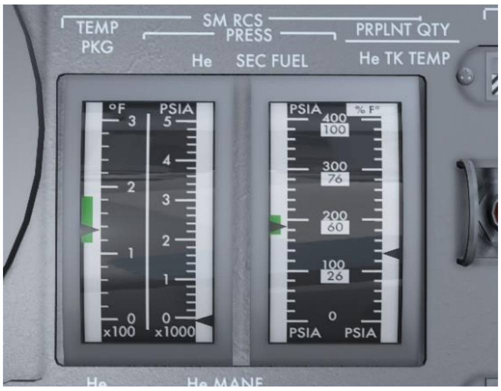
- Right click moves the selection rightwards (counterclockwise).
- Left click moves it leftwards (clockwise).

A selector is usually identified by a label with marks showing what the selector is configured to.

Gauges
Gauges are used to show the status or signal from sensors located throughout the capsule. Circular gauges and vertical gauges exist in the Gemini craft.

A gauge can consist of one or multiple needles showing the current signal, typically the amount of fuel left, oxygen levels, and pressure and temperature of various onboard systems.

Some gauges can be controlled by a selector, where the selector chooses the input/source of the gauge.



Vertical gauges are used to read the state of a system or a quantity.

Talkbacks
Talkbacks can show gray or barberpole (bp). They indicate if a valve is open or closed, or if a system or flag is enabled or disabled. Gray usually means it is enabled, while barberpoled means it is disabled.

Thumb Wheel
A thumb wheel can be increased using right mouse button, and decreased using left mouse button. They can have a number used as an indicator, or simply be a unitless wheel.

Digital Number
Numerical digits are used to show a value, either on the computer or mission time.

Indicators / Caution Lights
Light indicators are used to show the status of a system, similar to the caution and warning light array.

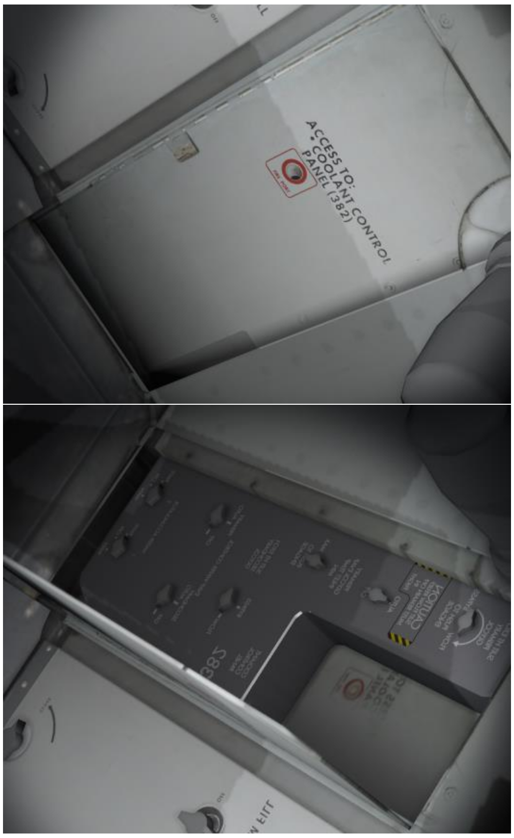
Master Alarm
The Master Alarm switch shows when a critical warning or issue is detected. An alarm will sound. The alarm can be disabled by clicking on it.

Analog Numbers
Analog numeric digits are shown using numbered drumrolls. It will automatically rotate to the value a system wants to display.

Caution & Warning Lights
Caution and warning lights are used to highlight systems that require attention, either due to issues, out of tolerance values or warnings. Extinguished lights means that everything is OK, while illuminated lights means that the system needs attention.

Computer Buttons
The computer buttons function in the same was as a push button and is used to operate the onboard computer.

Computer Display
The computer display shows the current running program, verb, noun and data in three register displays (each with a green line above it). A dedicated caution light array for the computer is used to communicate its state.



Panel Cover
Some panels are covered and can be opened. Interaction is similar to a protected switch.

4. KEYBOARD CONTROLS

MANEUVERING

Maneuvering is done using the keyboard or joysticks. The input is configured through the Reentry – An Orbital Simulator settings dialogue.

ORIENTATION

W: Pitch down

S: Pitch up

A: Yaw left

D: Yaw right

Q: Roll left

E: Roll right

TRANSLATION

U: Forward

O: Backwards

I: Upwards

K: Downwards

J: Leftwards

L: Rightwards

TOOLS

F4: Switch to the Lunar Module/Command Module

T: Flashlight (move it around by using the mouse)

C: Show/Hide Radio Communication menu (both UI and circular cockpit buttons)

M: Show/Hide Mission Pad

V: Show/Hide View Selector

ESC: Show/Hide in-game menu

VIEW SELECTOR

The view selector can be used to move the camera to the different pre-defined snap points, and switch the view into the Lunar Module.

External will show switch to the external view of the active space craft.

Orbital will show the orbit view and the current trajectories of the spacecrafts.

Switch to LM/CM will change the active craft.

The rest are various views, a photocamera mode (yet to be implemented) and toggling the visibility of the Mission Pad.

COMMUNICATION

The Communication window will let you trigger a radio check and open the various tools used during an Apollo Mission to plan TLI, burns and open the CREW MEMBERS view.

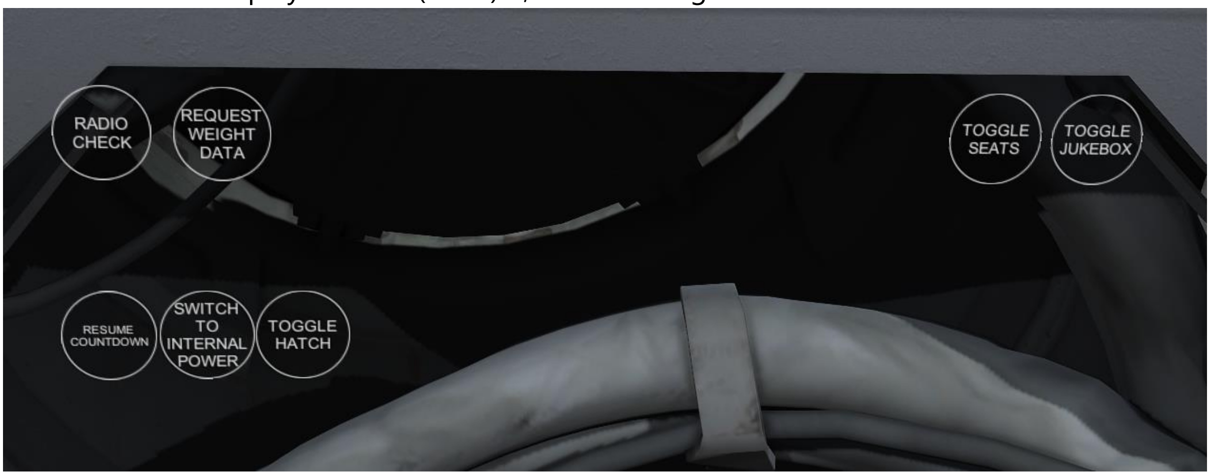
This window is frequently used during the mission as it will be the main mission planning tool used to plan and execute burns. It is important to become familiar with the Burn Planner (delta-V burns), the S-IVB Burn Planner used to plan the S-IVB burn called TLI (Trans-Lunar Injection), and the TEI tool used to plan the Trans-Earth Injection burn, used to get back to Earth from the Moon.

These tools will be covered later in the manual.

FUNCTION-BUBBLE BUTTONS

Circular buttons (bubbles) are used to trigger or toggle various functions used during cockpit operation. These are usually short radio commands, or toggling various equipment.

Below the main display console (MDC) 2, the following bubbles exist:



Radio Check is used to verify the radio.

Request weight data is used to request the current weight of the Command Module and the Lunar Module (if available) in lbs. This data is used with the computer.

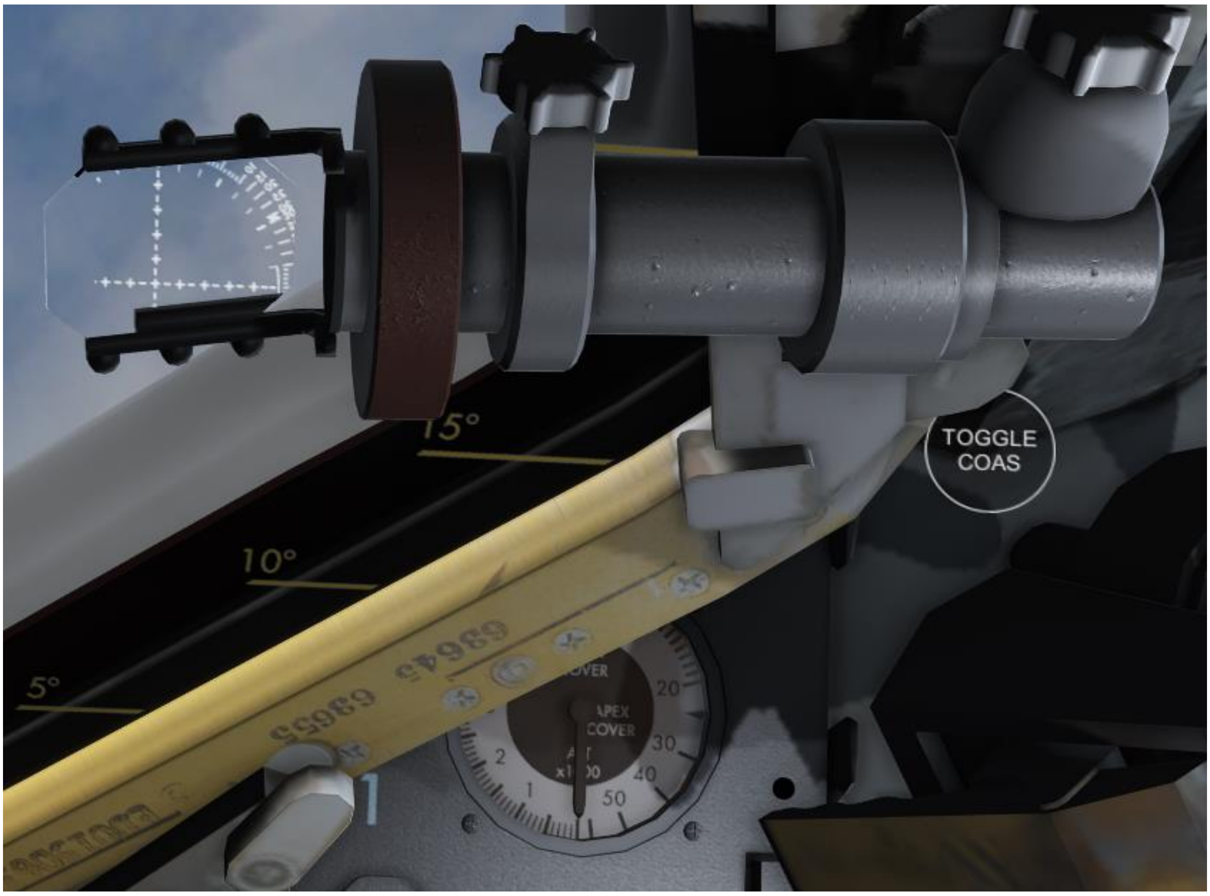
Hold/Resume countdown is used to hold or resume the countdown before a launch.

Switch to internal power is used to disconnect the rocket from the umbilical tower power source before ignition.

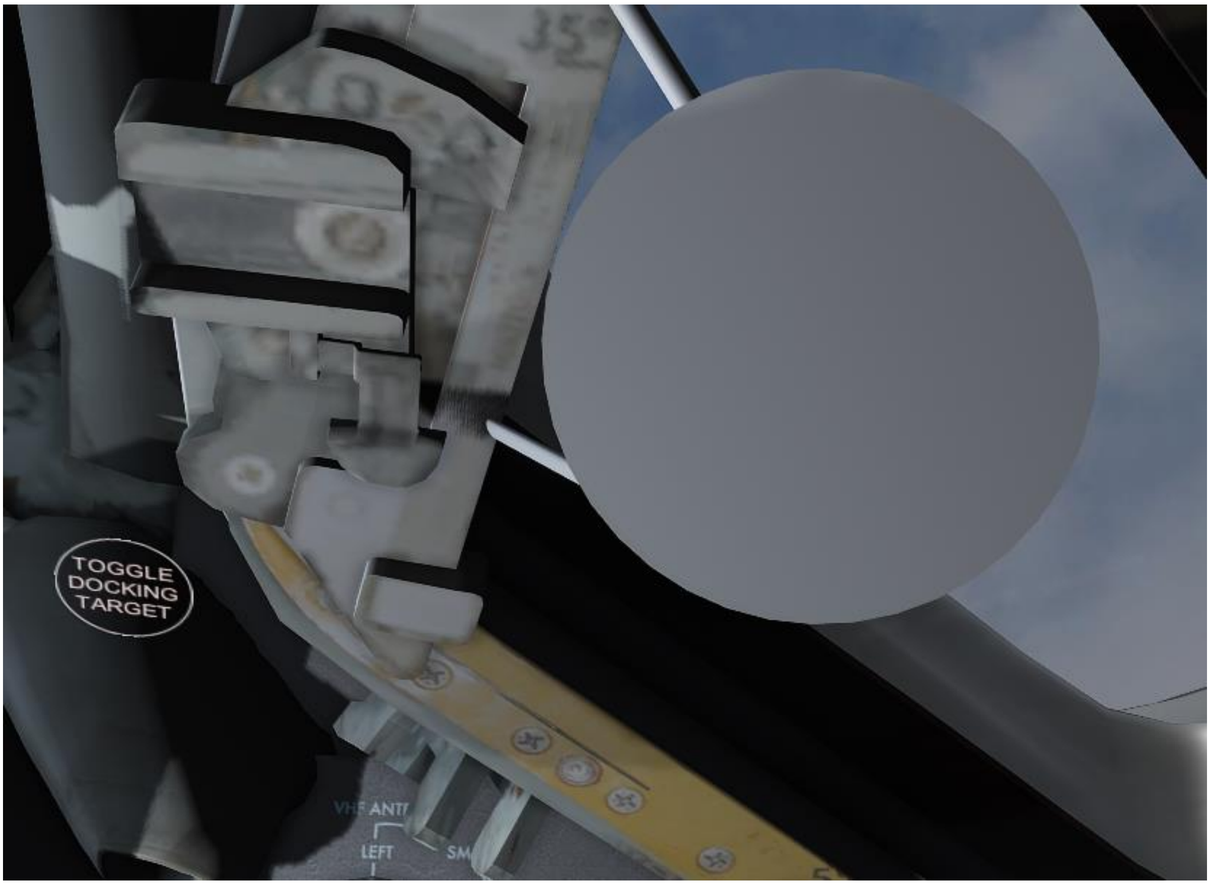
Toggle Hatch is used to open or close the main hatch of the Command Module, where the astronauts ingress pre-launch.

Toggle seats is used to adjust the seats for orbital configuration. When in orbit, the seats are stowed to allow more space in the cabin, and easier access to various switches. It is also normal to hide the seats during pre-launch procedures.

Toggle Jukebox will show or hide the onboard audio tape player/recorder, and is used to play music during the journey. Custom music can be added to the music directory in AppData\LocalLow\Wilhelmsen Studios\ReEntry\CustomMusic



Toggle COAS is use to set the COAS (optics) in the left window (F9) used during docking.



Toggle Docking Target is used to insert a docking target in the right windows of the Command Module, used if the Lunar Module will be the active docking vehicle with the Command Module. This can be used when the Lunar Module has ascended from the Lunar Surface and will dock with the Command Module again. Usually the Command Module will be the active vehicle during docking.

Open Hatch is used to open the tunnel hatch that allows entry into the Lunar Module (once it is docked).

CREW MEMBERS

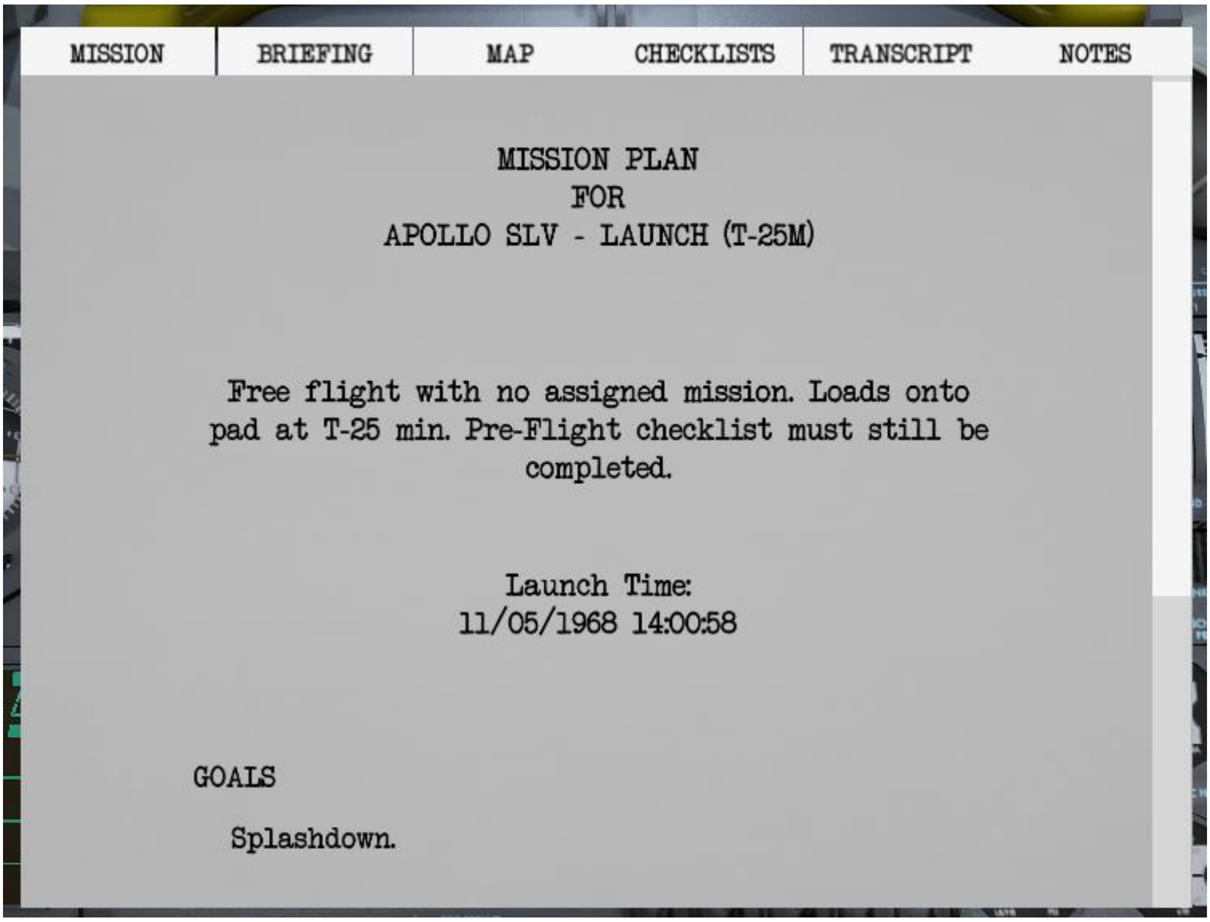
The Crew Members window can be used to change the name of the crew (override the mission specific names set in the Mission Definition/Mission Editor), and move them in/out of the CSM<->LM.

Other functions used during a mission (usually not very frequent except for the PADs) are also accessible in the window.

All the available PADs and their in-game forms can be requested and toggled from the REQUEST PADs tab, quite similar to the MISSION TOOLs menu in Project Gemini for Reentry.

MISSION PAD

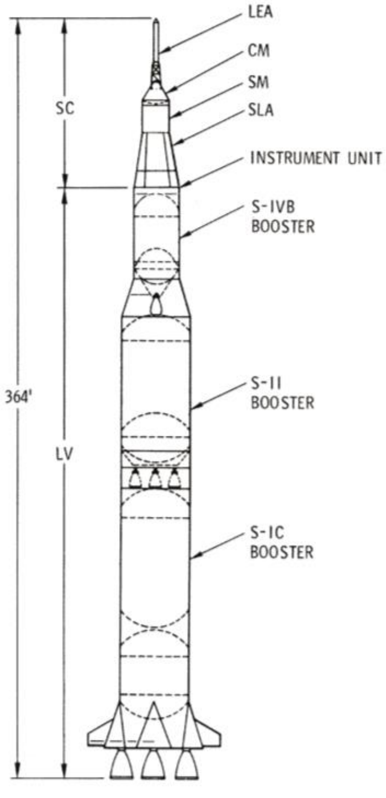
The Mission Pad is used to access data about the current mission, open a map of Earth, the Moon and the stars, access all the checklists for the Command Module and the Lunar Module, read the mission transcript and take notes.


MISSION
BRIEFING
MAP
CHECKLISTS
TRANSCRIPT
NOTES
MISSION PLAN
FOR
APOLLO SLV - LAUNCH (T-25M)
Free flight with no assigned mission. Loads onto pad at T-25 min. Pre-Flight checklist must still be completed.
Launch Time:
11/05/1968 14:00:58
GOALS
Splashdown.

II. MAJOR COMPONENTS

II. MAJOR COMPONENTS

The Apollo spacecraft is composed of three main parts. The first part is the Command Module. The Command Module is where the three astronauts operate the spacecraft. The Command Module is also the part of the spacecraft the reenters and lands back on Earth, the capsule.



The Service Module is attached to the Command Module during the entire mission, until it is jettisoned right before reentry. The SM contains many of the systems needed for a longer duration in space. It also has a bell-shaped engine named the Service Propulsion System, and is used to perform significant orbital maneuvers.

The last major part is the Lunar Module itself, used to land on the Moon.

The combined spacecraft is usually referred to as the CSM, the Command/Service Module.

The spacecraft is launched and inserted into an orbit on a Saturn V launch vehicle. It is a three-stage vehicle consisting of the "S-IC" as the first booster stage, then the "S-II" as the second booster stage, and lastly the "S-IVB" as the third stage.

An Instrumentation Unit (IU) contains a lot of equipment needed by the SLV, and contains the computer in the launch vehicle (LVDC) used during guidance, and SLA panels acting as the adapter between the launch vehicle and the spacecraft. When the spacecraft is separated from the S-IVB, the SLA panels are jettisoned. The Lunar Module is located inside this adapter and will be exposed when the SLA panels are gone.

A Launch Escape Assembly sits on top of the spacecraft, and is used during an abort in the early stages of the ascent.
The entire spacecraft can be seen in figure 2.0.1.

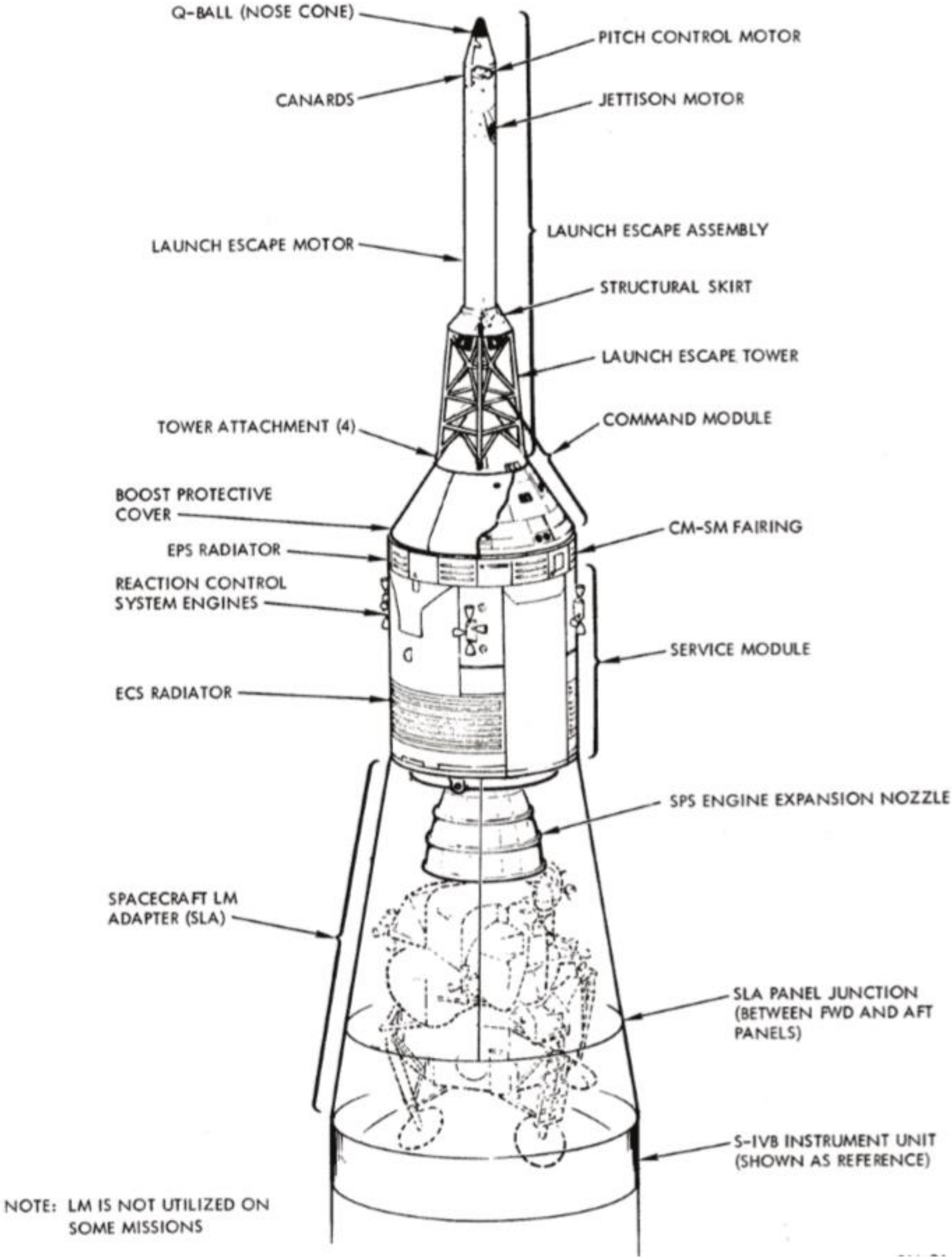


Figure 2.0.1 – The entire spacecraft

1. THE COMMAND MODULE

The Command Module is the control center of the spacecraft. It contains the equipment used to control and monitor the spacecraft, as well as the necessary safety equipment for the crew. It has a conical shape. It has three compartments, the forward compartment, the crew compartment, and the aft compartment.

Heat shields are protecting the command module during ascent and reentry.

The capsule can be seen in Figure 2.1.1

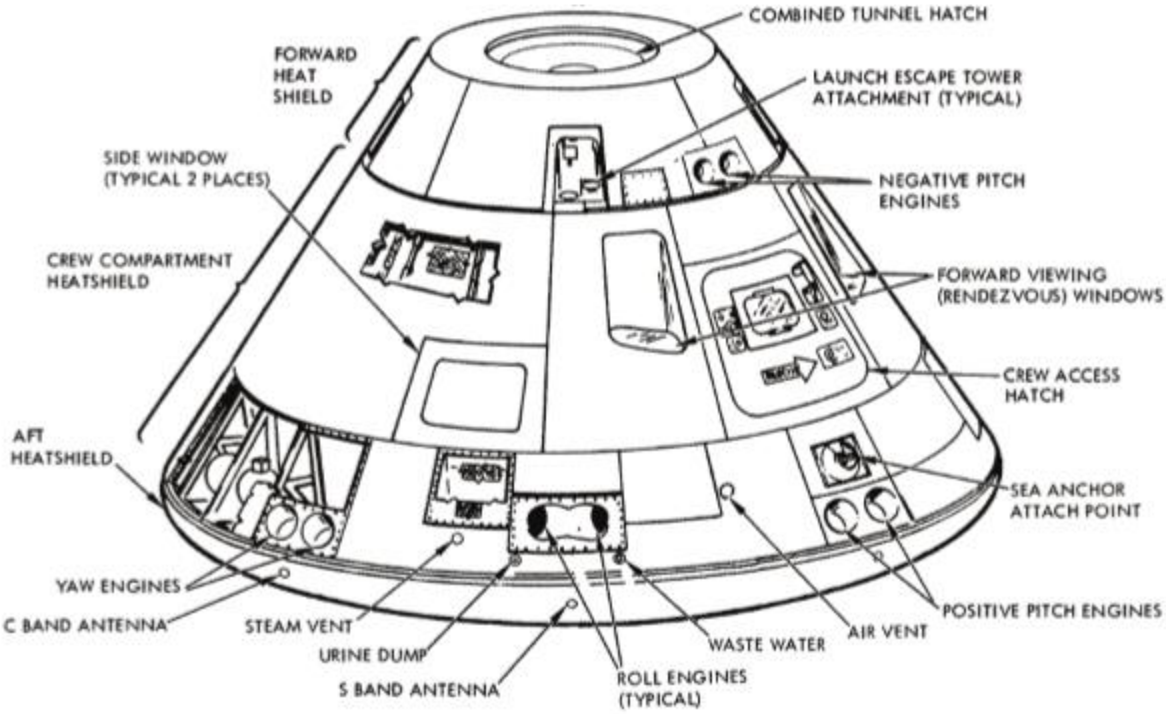


Figure 2.1.1 – The Command Module

The forward compartment is the top part of the capsule. It houses the recovery equipment used during landing (Earth Landing System), docking equipment and a tunnel for access to the Lunar Module. It also has two negative pitch reaction control system engines used to pitch the spacecraft. A heat shield protects it from heat and dust.

The Launch Escape Tower is attached on top of the forward compartment heat shield.

The aft compartment is in the bottom of the capsule, below the crew compartment, and above the aft heat shield. It has ten reaction control systems used for attitude control together with the negative pitch reaction controls on the forward compartment. It houses many of the important systems and substances needed during the last part of the flight.

The forward and aft compartments can be seen in figure 2.1.2.

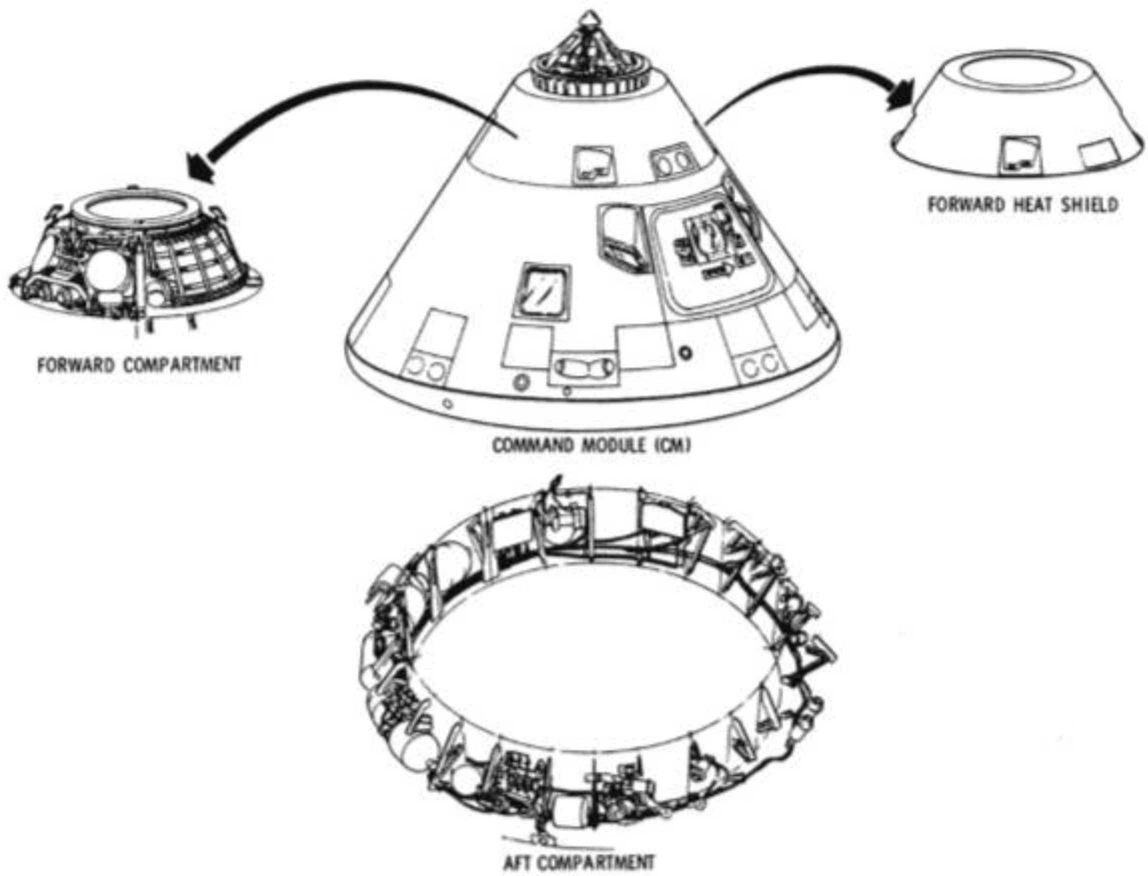


Figure 2.1.2 – The forward and aft compartment of the CM

The crew compartment is a sealed cabin. Its pressure is maintained by the Environmental Control System, and is where the astronauts are sitting. It has the control panels, crew couches, controls, and displays etc.

Five windows are installed to let the astronauts see outside the spacecraft, and for photography. Two forward viewing windows and two side observation windows, and a hatch window. The hatch is used for access. This is typically where you will be spending most of the time while flying an Apollo mission.

There are many control panels located in the crew compartment. All panels are numbered to be able to find and memorize where switches are. Figure 2.1.3 shows the panel numbering system.

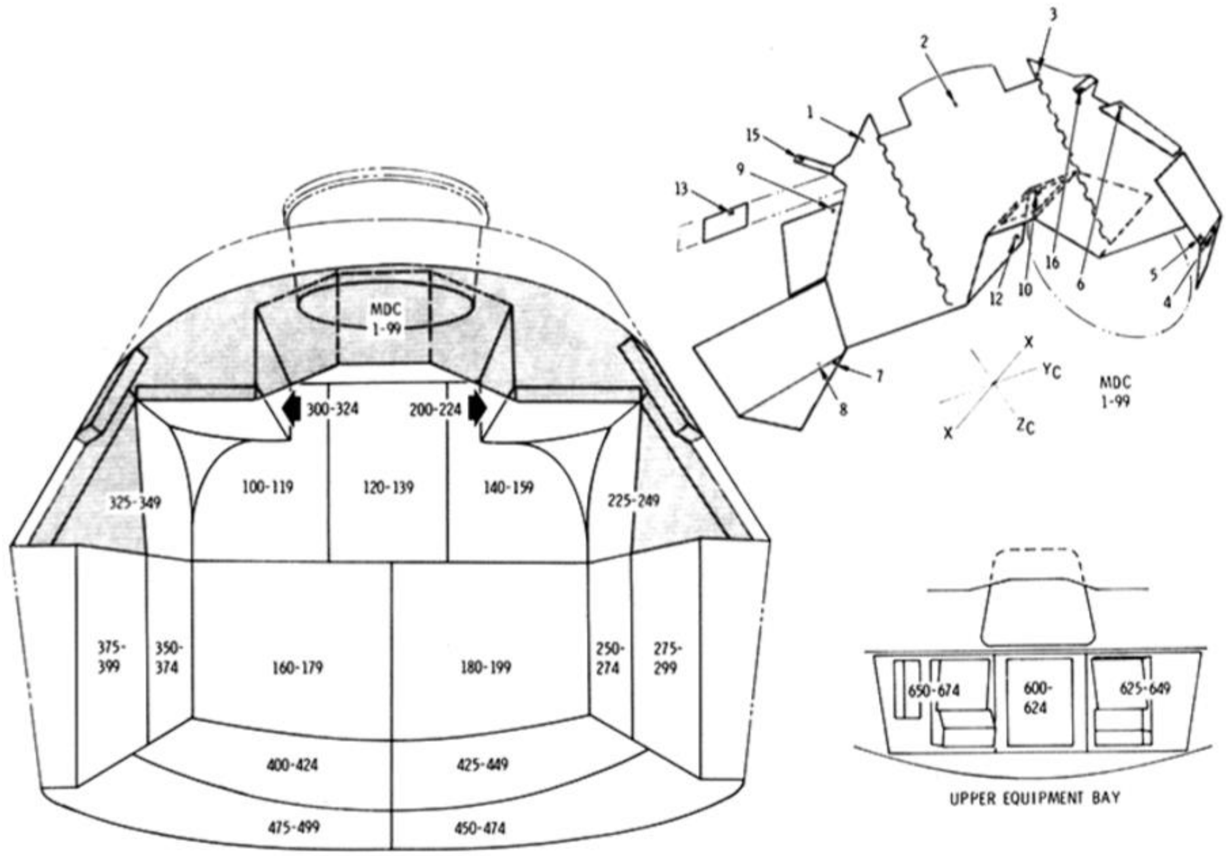


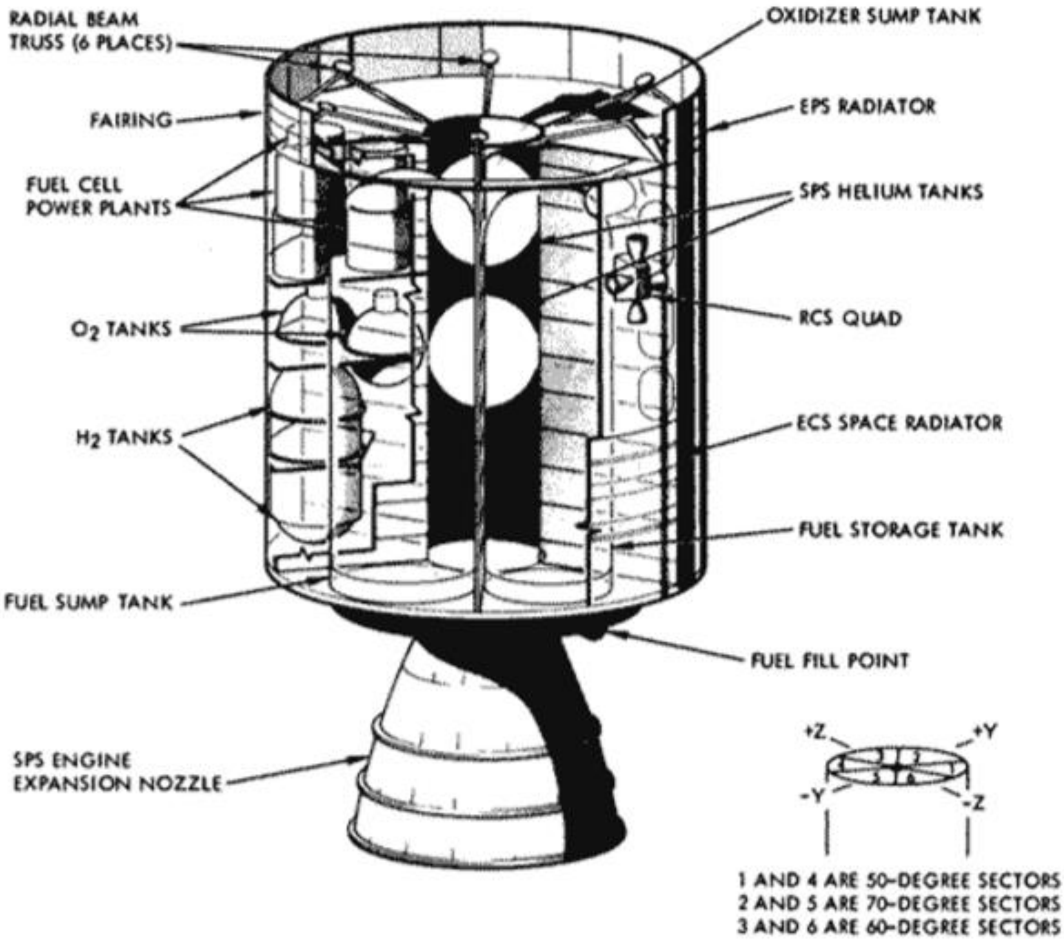
Figure 2.1.3 – The Panel Numbering System

Panel 1-99 is the main display console. The first digit of the XXX numberd display can be used to remember in what area the panels are. 100s are the lower equipment bay/"floor", 300s are on the left hand side wall, 200's are on the right hand side wall and 400's are on the aft wall. 600s are on the upper equipment bay, just above the astronauts' heads/behind the hatch.

2. THE SERVICE MODULE

The Service Module is attached to the aft compartment of the Command Module. It is a cylindrical structure that contains essential systems and equipment for survival in space, as well as general operations throughout the mission.

The systems and equipment in the Service Module can be seen in Figure 2.2.1.



SERVICE MODULE ITEMS

Sector I
Empty NASA equipment

Sector II
Environmental system space radiator
Service propulsion system
Reaction control system package (+Y-axis)
Service propulsion system oxidizer sump tank

Sector III
Service propulsion system
Reaction control system package (+Z-axis)
Environmental system space radiator
Service propulsion system oxidizer storage tank

Sector IV
Fuel cell power plant (three)
Helium servicing panel
Super-critical oxygen tank (two)
Super-critical hydrogen tank (two)
Reaction control system control unit
Electrical power system power control relay box
Service module jettison controller sequencer (two)

Sector V
Environmental control system space radiator
Service propulsion system fuel sump tank
Reaction control system package (-Y axis)

Sector VI
Environmental control system space radiator
Reaction control system package (-Z axis)
Service propulsion system fuel storage tank

Center Section
Service propulsion system helium tank (two)
Service propulsion system engine

Fairing
Electrical power system space radiator's (eight)

Figure 2.2.1 – Service Module Equipment

Please note that the primary oxygen and hydrogen tanks are stored in the SM, as well as the fuel cell power plant. Once you separate from the SM, these systems will not function in the

CM. The CM is designed for this, and contains their own life-support systems used during reentry.

It’s generally a good practice to reenter as soon as possible after the SM is jettisoned.

The Service Propulsion System (SPS) is also located in the SM, and the big nozzle in the end is part of the SPS. This can be configuring on the main CM panels, and is used to significantly alter the trajectory of the spacecraft (large delta-V burns).

The SM also has four identical Reaction Control System Quads used for attitude and translational maneuvers and small delta-V burns.

3. SPACECRAFT LM ADAPTER

The SLA is the large, truncated cone that connects the CSM with the S-IVB. The nozzle of the Service Propulsion System is inside this, above the Lunar Module. The separation of the S-IVB and the CSM is done manually through the CM panels.

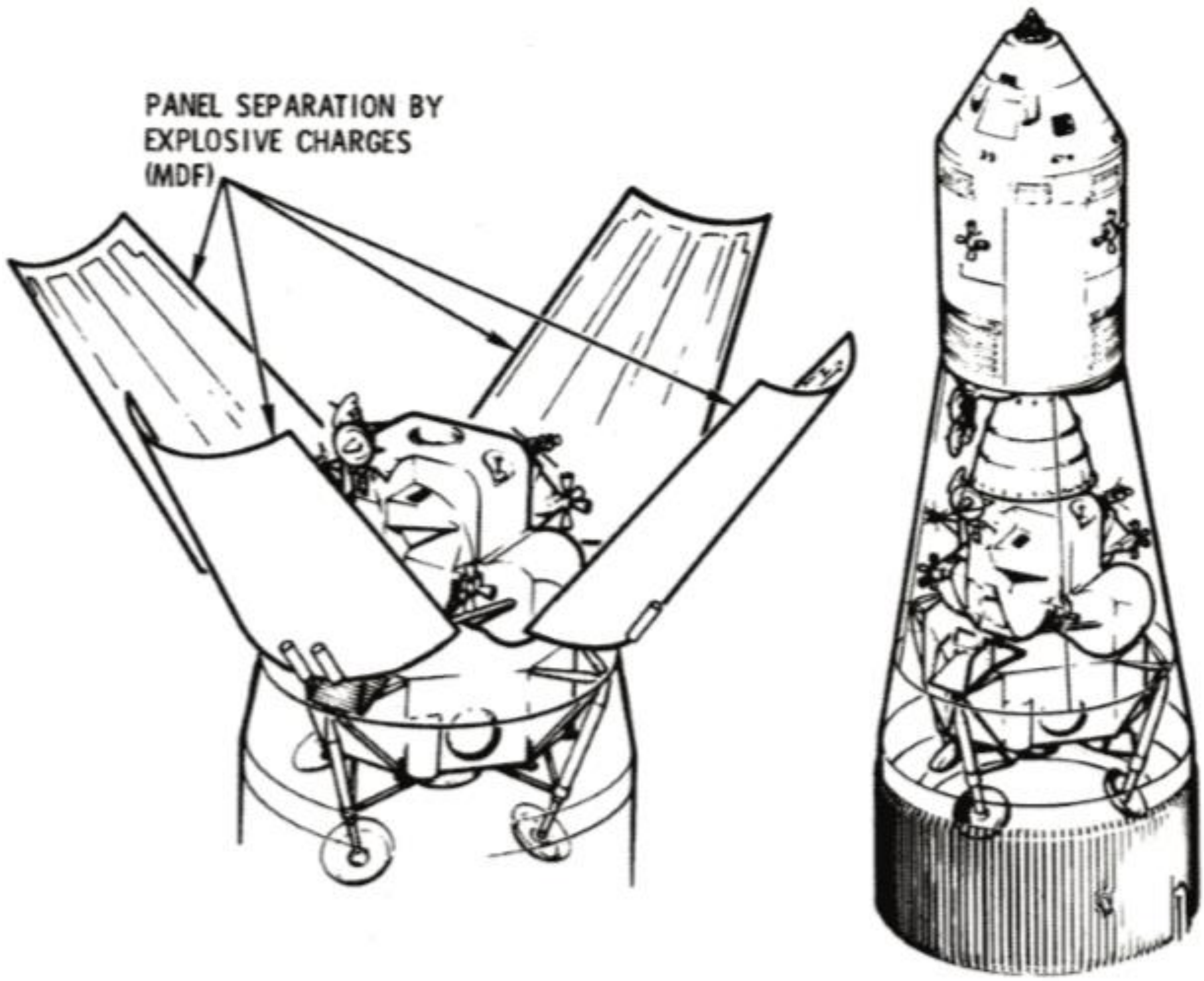


Figure 2.3.1 – The SLA

4. MAIN DISPLAY CONSOLE

The CM contains the main control panels and displays for spacecraft operation. There are hundreds of switches and controls, where most of them are located on the Command Module Main Display Console.

The main console will be your primary control surface, and allows you to control most of the systems internally. There are other switches located elsewhere in the cabin, due to their infrequent use. From the panels you control the switches, circuit breakers, selectors, displays, and instruments that configures internal systems.

There are so many switches so it can sometimes be hard to navigate them. It is a good practice to at least learn the panel numbers, so you know where they are. Then, you can use Figure 2.4.1 to learn where the switches for various categories are located.

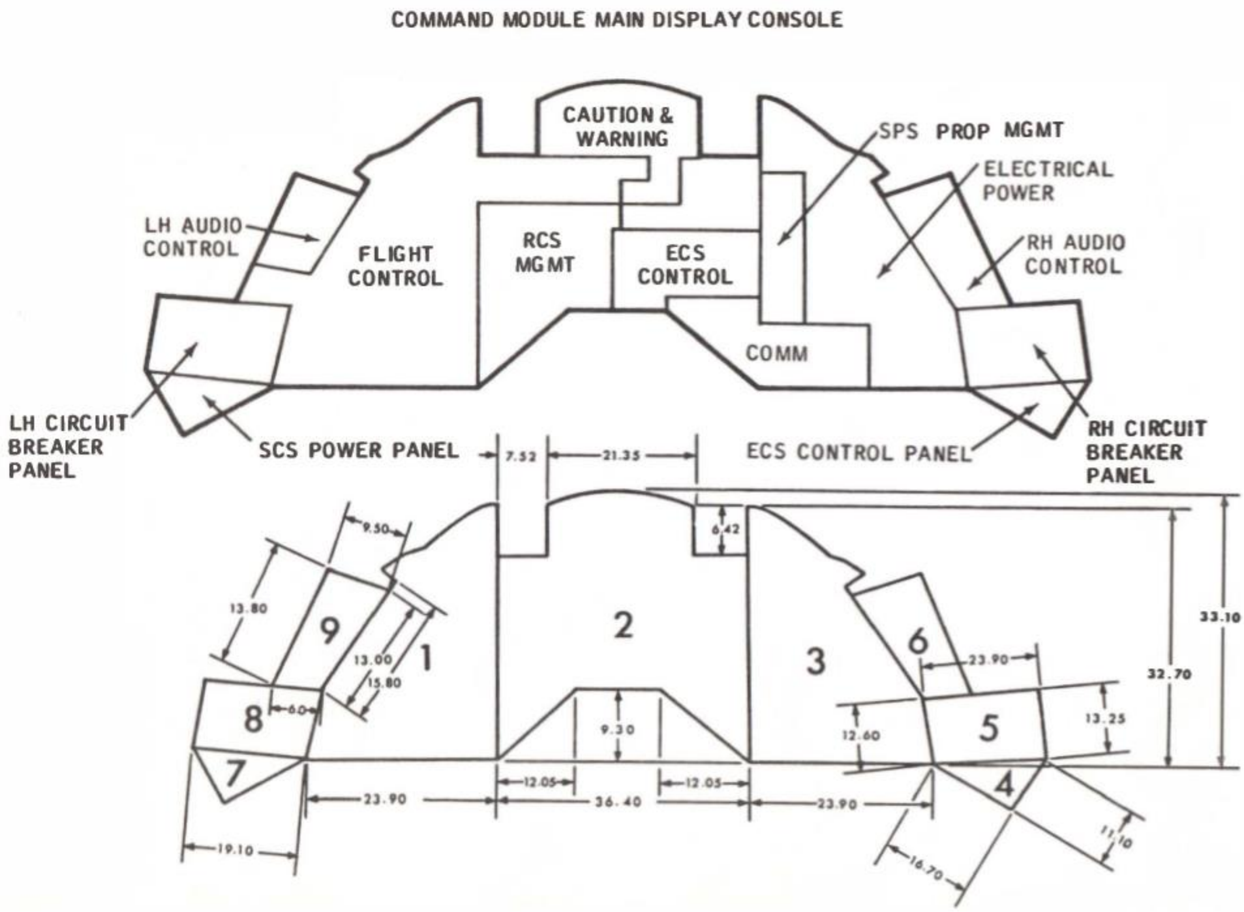


Figure 2.4.1 – The Command Module Main Display Console from CSM News Reference, NASA

The panels are arranged by different duties as seen in Figure 2.4.2.

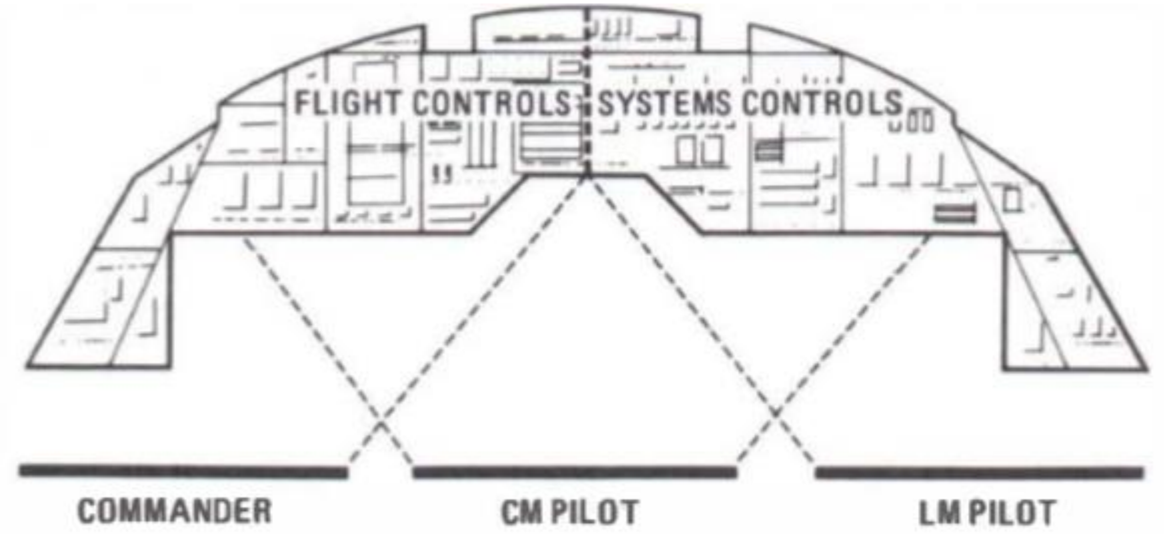


Figure 2.4.2 – Flight crew duties

Flight controls are located on the left-center and left side of the main display controls. The commander is responsible for the stabilization and control, propulsion, crew safety, earth lading and emergency detection.

The CM pilot is in the center, and can reach the flight controls as well as system controls. The reaction control propellant management, caution and warning system, the environmental control system and cryogenic storage are among the responsibilities.

The LM pilot has the responsibilities of the communications, electrical control, data storage, fuel cell system and the service propulsion system.

Any of the crew must know all the systems to take control if needed, and it is common to switch places/roles during a mission. Also, as you are the single player in the simulator, you are responsible to take the roles of all three astronauts.

III. THE SATURN V

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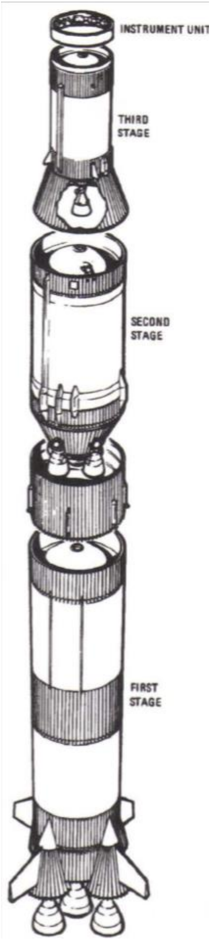


The Saturn V launch vehicle is the most complex, powerful and the biggest rocket compared to the previous U.S. launch vehicles. It has three stages and an instrument unit. It is 363.0 ft (110.6 m) high, including the spacecraft.

The Saturn V has three stages.

1) Stage 1: S-IC
2) Stage 2: S-II
3) Stage 3: S-IVB

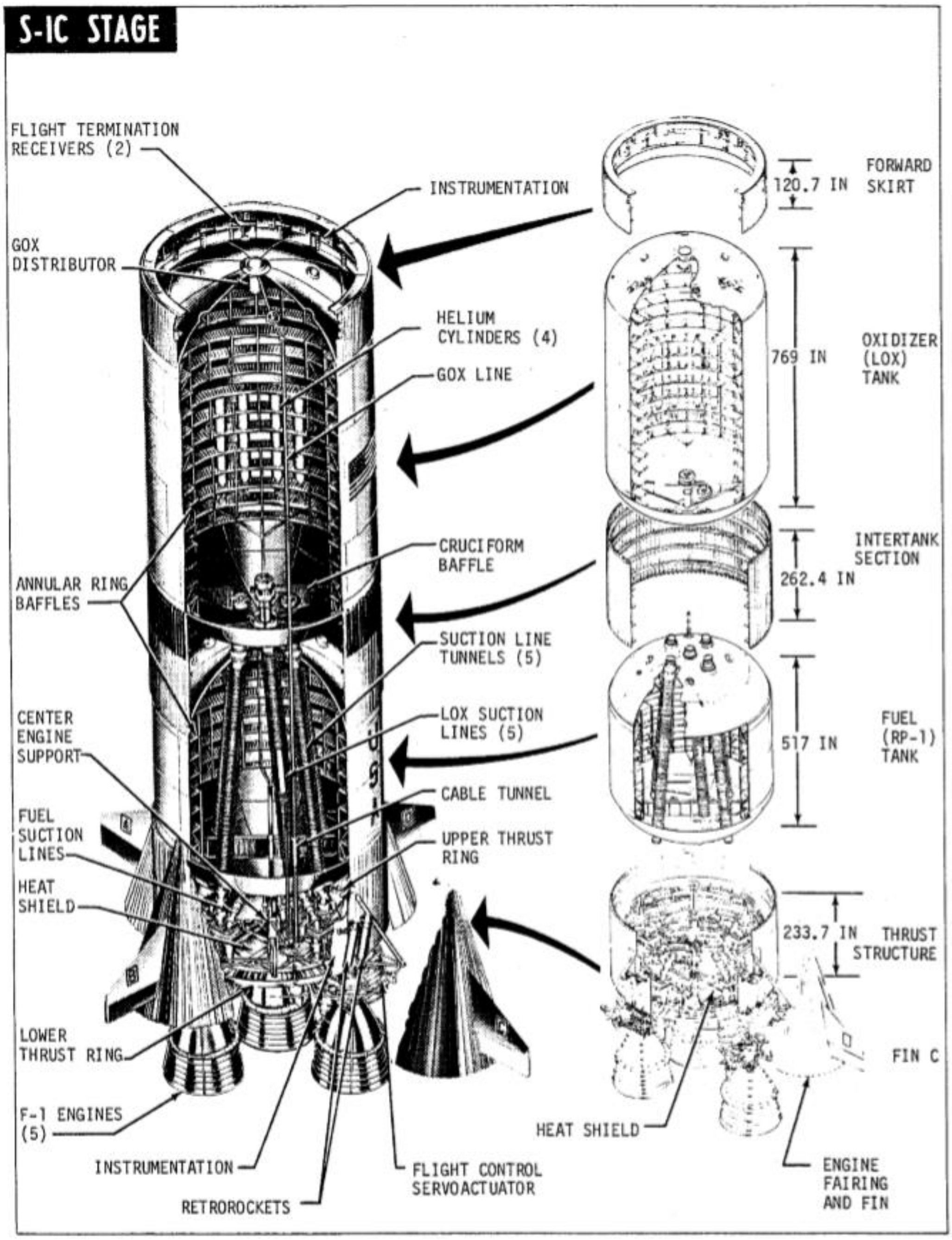
The first stage, S-IC, lifts the entire Saturn V stack, including the spacecraft, off the pad and to an altitude of 38 miles. It is designed to boost the spacecraft and the other stages off the ground and above the areas of maximum dynamic pressure, Max Q.

The second stage, S-II, takes over from the first stage and takes the rest of the stack into space. The third stage, the S-IVB, accelerates the spacecraft the last bit to orbit.

The S-IVB stays connected after cutoff, before being reignited for Trans-Lunar Injection. After the TLI-burn, it is separated from the spacecraft. At this point, the spacecraft extracts the Lunar Module from the S-IVB before heading towards the Moon. This is the last time the Saturn V is part of the Lunar mission profile.

1. S-IC STAGE

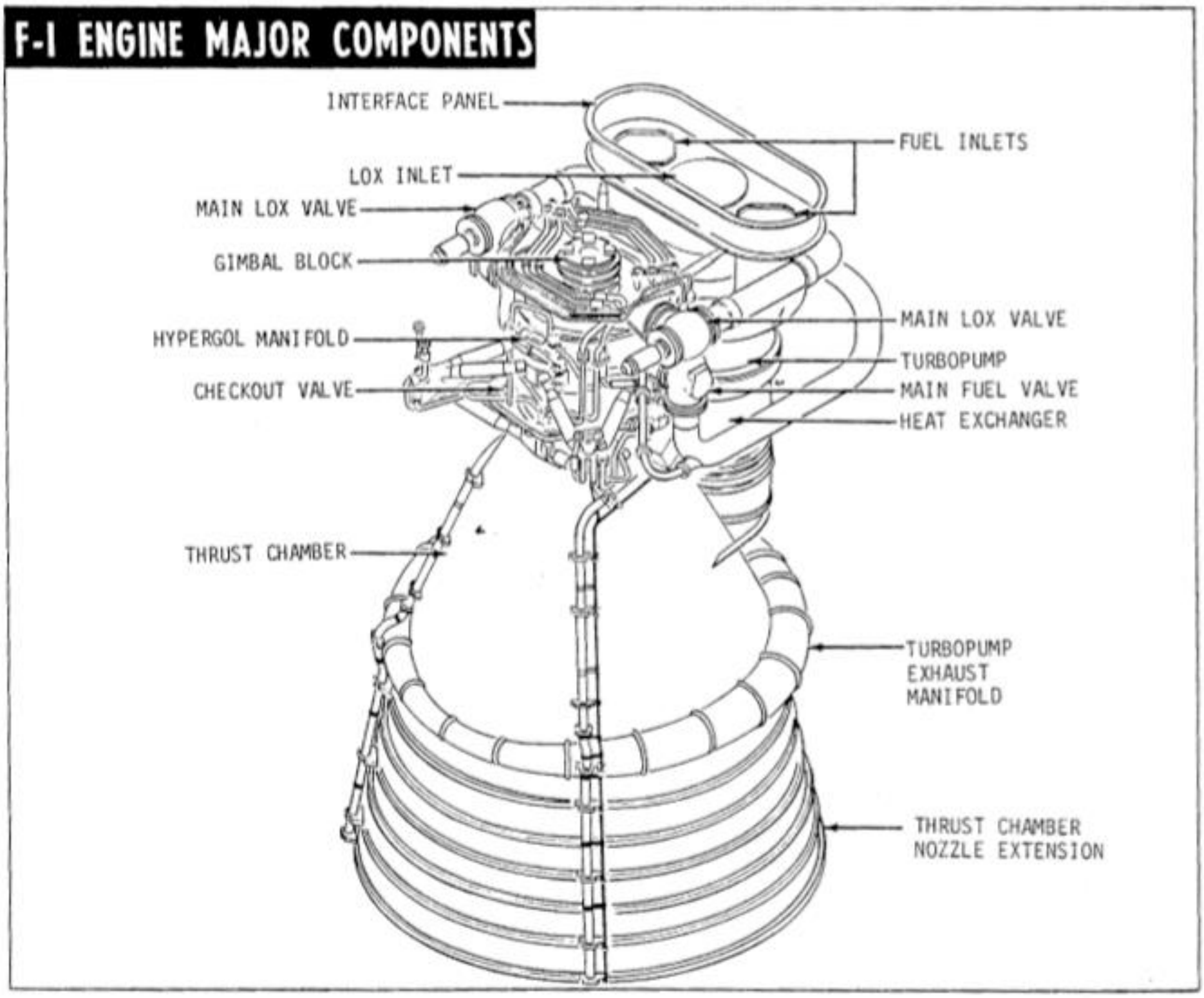
The S-IC stage is the first stage of the Saturn V. It is 138 feet long and is powered by five F-1 rocket engines. It used liquid oxygen as the oxidizer and RP-1 as the fuel. The five engines are grouped so four outboard F-1 engines surrounds a middle center F-1 engine. The four outboard engines can be gimballed for ascent attitude control and the center F-1 engine is fixed. The center engine is shut down earlier than the other engines.



After separation, it falls back to Earth and lands in the ocean.

The major components of the S-IC stage are the five Rocketdyne F-1 engines, a 345.000-gallon lox tank, and a 216.000-gallon fuel tank.

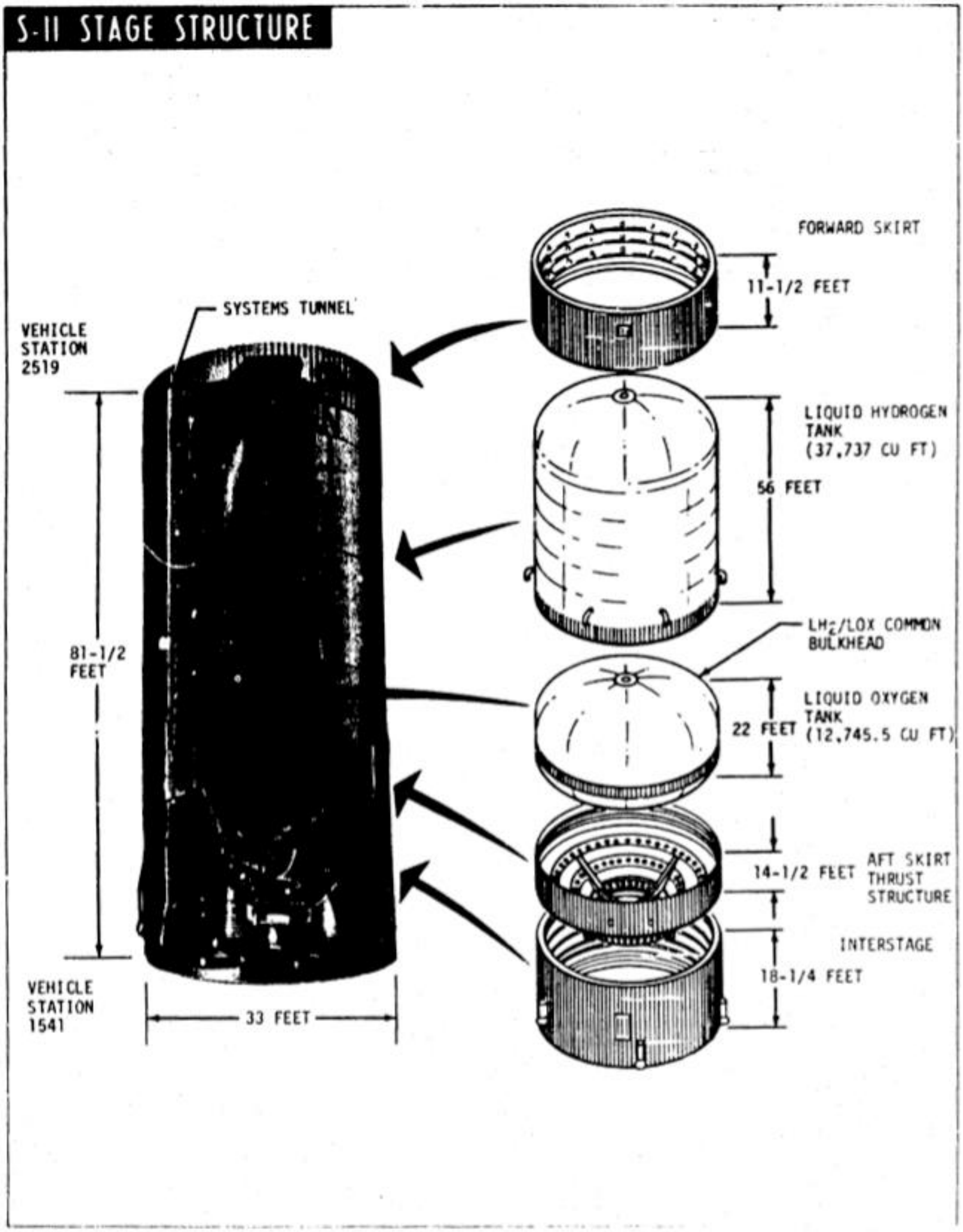
The engines have a burning time of 150 second and are producing 7,500,000 LB of total thrust.



After staging, a set of retrorockets are mounted in pairs in the fairings of the F-1 engines. These retrorockets provide separation thrust after S-IC burnout.

2. S-II STAGE

The S-II stage is the second stage of the Saturn V. It is 81.5 feet long and is powered by five liquid propellant J-2 rocket engines. They produce a total nominal vacuum thrust of 1.150.000 pounds of thrust. Again, the outboard engines are gimballed, and the center is fixed. The center engine will cut off earlier than the outboard engines due to oscillations.

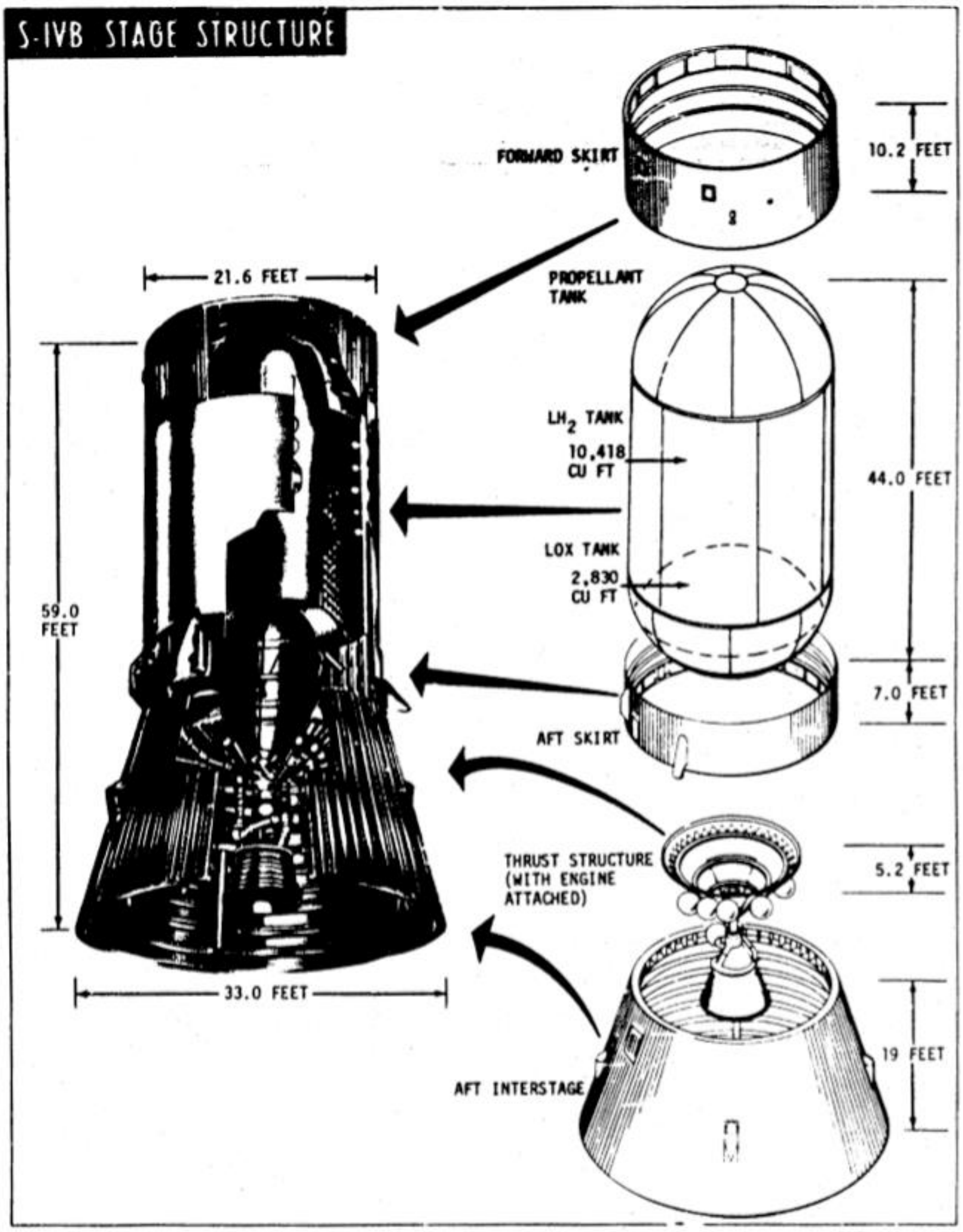


The five single start J-2 engines uses liquid oxygen and liquid hydrogen for propellants.

The S-II stage separate and retard from the launch vehicle after separation using retrograde rockets.

3. S-IVB STAGE

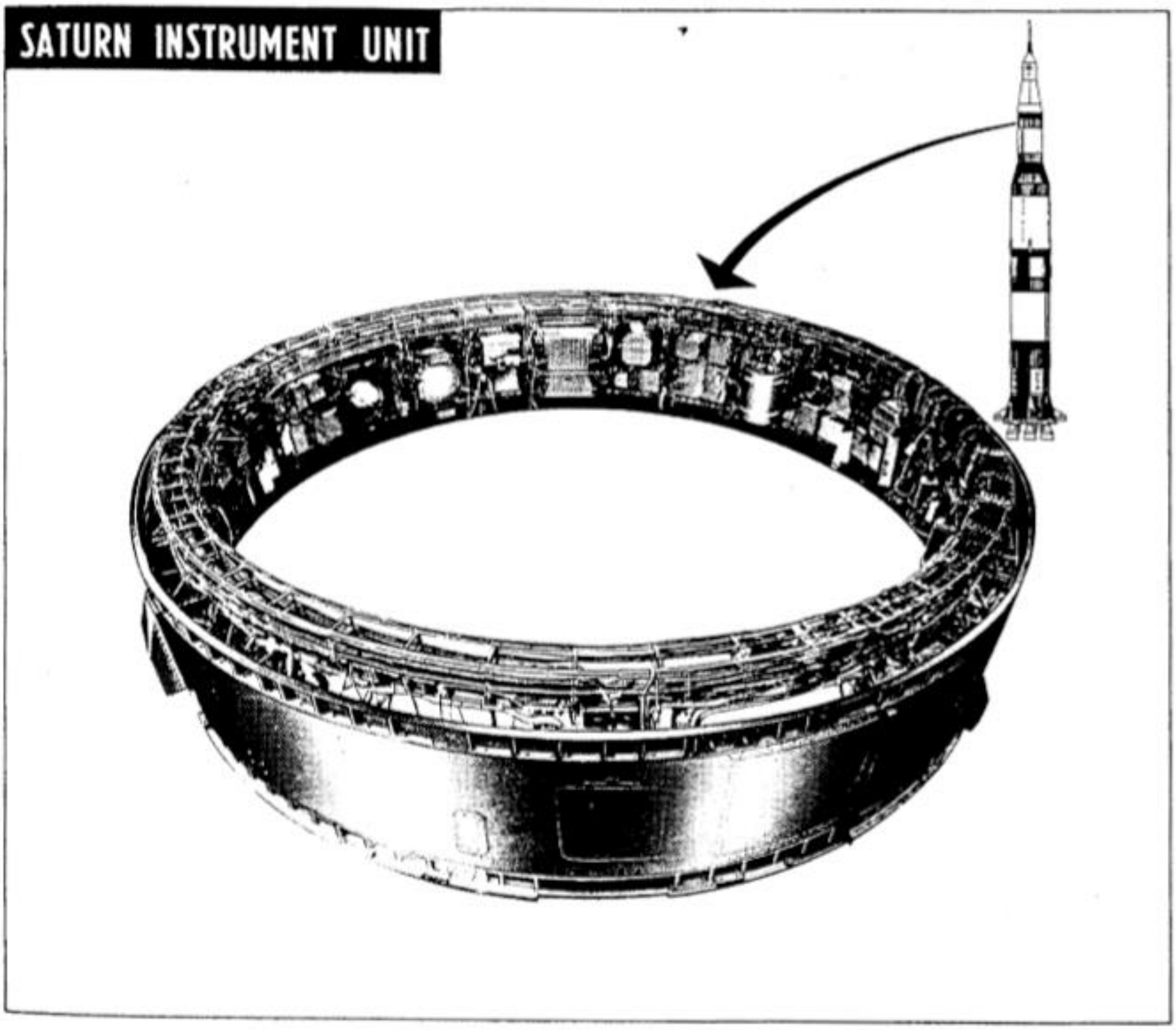
The S-IVB stage is the third stage of the Saturn V launch vehicle. It has one single J-2 engine designed to do two things, boost the spacecraft into orbit, and do the TLI burn.



Prior to the second burn, the systems are readied for another engine start. It needs about 10 minutes of preparation time before being able to perform the second engine ignition.

4. INSTRUMENTATION UNIT

The Instrumentation Unit is a ring mounted on top of the S-IVB stage, just before the SLA. It contains the guidance, navigation, and control equipment which will guide the vehicle from the launchpad and into the mission trajectory.



The Launch Vehicle Digital Computer and the Launch Vehicle Data Adapter is a digital computer system that operates many of the major components of the launch vehicle. They are located in the IU.

IV. GUIDANCE & CONTROL

IV. GUIDANCE & CONTROL

1. GENERAL

The command module has two guidance and control modes, where both systems provides attitude reference, attitude control and thrust control.

The first and primary mode is the Primary Guidance, Navigation, and Control System (PGNCS), and the secondary is the Stabilization and Control System (SCS).

Both systems contains functions to execute attitude and translational control using the reaction control systems (RCS).

Major velocity changes are done through the service propulsion system.

Using the main display panels, you can configure the spacecraft to use the PGNCS or the SCS, or a mix between the two guidance and control modes.

The PGNCS is mostly controlled by the command module computer, as well as the attitude and translation sticks. The SCS is mostly controlled by configuring the panels and the different SCS systems. In this chapter, we will look at how both these systems work. At the end of the chapter, you should have a good understanding of these systems, how they work and how to operate them. As mentioned, the PGNCS is mostly controlled through the computer, so the Apollo Guidance Computer chapter will teach you how to use the PGNCS to navigate and control the spacecraft.

1.1 ATTITUDE REFERENCE

A spacecraft flying in space does not have a direct way of saying what direction is up, left or right. However, to be able to tell the direction the spacecraft is heading, it is important to establish a reference system to define these directions.

The Guidane & Control systems has a reference function that provides a display of the spacecraft attitude with reference to an established inertial reference. The established attitude can be seen through two Flight Director Attitude Indicators (FDAIs) located on the main display panels. One is located on panel 1, and the other on panel 2.

The FDAIs show the total attitude of the spacecraft relative to a reference platform. This reference platform can be Earth with the local horizon, or a set platform either by a preconfigured platform or a manually set platform.

The FDAIs can also point you in a direction using attitude errors, and a set of needles that will guide you towards the given direction, and angular rates (how fast are you rotating in any of the body axes).

The spacecraft has two ways to derive the total attitude relative to the set platform. The primary way is to use the IMU (Inertial Measurement Unit), and the secondary is to use the

GDC (Gyro Display Coupler). The IMU is basing the attitude on a gimbaled, gyro-stabilized platform and the GDC is based on an attitude based on the angular rate input from the gyro assemblies. Typically, FDAI 1 (MDC-1) will show the attitude relative to the IMU platform, while FDAI 2 (MDC-2) will show the attitude relative to the GDC platform.

The two platforms are usually aligned with eachother so that the GDC can take over from the IMU in the event of failures.

The Command Module Computer (CMC) and the FDAIs receive the total attitude to navigate in space from the IMU.

Errors are derived from comparing a set direction with the total attitude, and rates are derived from either gyro assembly 1 or 2. Gyro assembly 2 is the primary, but 1 can be used as a backup.

1.2 ATTITUDE CONTROL

Attitude control is used to maintain or drive the spacecraft to a set orientation. This can be done automatically, or manually – both using the attitude error described in IV.1.1.

The error signals can be routed to the Control Reaction Jet On-Off Assembly that condition the signals and send them to the correct reaction control system. These will fire the correct thrusters in the direction required to rotate the spacecraft to reach the desired direction.

The digital autopilot (DAP) is used to configure how fast will you get to a set attitude, and how precise it will maintain an attitude. The CMC is used to automatic control, and the rotational control is used for manual control.

1.3 THRUST AND THRUST VECTOR CONTROL

Major velocity changes are done through the SPS (Service Propulsion System) either through the Command Module Computer, or the Entry Monitoring System (EMS). The EMS can be used at any point during the mission, not only during reentry. Both systems provides an off-signal for the engine to cut off.

In addition to this, it is possible to manually control the on/off signal for the SPS directly.

As the SPS is using fuel, the center of gravity will shift slightly. The SPS engine can be gimbaled to account for this. The SPS trim settings can be used to gimbal the SPS engine to account for this (not yet simulated).

2. PRIMARY GUIDANCE, NAVIGATION & CONTROL SYSTEM

The PGNCS is the primary control system of the command and service module. Three subsystems are used by the PGNCS:

1) Inertial subsystem (ISS)
2) Computer subsystem (CSS)
3) Optics subsystem (OSS)

These three systems work together, but also function independently, to measure the spacecrafts attitude and velocity, controls the thrust vector of the Service Propulsion Engine, provides abort information and display data.

The PGNCS can provide automatic control over many of the systems in the spacecraft via the Command Module Computer (CMC). The CMC is part of the CSS.

The guidance and navigation system needs alternating current (AC) power, and can receive power from both AC bus 1 and AC bus 2 on MDC-5.

The PGNCS subsystems also require direct current (DC) power, and can receive power form the Main DC busses.

It is normal to have both the MNA and MNB circuit breakers closed in case one of them goes down. These circuit breakers give DC power to the ISS, CSS and the OSS.

The Electrical Power System chapter describes the electrical circuits onboard in detail.

A set of Coupling Data Units (CDUs) allow the ISS and the OSS to interface with the computer. It is basically signal converters that converts signals from analogue to digital and vice versa.

The PGNCS is initiated and aligned during the prelaunch phase. During ascent and flight, it will continually track changes to acceleration and velocity to understand where the spacecraft is located and headed.

The reference platform stored in the IMUs will drift due to mechanical errors and must be aligned at times. This is done through the Optics Subsystem using the Computer.

2.2 INERTIAL SUBSYSTEM

The Inertial Measurement Unit (IMU) provides an inertial reference with a gimbaled, three-degree-of-freedom, gyro-stabilized stable platform. This basically means it knows the attitude of the spacecraft relative to a given platform reference. Three CDUs are used to convert signals.

The IMU can measure the angle differences with the current attitude and the desired angles of the CMC. If automatic attitude mode is selected, the CMC will use the Reaction Control System to drive the spacecraft to the desired attitude.

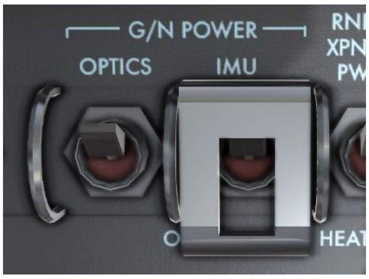
REFSMMAT

The platform reference is based on different fixed points against the stars. These points are referred to as REFSMMAT – REFerence to a Stable Member MATrix. It is a numerical definition of a fixed orientation in space and is usually (but not always) defined with respect to the stars. There are many REFSMMATs to choose between during the mission. This is selected using the computer, or provided by mission control.

It is important to understand REFSMMATs. During pre-launch, the reference platform is set to the location of the tower and the rocket direction on the pad (up). During Lunar Landing, the platform of the Lunar Module is set to the landing location, and during entry, the platform is set to the Entry Interface to make it easier to navigate through the atmosphere.

The different references are used to make various operations easier. For example, if the spacecraft needs to perform a burn in a given direction, the direction of the burn is used to align the platfom with the burn direction, so the pilot can easily see on the FDAI if the spacecraft is pointing in the right direction as the eye of the burn direction on the FDAI would be on pitch=0 and yaw=0.

POWER



The ISS power is selected using the circuit breakers on MDC-5 and the IMU is turned on during the prelaunch phase using the guarded switch on LEB-100, a panel located down by the feets of the commander.

This is usually done when you enter the cockpit, but from a cold and dark start, the IMU needs to be powered and activated. It will spend 90 seconds on spinning up the IMU before being functional. Then the computer is used to align the IMU with the launch REFSMMAT using Program 01. During IMU spinup, the NO ATT light on the CMC panel illuminates.

ALIGNMENT

IMU CAGE MODE

If the IMU is reactivated during flight, it must be realigned with the stars. The IMU CAGE switch on MDC-1 will lock the three axes at 0 degrees. Uncaging will release the gyros, and a new orientation is set.
The REFSMMAT will decide the orientation, while the optics will remove drifting errors that accumulates over time. The IMU Cage is usually only needed after a shutdown or malfunction.

Heaters maintains the temperature of the IMU and the ISS through blowing air, radiation and coolant.

2.3 COMPUTER SUBSYSTEM

The Computer Subsystem is the Command Module Computer, usually named the Apollo Guidance Computer (AGC) with two display and keyboard panels (DSKYs). One of the DSKYs is on the main panel and the other is next to the optics panel in the lower equipment bay. It is used to process and control information from the IMU and the Optics Subsystem, and can run programs and store data. The computer is one of your main tools for navigation and control of the spacecraft.

The DSKY consists of warning lights, a keyboard and a display.

The computer is a highly sophisticated general purpose computer. It allows automatic execution of computer programs, controls the ISS and OSS either automatically or manually through the DSKYs. It allows the crew to enter data, display data and to execute programs.

The computer is your primary guidance tool and provides you with an RCS Digital AutoPilot (DAP). It uses the Reaction Control System (RCS) to provide rotational control.

DIGITAL AUTOPILOT

The digital autopilot can assume control through configuration on the Main Display Panel 1 (MDC-1).

The SC CONT switch is the Spacecraft Control switch (MDC-1) and allows either the Command Module Computer or the Stabilization and Control System to control the spacecraft. The CMC is the primary mode, and the SCS is the backup/secondary mode.

To enable the DAP, this switch needs to be in CMC, meaning the computer will have control over the spacecraft.

The CMC MODE switch controls the DAP modes. It has three positions.

AUTO: Automatic mode lets the computer define a target to be maneuvered to. This can be a burn direction, prograde direction, retrograde direction and so on. The crew can insert the desired attitude (roll, pitch, yaw) and request the computer to manuever to and maintain this position. This procedure is explained later.

HOLD: This will hold the current orientation. Any manual attitude changes used with the stick will update the HOLD attitude to the new one. This is good if you want to maintain a given orientation in space. When the stick is released, the spacecraft will stop in the new orientation.

FREE: You control the attitude using the stick, and they are treated as acceleration commands, and the spacecraft will drift freely.

DAP PARAMETERS

The computer contains a set of parameters used by the DAP to orient the spacecraft. These parameters contains the maximum rate the craft will reach to orient itself towards a set attitude, and how precise it will hold that attitude. The DAP can for example be configured so the maximum rotation rate is 0.2 degrees/second, and that it should try to maintain the attitude with a precision of 5 degrees.

You will learn how to interact with the computer in the computer chapter, and the specifics of setting the DAP.

To set up the DAP, Key V48E to start the DAP routine.

AUTOMANEUVERING

The CMC can command the spacecraft to maneuver to a specific attitude. The crew will use a special routine in the AGC to request the automaneuer. The computer will ask the crew to input the roll, pitch and yaw and the command to execute the maneuver.

Key V49E on the DSKY to start the automaneuvering routine.

OPERATION

The computer is operated through the DSKYs. The Computer chapter will go through the details needed to use the computer.

POWER

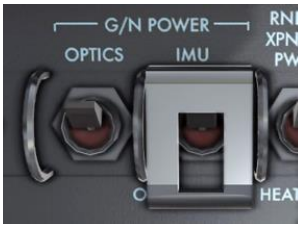
The computer draws power from either the MNA or MNB DC bus using the fuses on MDC-5.

2.4 OPTICS SUBSYSTEM

The Optics Subsystem is the eyes of the spacecraft. It is composed of a scanning telescope (SCT), a sextant (SXT), and controls to configure and drive these. The primary function of the optics subsystem is to determine the spacecraft position and attitude with relation to starts and/or landmarks.

The navigator will use the SCT or the SXT to mark two or more star sightings/landmarks. The CMC will use these marks using old navigational technology to update its position in space.

The Scanning Telescope is slaved to the Sextant so they point in the same direction. The Scanning Telescope has a 60 degree field of view and has 1x magnification, while the Sextant has 1.8 degrees field of view with a 28x magnification. The crew uses the scanning telescope to get a broader view of the environment/starfield while the sextant is to look at the precise center of where of the view the mark will be placed. The star/landmark is places in the center view of the sextant for the mark.

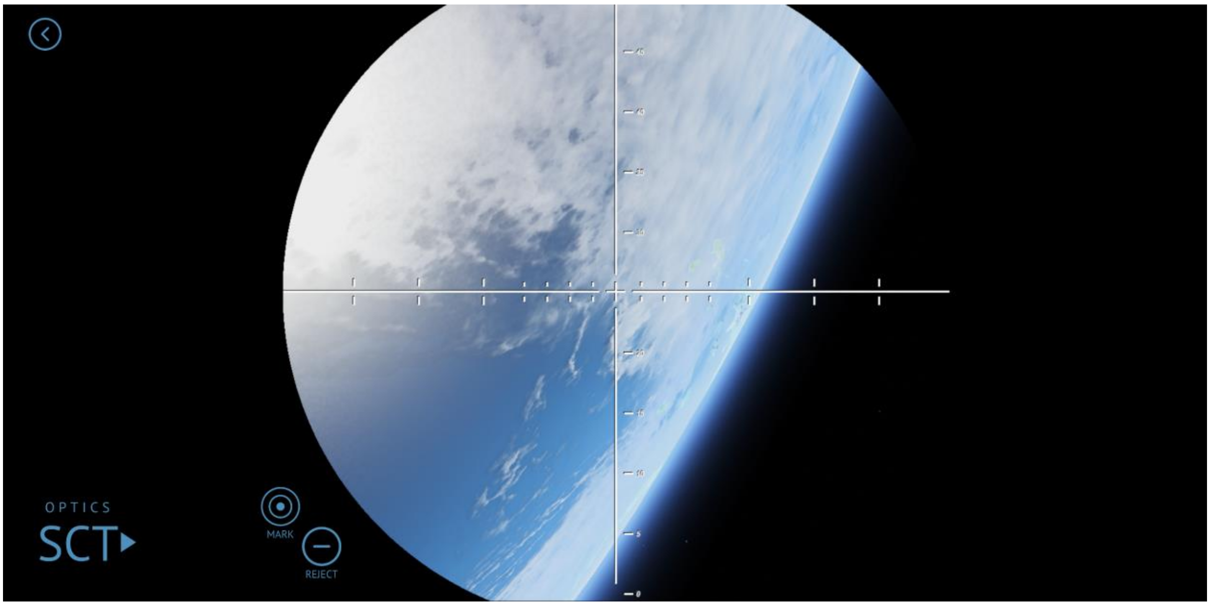


The optics switch on LEB-100 activates the Optics Subsystem while the dedicated optics panel, LEB-121 and LEB-122 control the system itself.

OPERATION

The two scopes can be accessed from the lower equipment bay (LEB).

By left-clicking a scope, the astronaut will look through the scope.



The scope user interface has a button to quickly switch between the two scopes using the small triangle next to the scope name (SCT in the image above). Two buttons are available, MARK and EJECT. These will be covered in the optics chapter.

The scope can be moved using CTRL+ARROW KEYS.

The panel below the scopes is used to configure the OSS.

POWER

Power is drawn from either the MNA and/or the MNB DC bus based on the circuit breakers on MDC-5.

2.5 MODES OF OPERATION

This section will cover different special modes of operation.

S-IVB TAKEOVER

During the boost phase, the IU and the LVDC assumes control of the rocket and guidance. The CMC can take over this guidance in the event of a failure. This is done by placing the LAUNCH VEHICLE GUIDANCE switch to CMC. This will enable the DAP as the guidance control.

When the CMC is in control, manual mode is also possible. By configuring the DAP with an extended verb, it is possible to manually fly the Saturn V into orbit.

During ascent, Key V46E on the computer for manual control.

3. STABILIZATION & CONTROL SYSTEM

The Stabilization and Control System (SCS) is the secondary control system of the spacecraft. It contains a set of backup electronics and systems for the Primary Gaudance and Control system. It is fully customizable and it is possible to mix the two systems to maneuver the spacecraft. It is therefore very important to understand the SCS and know how to operate it.

The SCS provides the capability for controlling rotation, translation, SPS thrust vector, and displays necessary for man-in-the-loop control functions.

It has three basic subsystems: attitude reference, attitude control, and thrust vector control.

The following hardware is available to interface with the SCS:

- Rotational Hand Controllers (RHC), 2 units
- Translation Hand Controller (THC)
- Attitude Set Control Panel (ASCP)
- Gimbal positin and fuel pressure indicator (GP/FPI)
- Flight Director Attitude Indicator (FDAI) – 2 assemblies
- Gyro Display Coupler (GDC)
- Gyro Assemblies (GA)

3.1 GYRO DISPLAY COUPLER

The Gyro Display Coupler (GDC) is the backup platform for the IMU and is using rate data from a couple of Body Mounted Attitude Gyros (BMAGs). This rate data is used to rotate the platform based on how the spacecraft rotates and is referred to as the GDC's Euler mode.

The GDC can be used as a backup reference system to the PGNCS/CMC by setting the CMC ATT switch from IMU to GDC. This is normally only done if the IMU should fail.

BODY MOUNTED ATTITUDE GYROS (BMAG)

There are two BMAG assemblies with three BMAGs in each of them, GA-1 and GA-2. They detect the rates of the spacecraft in all three axes, and sends it to the GDC. The GDC adds these rates to its known attitude, updating the known orientation. Both gyro assemblies are typically caged and determine only the spacecraft's rate. The rate is then sent to the GDC. The three BMAG switches on MDC-1 determine which set of gyros the GDC receives rate data from. Setting a switch to either Rate 1 or Rate 2 determines which BMAG the GDC receives rate from in that axis. BMAG one is capable of being uncaged to determine attitude errors. The center setting of the BMAG switches, Att 1/Rate 2, tells the GDC to accept rate data from BMAG 2 and attitude data from BMAG 1. In order to do this, BMAG 1 must be uncaged by the Electrical Control Assembly (ECA). This is done automatically when setting a BMAG switch to the center position.

The GDC can be aligned to the IMU using the GDC Align pushbutton on MDC-1 along with the GDC ALIGNMENT TO IMU GIMBAL ANGELs checklist.

The BMAGs can be turned ON using the rotational knobs on MDC-7.

The BMAGs can be configured using the BMAG MODE switches on MDC-1.

Setting the .05G switch from OFF to .05G sets the GDC into entry mode. This is normal during reentry and is used by the Entry Monitoring System.

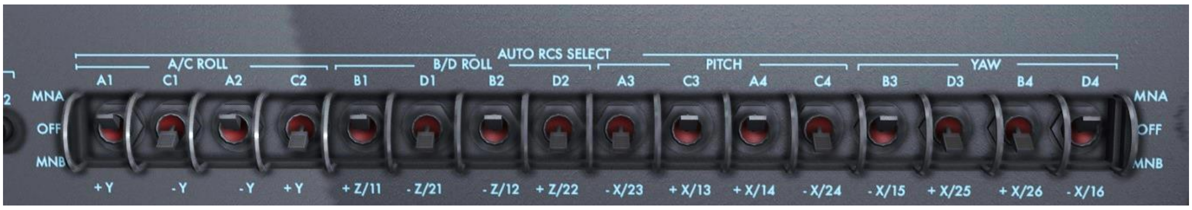
Attitude changes happens by sending signals through the Electronics Control Assembly (ECA). The ECA contains the logic for the SCS system and contains the electronics used for attitude control and singla processing. It also translates commands from the input controllers to the Jeaction Jet and Engine On/Off Control (RJ/EC).

The SCS ELECTORNICS PWR selector on MDC-7 controls the power for the ECA.

The RJ/EC sends commands to control the reaction control system (RCS) thrusters on both the Service Module and the Command Module. The Service Module has 16 RCS jets and the Command Module has 12 RCS jets. The RJ/EC is used by both the PGNCS and the SCS.

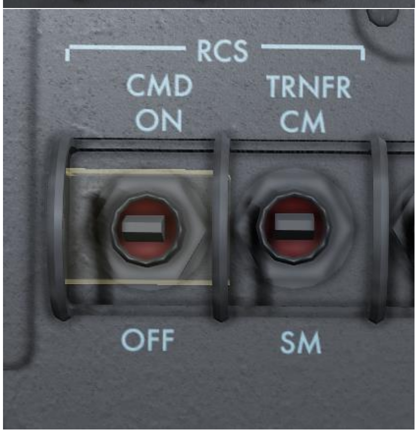
If the spacecraft control is set to CMC, the PGNCS uses the RJ/EC, and if set to SCS, the ECA is used to control the RJ/EC. All it does is to open the correct RCS solenoids based on its input.

The individual auto solenoids can be controlled from the 16 AUTO RCS switches on MDC-8.



Each solenoid/jet can receive power from either MNA or MNB.

The RJ/EC itself receives AC power through the Signal conditioner / driver bias power switches on MDC-7.



The RCS CMD switch on MDC-2 is used to block all signals passing through the RJ/EC. This disabled all RCS auto coils while on the OFF position.

This is a spring switch and will automatically return to the center position. Set it to ON to enable, and OFF to disable.

3.2 ROTATIONAL HAND CONTROLLERS

The rotation controllers are hand sticks that is used to manually rotate the spacecraft. Two identical controllers are available. Using the keyboard or a joystick, you can pitch, yaw and roll the spacecraft.

KEYBOARD COMMANDS

W: Pitch down

S: Pitch up

A: Yaw left

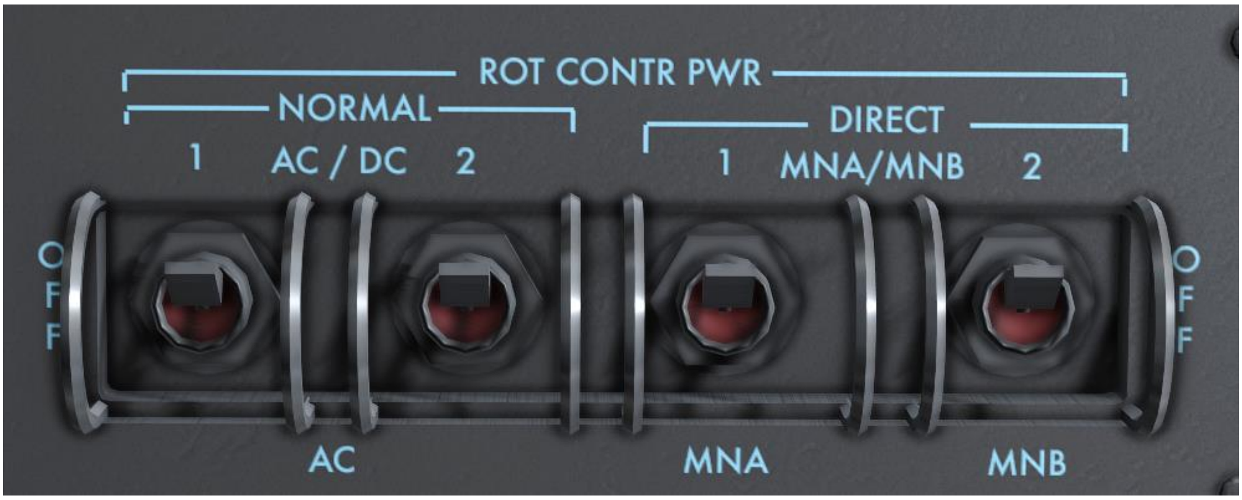
D: Yaw right

Q: Roll left

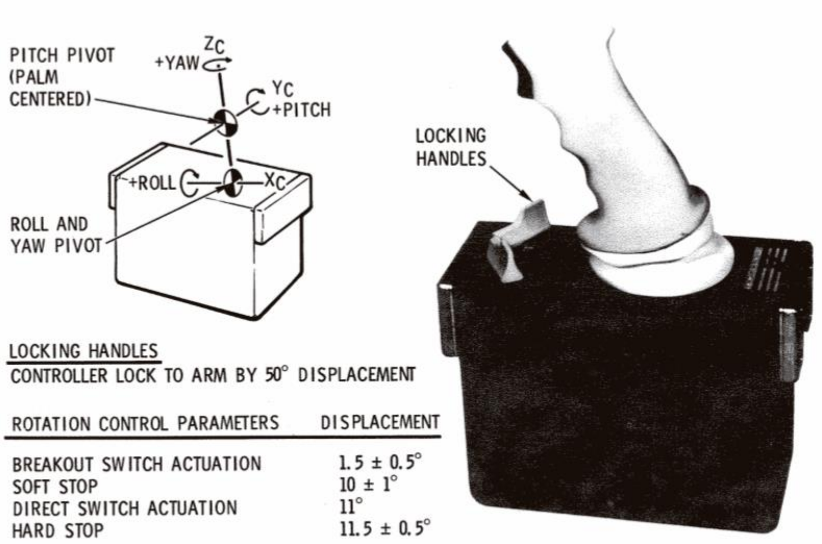
E: Roll right

Each hand controller can be tilted to create a rotation using onboard electronics. A direct mode is also available where the hand controller displacement will directly trigger the RCS direct solenoids.

The hand controllers are activated using switches on MDC-1:



Both rotational controllers can be turned on or off using the NORMAL PWR switches. They require AC power, and DC power preferably to operate normally. If DC power fails, they can still work with just AC power. The DIRECT switches are used to enable the DIRECT part of the controllers where they will trigger the direct solenoids of the RCS if needed.



The RHC Normal mode applies signals to automatic coils of the RCS through the RJ/EC.

3.3 TRANSLATION CONTROL

The translation control provides means of accelerating along one or more of the spacecraft axes. It uses the RJ/EC to fire the correct coils to translate up/down, forward/backwards and left/right.

KEYBOARD COMMANDS

U: Forward

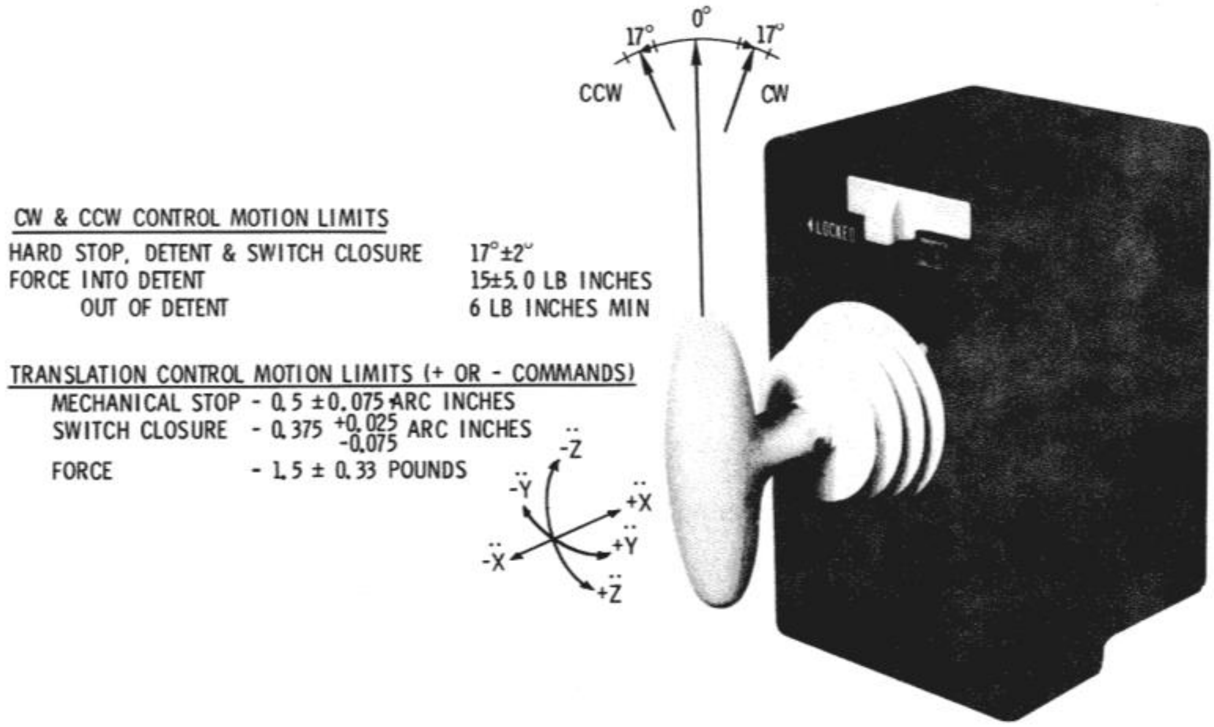
O: Backwards

I: Upwards

K: Downwards

J: Leftwards

L: Rightwards

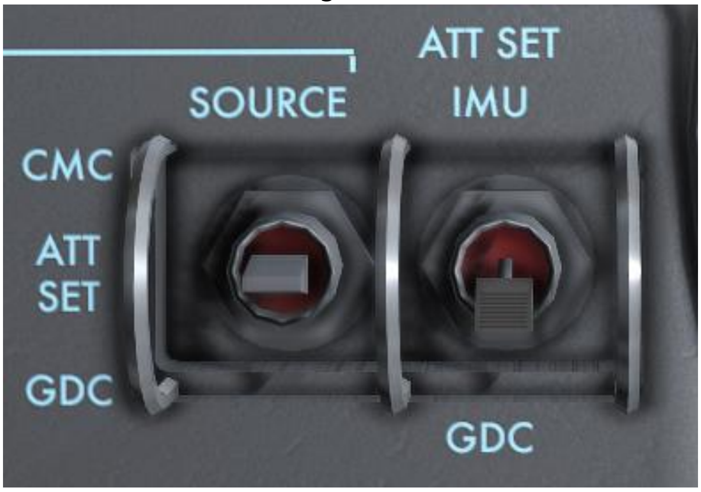


3.4 ATTITUDE SET CONTROL PANEL

The ASCP provides, through thumbwheels, a means of positioning differential resolvers for each of the three spacecraft axes. It can be used to see the current pitch, yaw and roll of the spacecraft based on either the GDC or the IMU.

By setting the FDAI source to ATT SET, the error needles on the FDAI will display the direction to the attitude set on the ASCP. The FDAI needles shows the error from the set ASCP attitude. If the error is zero (needles centered), you are in the attitude set by ASCP.

You can use the following switches to use the ASCP on an FDAI:



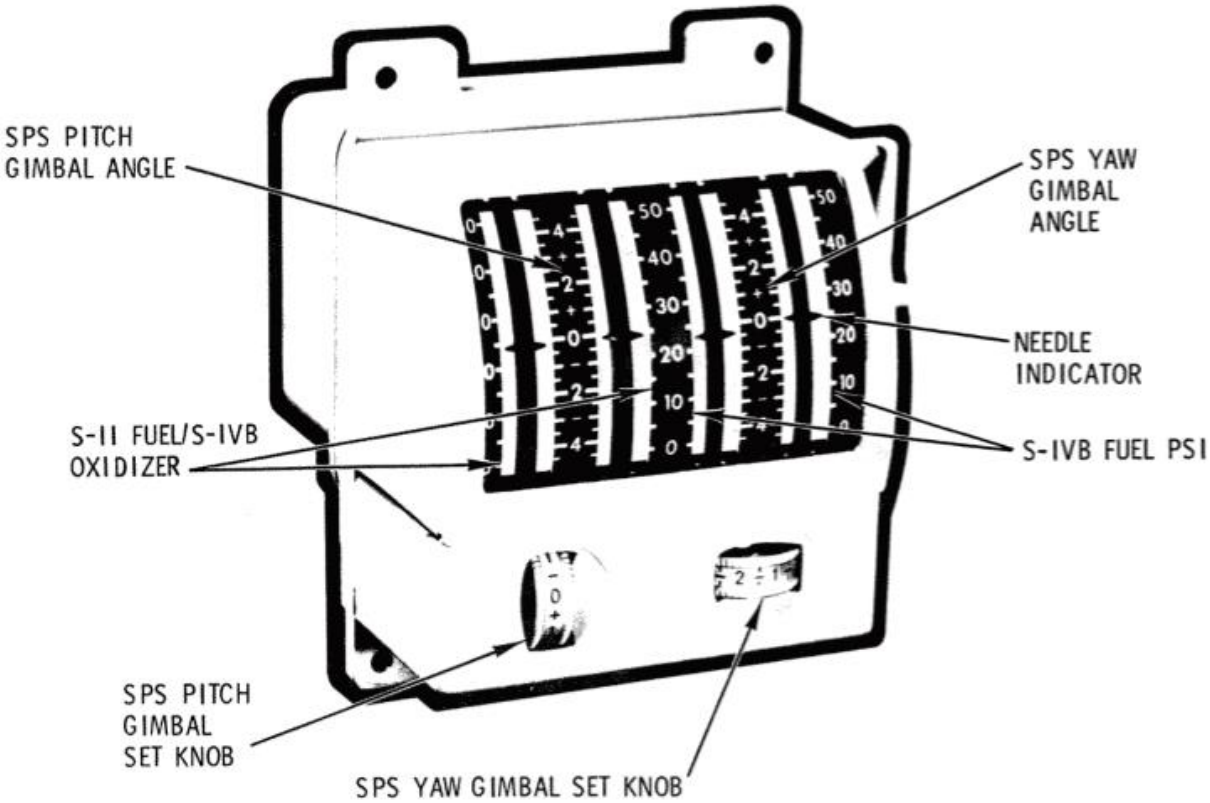
If ATT SET is set to GDC and the GDC Align pushbutton is pressed, it will align the GDC to the attitude set on the ASCP.

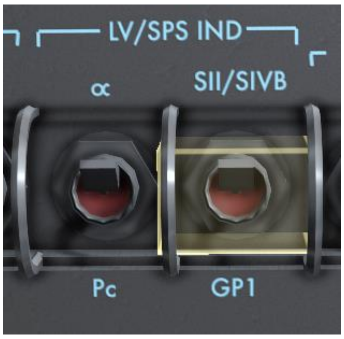
The IMU angles can thus be aquired from the ASCP, in additon to the Noun 20 display on the DSKY – this can be used to realign the GDC to the IMU.

You interact with the thumbwheels on the ASCP using the normal thumbwheel controls.

3.5 GIMBAL POSITION AND FUEL PRESSURE INDICATOR

The GP/FPI contains redundant indicators for both the pitch and yaw channels of the SPS Gimbal Position. During boost, the indicators display S-II and S-IVB propellant tank ullage pressures.

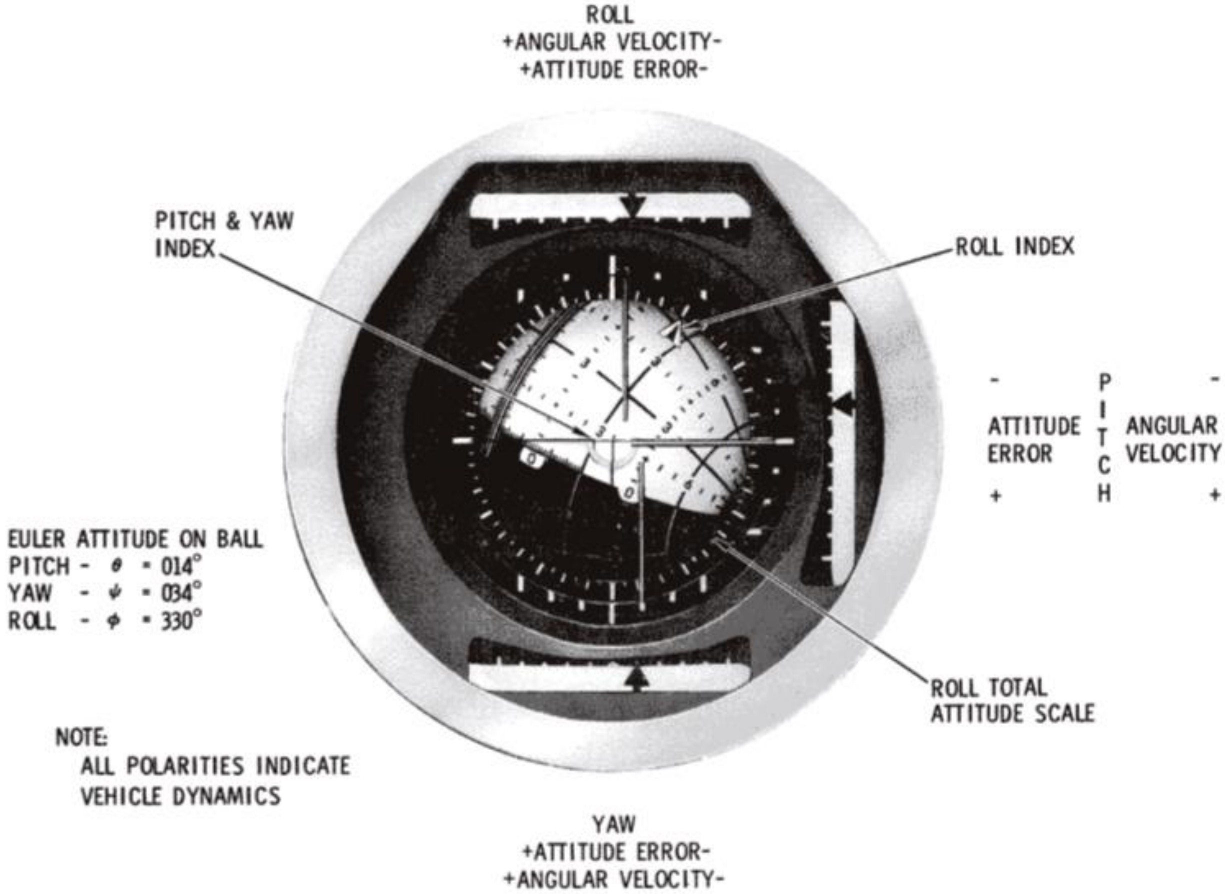




The SPS IND switch on MDC-1 is used to either see the boost properties on the display manel, or the Gimabl Position Indicator on the panel. The two thumbwheels is used to set the Gimbal Position manually.

3.6 FLIGHT DIRECTOR ATTITUDE INDICATORS

Two FDAIs are avaliable and can be configured using the switches on MDC-1. It displays the angular velocity (rate), attitude error through error needles (used as "point to" indication) and the total attitude.



The body rate displayd on either or both FDAIs is derived from the BMAGs in either gyro assembly 1 or 2.

The FDAIs are controlled using the following switches on MDC-1:

The FDAI scale switch is used to set the scale of the rate and error needles.

The scale can be configured to the following settings:

- Pitch rate: +/-1 deg per sec, +/-5 deg per sec, +/-10 deg per sec
- Yaw rate: +/-1 deg per sec, +/-5 deg per sec, +/-10 deg per sec
- Roll rate: +/-1 deg per sec, +/-5 deg per sec, +/-50 deg per sec

The FDAI attitude error needles indicate the difference between the actual and desired spacecraft attitude, and function as a “fly-to” command. The attitude error can be derived from several sources:

- The uncage BMAGs from GA-1
- CDUs from the PGNCS
- ASCP-GDC/IMU

The total attitude with respect to a selected inertial reference frame is displayed through the FDAI ball. The source is used to select where the total attitude is based on.

Using the FDAI SELECT switch, you can select what FDAI to configure. If it is set to ½, the FDAI 1 will automatically have the CMC source and FDAI 2 will have GDC as the source. If it is set to either 1 or 2, the SOURCE and ATT SET switches are used to configure what the FDAI should display.

The source of the rate information for display will always be from BMAG 2 unless BMAG 1 is put into a backup rate configuration. The normal selection is when BMAG MODE switches in the ATT 1/RATE 2 or the RATE 2 position. The backup source is selected when the BMAG MODE switch is in the RATE 1 position.

ORDEAL

The ORDEAL (Orbital Rate Display-Earth and Lunar) unit can modify the FDAI attitude. The ORDEAL is designed to, when active, automatically set the orientation relative to Earth or the Moon. When in space, the orientation can be in any direction, but when orbiting any of these celestial bodies, the orientation is perferred to be relative to them, in a local vertical attitude like in Project Gemini.

Operating the ORDEAL is simplified and will automatically override the attitude of the selected FDAI to Local Vertical. This is useful for many maneuvers when orbiting the Earth/Moon.

Setting either FDAI (usually FDAI 1) to INRTL will configure the FDAIs to use the normal INRTL reference, while ORB RATE will enable the ORDEAL and snap the FDAI to Local Vertical.

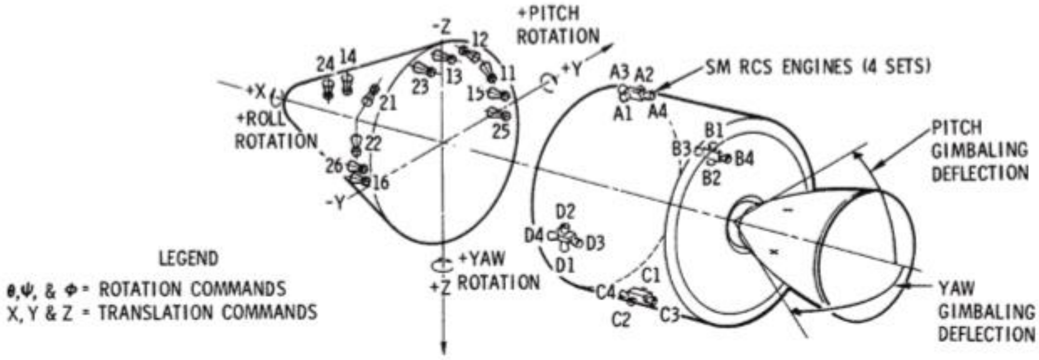
POWER

The FDAIs are powered from the power switching panel on MDC-7.

OFF will depower the FDAIs, 1 or 2 will power the selected FDAI and BOTH will power FDAI 1 and FDAI 2.

3.7 REACTION CONTROL SYSTEM

The RCS provides rotation and translation thrust commands. Prior to CM/SM separation, the SM RCS engines are used for attitude and translation control. After SM separation, the CM attitude RCS thrusters are used. The CM does not have translational thrusters. Each RCS engine has two solenoid coils, one is the automatic and another is the direct. Only the automatic soil is controlled by the RJ/EC.



PITCH	YAW	ROLL B/D	ROLL A/C
+ θ C3	+ ψ D3	+ φ B1	+ φ A1
+X	+X	+Z	+Y
- θ A4	- ψ B4	- φ D2	- φ C2
+ θ A3	+ ψ B3	+ φ D1	+ φ C1
-X	-X	-Z	-Y
- θ C4	- ψ D4	- φ B2	- φ A2

SM RCS ENGINES

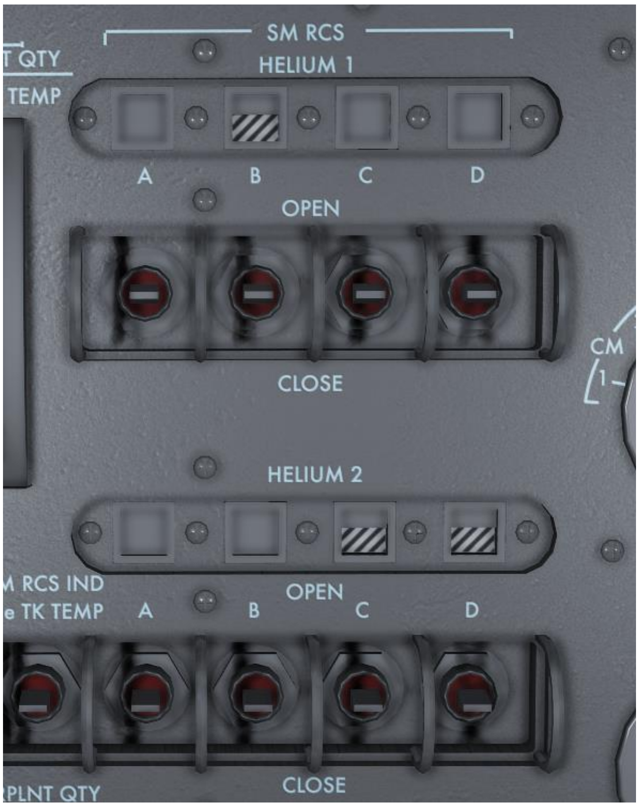
PITCH	YAW	ROLL B/D
+ θ 13	+ ψ 15	+ φ 11
- θ 14	- ψ 26	- φ 22
+ θ 23	+ ψ 25	+ φ 21
- θ 24	- ψ 16	- φ 12

CM RCS ENGINES

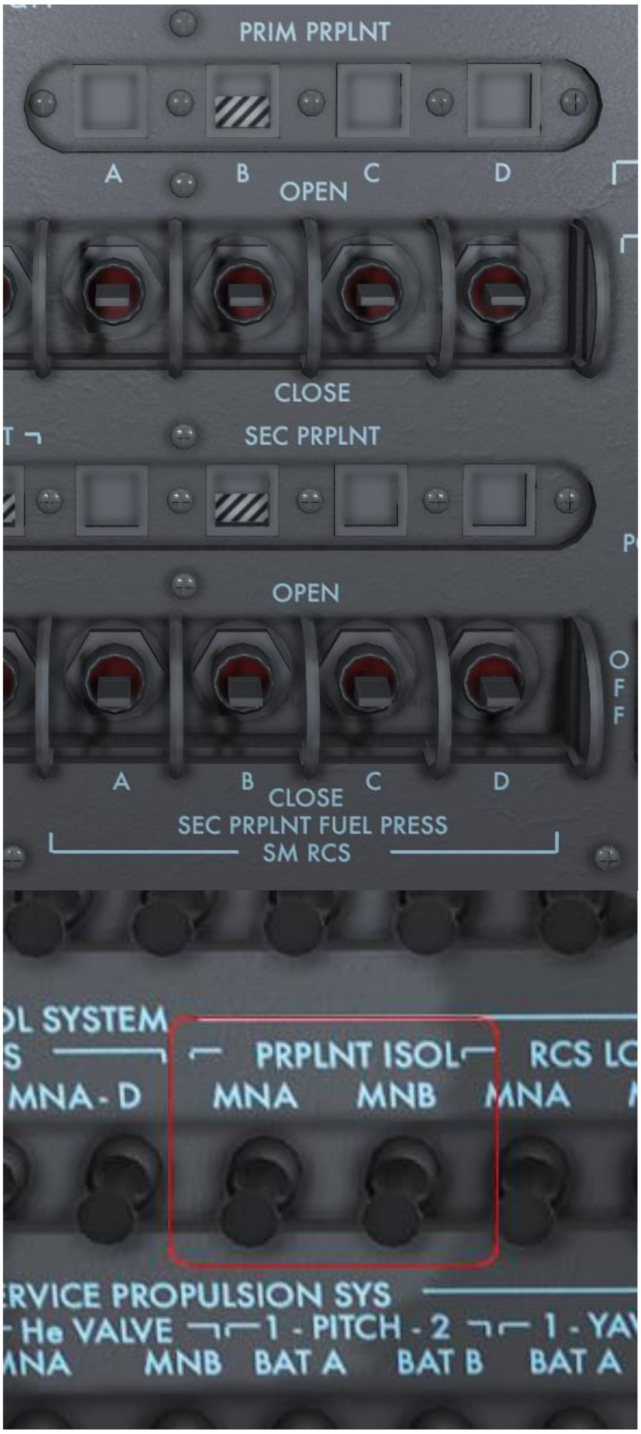
SERVICE MODULE RCS

The SM RCS controls the attitude and translation when the spacecraft is in the CSM configuration. Four identical packages are installed on the outside of the Service Module, 90 degrees apart from eachother.

These four quads has four thrusters in them each. With a total of 16 thrusters, the spacecraft can maneuver in all axes for both attitude and translation. The four quads are named Quad A, Quad B, Quad C and Quad D. Each thruster on the quad is numbered from 1 to 4. So thruster A2 means the thruster 2 on Quad A. Each package has its own fuel system.



Helium is used to pressurize the fuel and the oxidizer in each package. Each package has two helium tanks with a magnetically latched isolation valve. 8 switches on MDC-2 will unlatch or latch the valve.
Each switch has a talkbak indicator that displays if a valve is latched or unlatched. Gray means that helium tank is open and barberpoled means it is closed.
The image shows the switches used to configure the Helium flow in each of the four quads (A, B, C, and D).
The switches are spring loaded so it will return to the center position when released.
In the image, quad A has both the Helium tanks open, while quad B has Helium tank 1 closed and the Helium tank 2 open.
Helium must be available for the Quad to function.

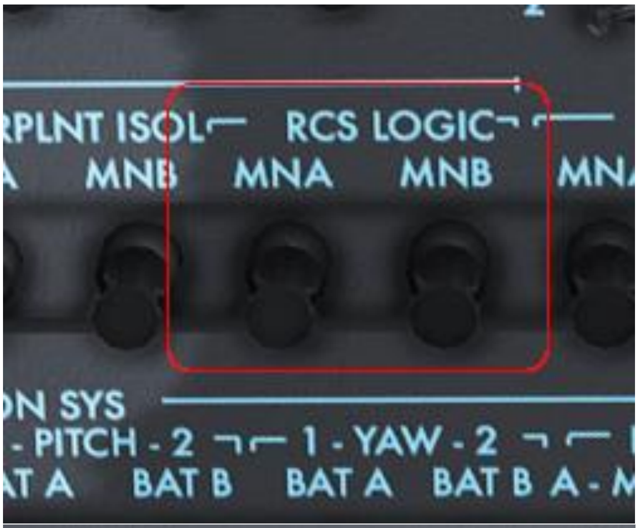


The Helium surrounds a bladder with propellant. When the Helium pressurizes outside the bladder, the propellant is ready.
Each quad has two propellant tanks, one primary and one secondary.

For the fuel to enter the bladder, it must be opened. This works in the same way as with Helium. The switches are used to open or close the valve with a talkback indicator that shows if the valve is open or closed. For redundancy, both the upper and lower row of talkback indicators shows the state of the primary valve.

The secondary propellant valves do not have talkbacks to indicate their valve state.

The PRPLNT ISOL circuit breakers on MDC-8 is used to provide DC to the propellant valves, and needs to be on for it to function.

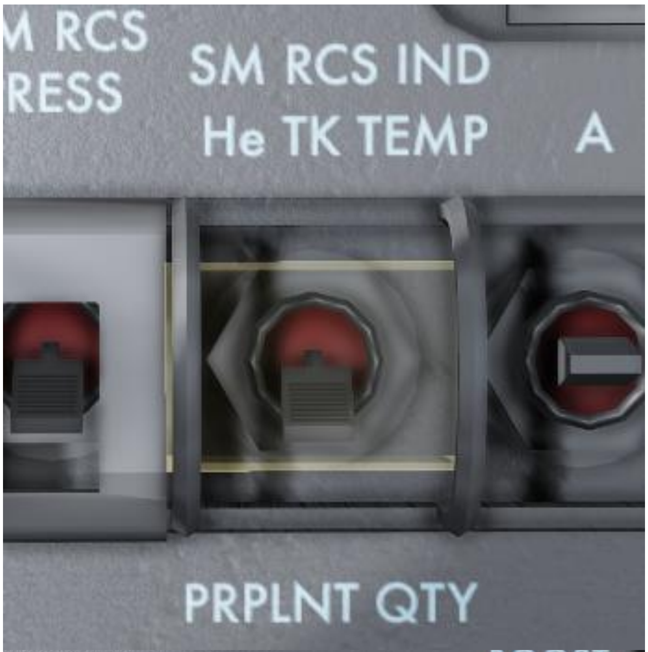


The RCS LOGIC must also be powered for the automatic coils to function.

Each quad is heated by two SM RCS Heaters. These are activaed based on sensors inside the quads.
The heaters must be powerd to function and is done with these circuit breakers.

The SM RCS HEATERS switches are used to control if the primary or secondary heaters are used. Only one heater can be operational at a time.

The SM RCS gauges can be used to monitor each package. It provides information about the temperature, helium pressure, secondary fuel pressure and either helium temperature or fuel quantity.



The SM RCS IND switch chooses if the last gauge above will show the Helium Tank Temperature or the Propellant Quantity.

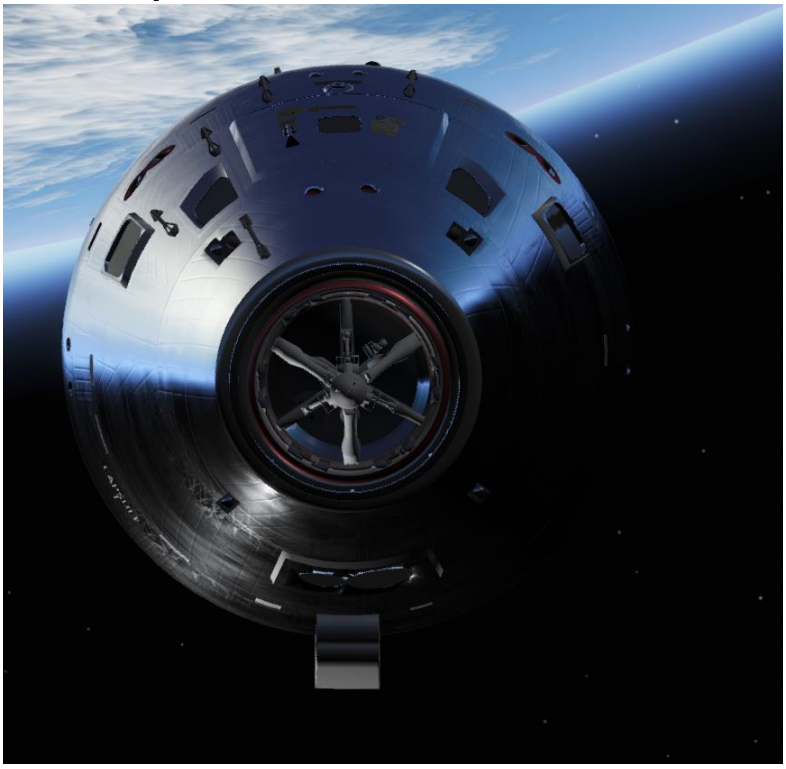
The RCS INDICATORS selector allows you to choose what quad to see information from

The Caution and Warning Lights will illuminate the SM RCS for the right package if propellant quantity is low, or if the temperature is low.

COMMAND MODULE RCS

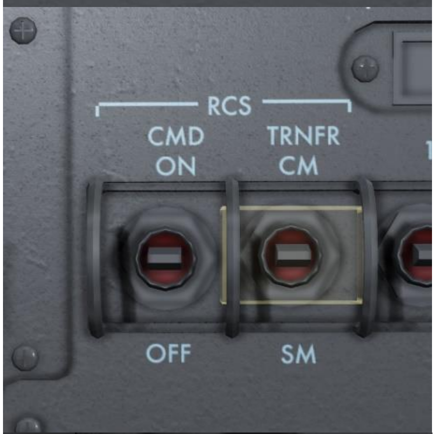
The Command Module RCS assumes attitude control after CM/SM separation. It has 12 thrusters in two redundant systems named 1 and 2. The Command Module thrusters are designed to function during reentry, so it is important that either system 1 or system 2 works, preferrably both.

The RJ/EC is controlling the automatic coils of the CM RCS, and the RHC is controlling the direct coils, just as with the SM RCS.



As with the SM RCS thrusters, the CM RCS thrusters is using Helium as the perssurization. The CM RCS PRESS on MDC-2 will pressurize the valves.

Propellant is needed for the thrusters to function. The CM RCS 1 and 2 is used to open this, one for each CM RCS system. A talkback indicator is gray when the propellant valve is open.



When the SM/CM separation is triggered, the CM RCS logic is automatically activated. If this fails to happen, or you need to do this manually, the TRNFR CM/SM switch on MDC-2 does this.

UP will be in CM mode, down will be in SM mode.

This is a spring switch that will return to the center position after deflection.

The CM RCS LOGIC switch on MDC-1 activates the CM RCS logic. This controls the sequential events during reentry and separation. If this is on, the RCS TRANSFER (above switch) will automatically happen on CM/SM separation. It also prevents the CM RCS to be fired during landing.

The CM PRPLNT PURGE will purge the Helium during landing if the PURGE switch is up and the CM RCS LOGIC is enabled, preventing toxic cemicals during recovery. It will release the Helium. DUMP will do this manually if needed.

As with the Service Module RCS thrusters, they need to be heated. They can be heated using the CM HEATER circuit breaker on MDC-8. This requires the CM RCS LOGIC switch to be on.

The CM RCS HTRS swith on LEB-101 activates the heaters. This needs to be done 20 minutes before use.

3.8 ATTITUDE CONTROL SYSTEM

It is possible to configure what systems are controling the attitude of the spacecraft using the switches on the main display console, most on panel 1 (MDC-1). There are two categories for the attitude configuration, automatic control and manual control.

AUTOMATIC CONTROL

The automatic modes are rate damping and attitude hold.

Rate damping provides the capability of reducing small or large spacecraft angular/rotational rates to within small limits, referred to as rate deadband, and holding the rates on each axis to within these rate deadband limits. It requires rate data from the GDC to be functional. To receive rate data, at least one BMAG needs to be powered. Lastly, when the rates are received, the rate damping is activated when rate command manual mode is selected.

The rate limit size is reflected on the FDAIs rate meters. The rate needles will be normal inside the band, and when the limits reach the edge, the rotation will be constant.

Attitude hold will try to hold the spacecraft in a given attitude, within an attitude deadband. Attitude hold will try to stop all rotations and tries to keep the spacecraft in that attitude. This is based on the GDC, so the GDC must receive this data from a BMAG. This is done by setting one of the BMAGs to ATT1/RATE2. When the data is available, the attitude hold mode is activated if the spacecraft is in rate command mode.

The two switches used to control attitude deadband and the rate deadband are located on MDC-1. The attitude deadband can be set to either MAX or MIN, and the rate deadband can be set to either HIGH or LOW. The rate switch sets the size of the deadband.

RATE Switch Position	Maximum Prop. Rate CMD (By Axis)	
	Pitch & Yaw	Roll
LOW	0.7 deg/sec	0.7 deg/sec
HIGH	7 deg/sec	20 deg/sec

MANUAL CONTROL

There are four manual control modes, Proportional rate, Minimum Impulse, Acceleration Command and Direct.

<u>Proportional rate</u> is used to command the spacecraft rates that are proportional to the rotation controller deflection. Using keyboard input, you are sending the max setting automatically, but using a joystick, it will be possible to use the stick defelction. When the deflection is stopped, the thrusters will stop fireing and the spacecraft will continue to rotate in the direction you set and slowly null the commanded rates.

To configure the spacecraft for Proportional Rate, the MANUAL ATTITUDE switches (MDC-1) must be in RATE CMD, and the stick must have a deflection. If the stick is released, the spacecraft will be in automatic control.

The LIMIT CYCLE switch must be in OFF to avoid using extra fuel when in Proportional Rate mode. The Limit cycle mode is used to set the ECA to command the RCS thrusters to be pulsed as the attitude approaches the deadbands (pseudo rate).

Minimum Impulse provides the capability of making small changes in the spacecraft rate. In this mode, the spacecraft will be in free drift. A stick deflection will create a one short burst that will fire the hets for 15 ms. Another can be created once the stick is released and defelcted again. It is normal to use this for fine attitude control, and the number of deflections can be counted.

Acceleration command allows continuous commands to the thrusters, and is the highest priority with exception of direct control.

Direct control is similar to acceleration command, except that it uses the direct coils of the thruster instead of the auto thruster. To enable direct control, the two ROT CONTR PWR DIRECT switches is set to either MNA or MNB.

The switches are located on MDC-1. Ullage is also using the Direct mode, and is using the thrusters to push floating fuel inside the tanks in the SM to the rear before performing an

SPS burn. Depressing the Ullage button will fire the jets used to translate the spacecraft in the forward dirtection.

The configurations can be seen in the table below.

			MANUAL					AUTOMATIC	
			DIRECT	ACCELERATION CMD	TRANSLATION	MINIMUM IMPULSE	PROPORTIONAL RATE (4)	RATE DAMPING	ATTITUDE HOLD
MANUAL ATTITUDE	ROLL	ACCEL CMD		✓	✓				
		RATE CMD			✓		✓	✓	✓
		MIN IMP			✓	✓			
	PITCH	ACCEL CMD		✓	✓				
		RATE CMD			✓		✓	✓	✓
		MIN IMP			✓	✓			
	YAW	ACCEL CMD		✓	✓				
		RATE CMD			✓		✓	✓	✓
		MIN IMP			✓	✓			
BMAG MODE	ROLL	RATE 2						✓	
		ATT 1/RATE 2							✓
		RATE 1						✓	
	PITCH	RATE 2						✓	
		ATT 1/RATE 2							✓
		RATE 1						✓	
	YAW	RATE 2						✓	
		ATT 1/RATE 2							✓
		RATE 1						✓	
SC CONT		CMC			✓	✓	✓	✓	✓
		SCS			✓	✓	✓	✓	✓
TRANS CONTROL		CW			✓	✓	✓	✓	✓
		NEUTRAL							
RHC DIRECT PWR		UP/DOWN	✓	(3)	(3)	(3)	(3)	(3)	(3)
		OFF							
ROT CONTROL		B.O. SW		CLOSE (2)		CLOSE(2)	CLOSE	OPEN	OPEN
		DIRECT SW	CLOSE						
LIMIT (1) CYCLE		UP							✓
		OFF					✓	✓	
ENTRY		.05G							
		OFF							✓

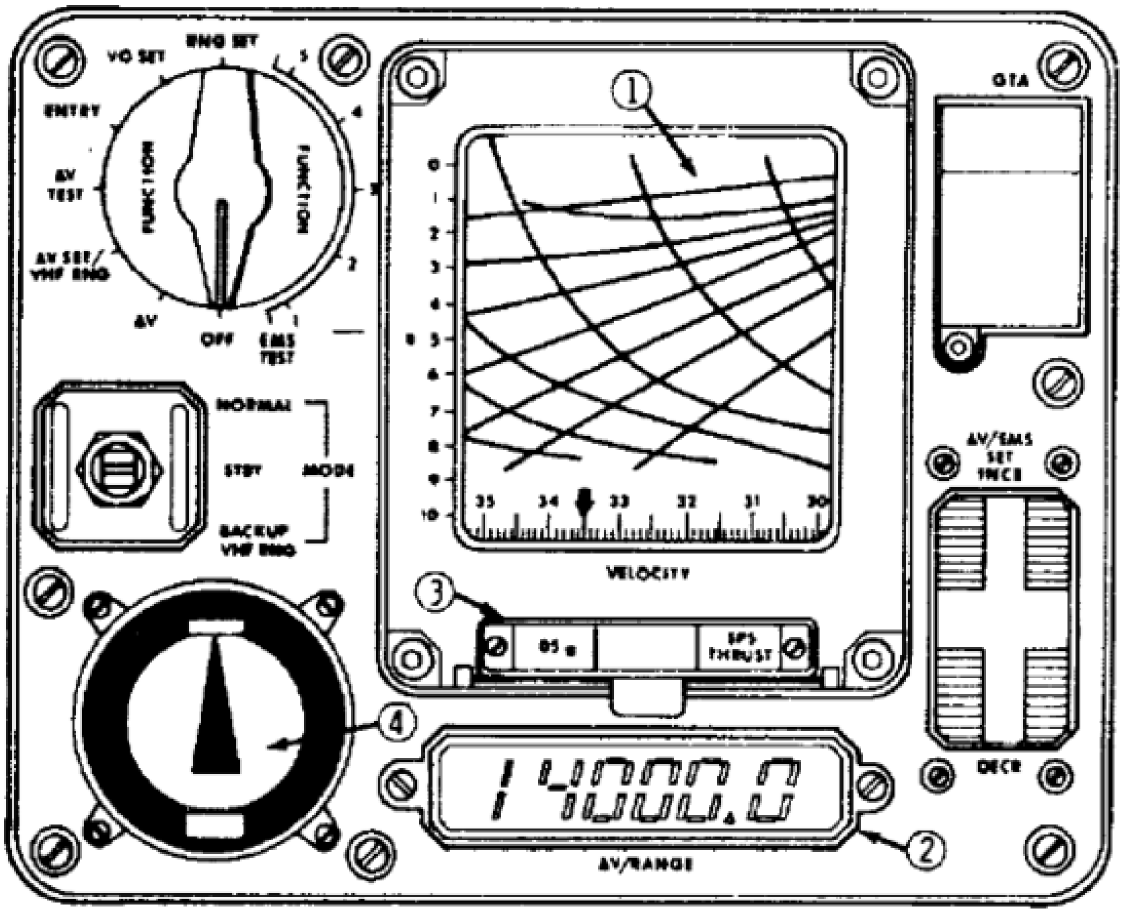
(1) NOT REQUIRED TO ENABLE A PARTICULAR FUNCTION.
INDICATES DESIRED POSITION FOR RCS PROPELLANT CONSERVATION.
(2) IF B.O. SW IS OPEN THE S/C WILL BE IN FREE DRIFT.
(3) IF "ON", DIRECT SW IN ROTATION CONTROL MUST BE "OPEN".
(4) MAXIMUM RATE ATTAINABLE IS FUNCTION OF RATE-HIGH/LOW SWITCH

GENERAL COMMENTS:
A. THE CAPABILITIES, IN GENERAL, ARE LISTED IN ORDER OF THEIR PRIORITY.
B. WHEN MORE THAN ONE SWITCH POSITION IS CHECKED (✓) THE CAPABILITY WILL BE ENABLED IN EITHER POSITION.

4. ENTRY MONITOR SYSTEM

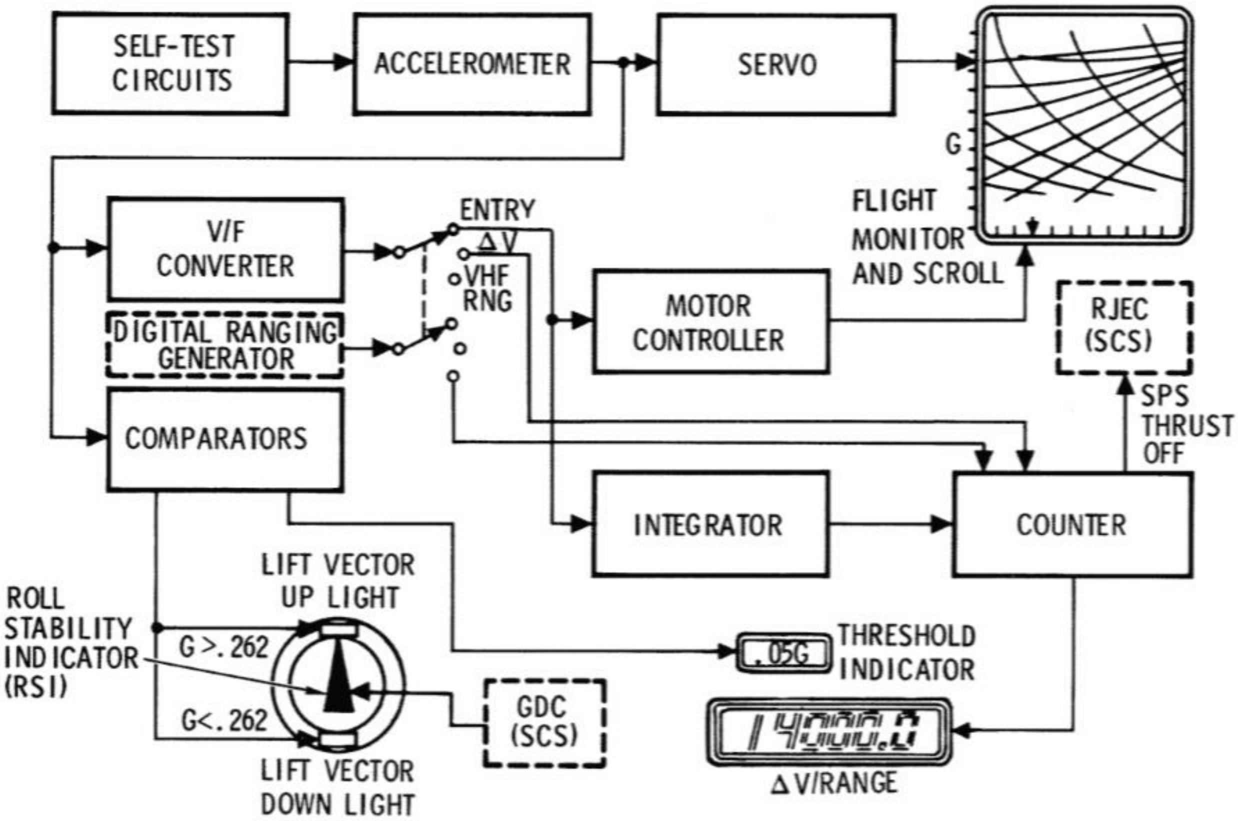
The Entry Monitor System (EMS) provides a visual monitor of automatic Primary Guidance and Control System (PGNCS) entries and delta velocity maneovers. The EMS also provides sufficient display data to permit manual entries in the event of PGNCS malfunctions together with a command sent to the SCS for SPS engine cutoff. The delta velocity display can also be used as the cue to initiate manual thrust-off commands if the automatic-off commands malfunction. During rendezvous the EMS provides a display of VHF ranging information.

Self-test provisions are provided by a function switch for three operational modes (entry, ΔV and VHF ranging) to provide maximum system confidence prior to actual use.



4.1 ENTRY FUNCTIONS

The EMS provides five displays and/or indicators that are used to monitor an automatic entry or to aid in performing a manual entry.



THRESHOLD INDICATOR (.05 G)

The threshold indicator illuminates when the atmospheric deceleration is sensed. The altitude at which this indicator is illuminated is a function of the entry angle (velocity vector with respect to local horizontal at the Entry Interface (400k ft alt), the magnitude of the velocity vector, geographic location and heading, and atmospheric conditions. Bias comparator circuits and timers are used to initiate this indicator. The signals used to illuminate the indicator is also used internal to the EMS to start the corridor evaluation timer, scroll velocity drive, and range-to-go circuits. This usually happens 30 seconds after the capsule enters the ENTRY INTERFACE; when the capsule passed 400,000 feet above the Earth's surface.

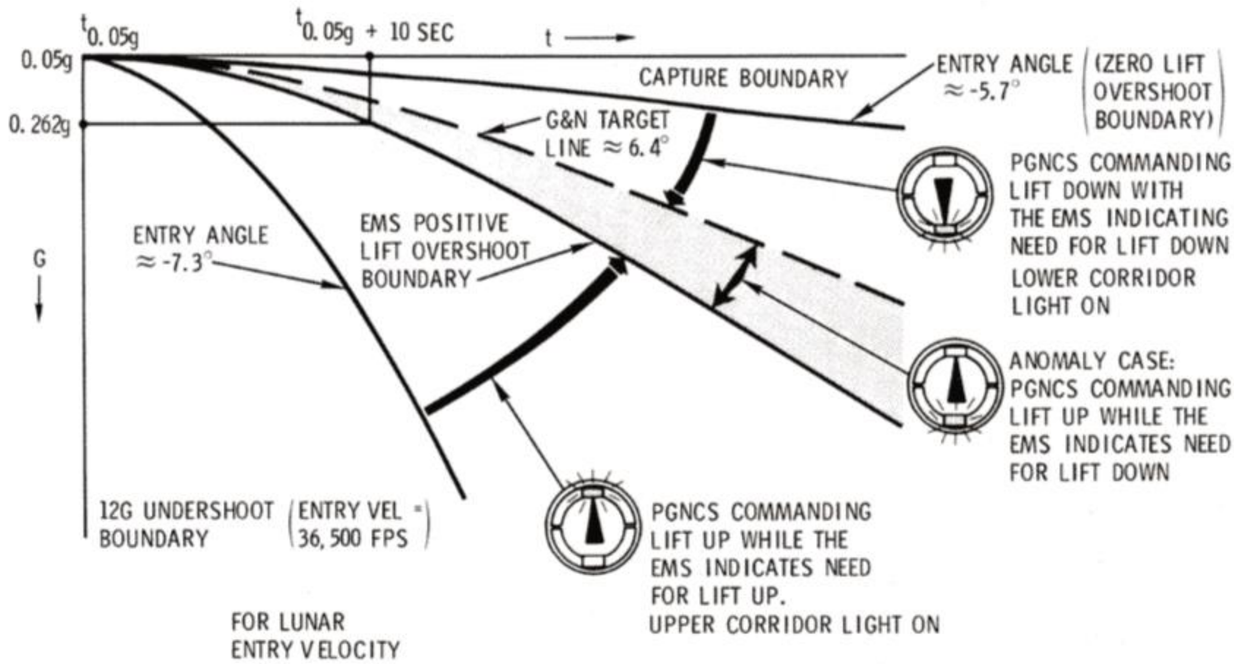
ROLL STABILITY INDICATOR

The Roll Stability Indicator (RSI) provides an indication of lift vector position throughout entry. ~~With the ATT SET switch in the GDC position, the RSI will be aligned prior to 0.05G by rotating the yaw thumbwheel on the Attitude Set Control Panel with the EMS ROLL switch in the entry position while pressing the GDC ALIGN button~~ (skip, automatic in Reentry – An Orbital Simulator). During entry, stability axis roll attitude will be supplied to the RSI by the Gyro Display Coupler. There are no degree markings on the display, but the equivalent readout will be zero when the RSI points toward the top of the control panel. During entry, the RSI rotates in the opposite direction to the spacecraft roll.

Note: For the RSI to function properly, it is important to align the GDC to the IMU before entry. The IMU should be align with the correct REFSMMAT before entry, and is the Local Vectical at Entry Interface.

CORRIDOR VERIFICATION INDICATORS

The corridor verification indicators are located above and below the RSI. They consist of two lights which indicate the necessity for lift vector up or down for a controlled entry. The indicators will be valid only for vehicles which utilize lunar entry velocities (approximately 36,000 ft/s) and entry angles (6.5 degrees). The corridor comparison test is performed approximately 10 seconds after the .05 G indicator illuminates. The lift vector up light (top of RSI) indicates G greater than approximately 0.262G. The lift vector down light (bottom of RSI) indicates G less than approximately 0.262G.



An entry angle is the angular displacement of the Command Module velocity vector with respect to local horizontal at 0.05G. The magnitude of the entry angles that determines the capture and undershoot boundaries will be a function of Command Module lift-to-drag (L/D) ratio. The angles shown are for a L/D of 0.3 to 0.4. The EMS positive lift overshoot boundary is that entry angles that produces approximately 0.262G at approximately 10 seconds after the .05G indicator is illuminated. An entry angle greater than the EMS positive lift overshoot boundary will cause the upper corridor verification light to be illuminated. Conversely, and entry angle less than the positive overshoot boundary will light the lower corridor light. Entry angles less than the capture boundary will result in noncapture regardless of lift orientation. Noncapture would result in an elliptical orbit which will re-enter when perigee is again approached. The critical nature of this would depend on Command Module consumables: power, control propellant, life support, etc. The Command Module and crew will undergo excessive Gs (greater han 10G) with an entry angle greater than the undershoot boundary, regardless of lift orientation.

ΔV/RANGE-TO-GO INDICATOR

The ΔV/range-to-go is an electronic numeric readout which has three functions. During entry the inertial flight path distance in nautical miles to predicted splashdown after 0.05G is displayed. The predicted range will be obtained from the PGNCS or ground stations and inserted into the range display during EMS range set prior to entry. For a delta-V maneouver, the display will indicate the delta-V (ft/sec) remaining. For rendezvous the display will indicate the distnace to the Lunar Module.

SCROLL ASSEMBLY

The scroll assembly provides a scribed trace of G versus inertial velocity during entry. The mylar scroll has printed guidelines which provide monitor (or control) information during aerodynamic entry. The entry trace is generated by driving a scribe in a vertial direction as a function of G level, while the mylar scroll is driven from right to left proportional to the Command Module inertial velocity change. Monitor and control information for a safe entry and range potential can be observed by comparing the slope of the entry trace to the slope of the nearest guidelines (G onset, G offset and range potential).

4.2 DELTA VELOCITY FUNCTIONS

In addition to entry functions, the EMS provides outputs related to delta velocity maneuvers during SPS of RCS thrusting along the CSM X-axis. Both the SPS THRUST lamp and the ΔV numeric counter display information during delta V. In addition, an automatic thrust-off command signal is supplied to the SCS when the ΔV counter reaches zero.

SPS THRUST-ON INDICATOR

The SPS thrust-on indicator will be illuminated any time a ground is present on the low side of either of the SPS bipropellant solenoid control valves if either of the EMS circuit breakers on MDC-8 are set.

DELTA VELOCITY INDICATOR

The numeric readout displays the delta velocity remaining along the CSM X-axis. It has the capability of displaying a maximum of 14,000 fps down to a -1000.0 fps. The readout is to

1/10 feet per second. The ΔV/EMS SET switch will be used to set in the desired delta-V for all SPS thrusting maneuvers. The ΔV display will count up or down with the EMS MODE switch in the NORMAL position. The display counds down with SPS or RCS thrusting along the CSM +X-axis or up with RCS thrusting along the CSM -X-axis.

SPS THRUST-OFF COMMAND

During SCS-controlled SPS thrusting a thrust-off command is supplied by the EMS. This thrust-off logic signal is supplied to the SPS engine on/off circuit when the delta V reads minus values of delta V. Consequently, the THRUST ON button will not turn on the SPS engine unless the ΔV display reads zero or greater.

4.3 OPERATING THE EMS

Four switches are used to activate and select the desired function in the EMS. The MODE switch, FUNCTION switch, ΔV/EMS SET switch, and the GTA switch.

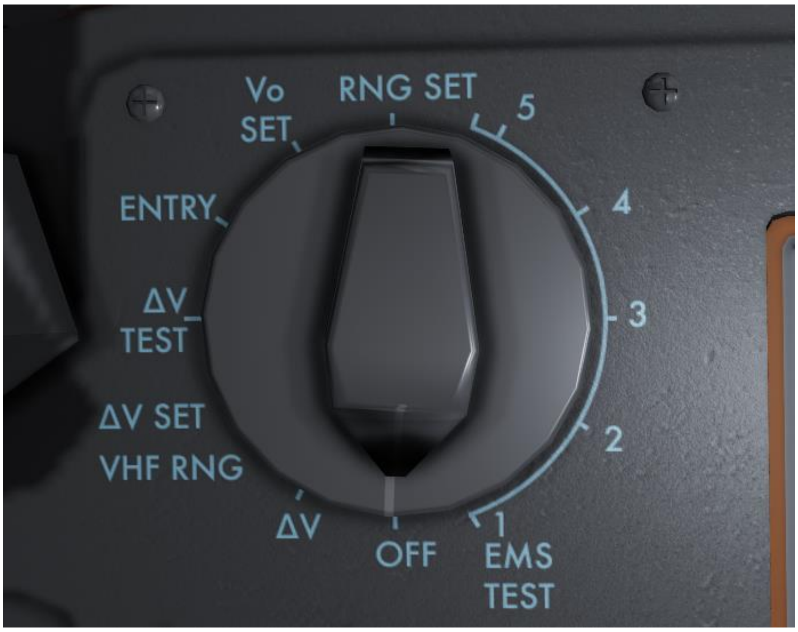
The MODE switch has three positins: NORMAL, STBY MODE and BACKUP/VHF RNG.

STBY applies power to the EMS circuits; it inhibits system operation but does not inhibit set functions.

NORMAL permits the self-tests to function. It also is the normal position for operations when the FUNCTION switch is in the ENTRY and ΔV positions.

BACKUP/VHF RNG is used either as a backup in the entry and ΔV operations and is the proper position during VHR ranging. It will be used as a backup to initiate the scroll velocity drive and the range display countdown in the event of a failure of the .05G circuits.

The FUNCTION swiths is a 12-position selector which is used to select the desired function in the EMS. Three positions are used for delta V operations. Eight positions are used for entry, entry set and self-tests. One position is used for VHF ranging, and one for OFF.



OFF deactivates the EMS except the SPS THRUST ON light and the roll stability indicator.

EMS TEST 1 tests the lower trip point of 0.05G – threshold comparator and enables slewing of the scroll.

EMS TEST 2 tests the high trip point of the .05G – threshold comparator.

EMS TEST 3 tests the lower trip point of the corridor verification comparator and enables slewing of the ΔV/RANGE display for EMS test 4 operations.

EMS TEST 4 tests the range-to-go integrator circuits, G servo circuits, G-V plotter and range-to-go circuits.

EMS TEST 5 tests the high trip point of corridor verification comparator and enables the slewing of the scroll. This is the only test that is required to execute before re-entry.

RNG SET establishes the circuitry for slewing the ΔV/RANGE display.

Vo SET establishes circuitry for slewing the scroll to the predicted inertial velocity at 0.05G.

ENTRY is the operational position for monitoring the Command Module earth atmosphere entry mode.

ΔV TEST is the operational position for self-test of delta V circuits.

ΔV SET/VHF RNG establishes circuitry for slewing the ΔV/RANGE display. Enables VHF ranging display.

ΔV is the operational positiong for accelerometer to drive the ΔV/RANGE display for X-axis accelerations.

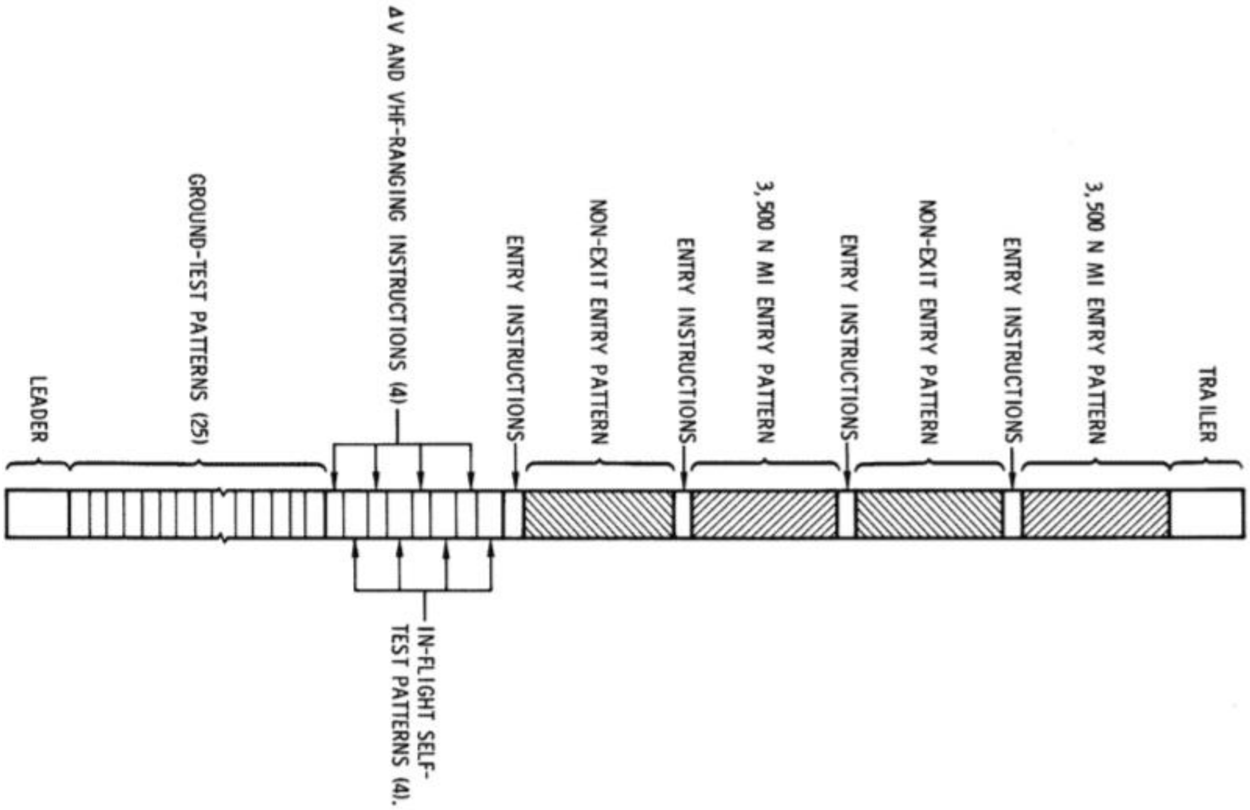
The ΔV/EMS SET switch is used to drive the ΔV/RANGE display or the EMS scroll. With the FUNCTION switch in the ΔV SET/VHF RNG, RNG SET, and EMS TEST 4, depressing the ΔV/EMS SET increase or decrease buttons will change the display readout. It is divided into 4 zones. Pressing the upper or lower zones will increase/decrease fast while the inner zones will increase/decrease slow (precision). You can hold the mouse cursor down for constant movement.

With the FUNCTION switch in the Vo SET, EMS TEST 1, and EMS TEST 5 position, it will drive the EMS scroll at approximately 0.0164 inch per second or 0.263 inch per second.

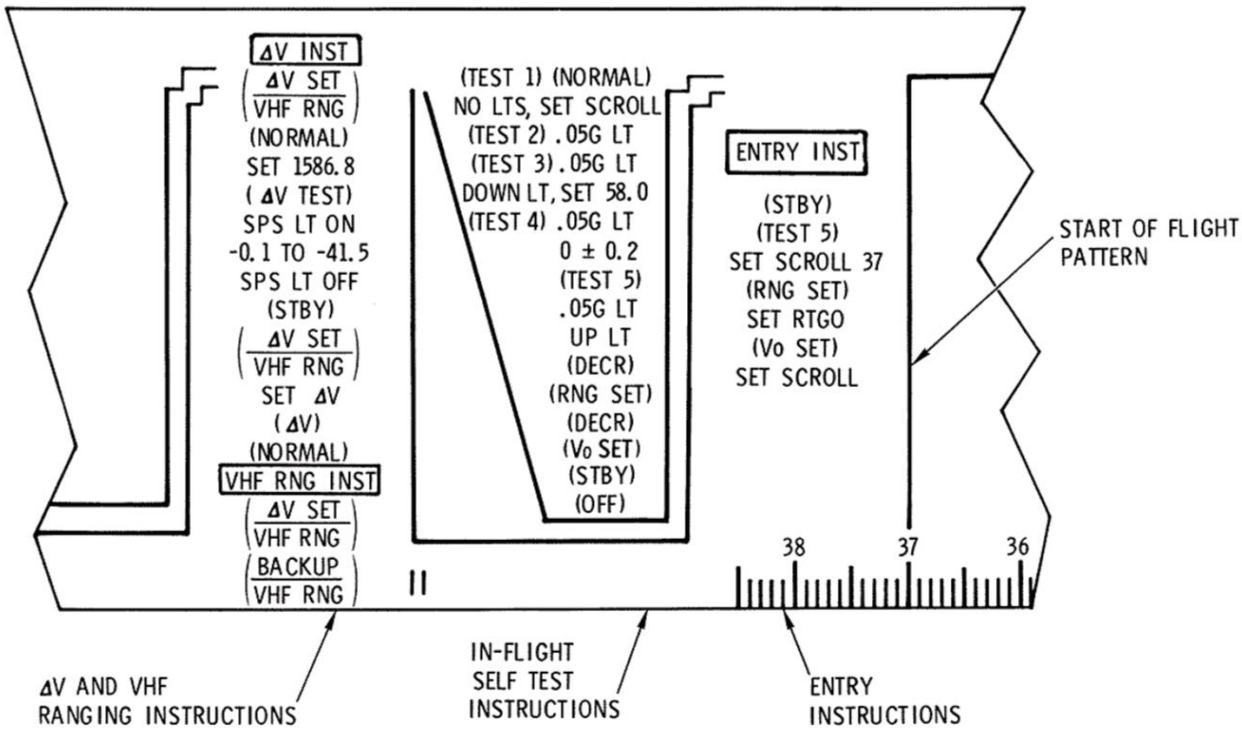
The GTA switch provides ground test capability. It can simulate 0G in the vertical stack configuration of the spacecraft (launchpad). This must be OFF before liftoff, and is only used during the EMS testing before the astronauts enters the cockpit.

4.4 ENTRY SCROLL

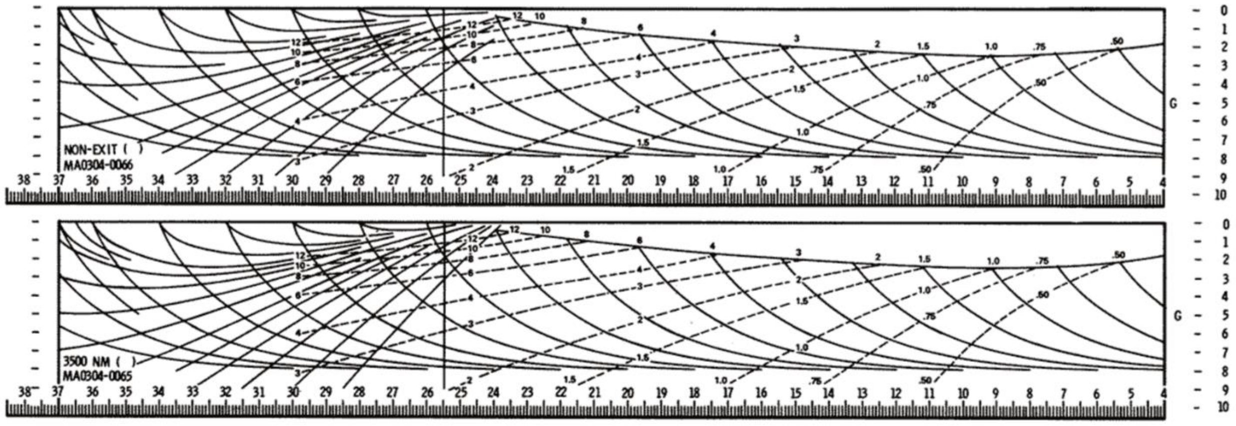
The EMS mylar scroll contains four entry patterns together with entry in-flight test patterns and the instructions for entry, delta V and VHF ranging.



There are four sets of ΔV and VHF ranging instructions that are alternated with four entry in-flight self-test patterns.



Following the fourth in-flight self-test pattern on the scroll is the first set of entry instructions. Entry instructions precede each of the four entry patterns. Each entry pattern has velocity increments from 37,000 to 4,000 fps together with entry guidelines. These lines are called G on-set, G off-set, and range potential guidelines. The G on-set and G off-set lines are solid lines and the range potential lines are broken.

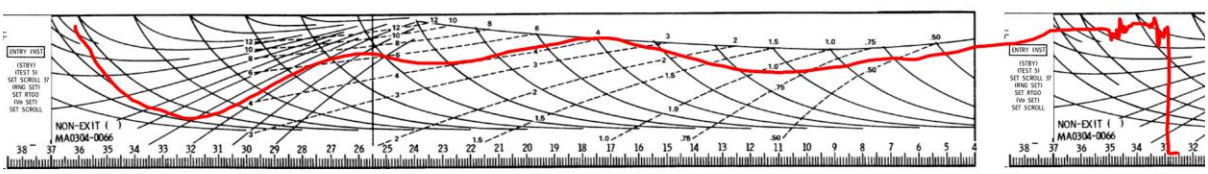


The G on-set lines slope downward, while the G off-set lines ray upward and terminate at 24,000 fps just to the right of the vertical line at 25,500 pfs (minimum velocity for Earth orbit). Below 24,000 fps the G on-set lines slope downward from the full-lift profile line which represents the steady-state minimum-G entry profile. During entry the scribe trace should not become parallel to either the nearest G on-set or G off-set line. If the slope of the entry trace becomes more negative than the nearest G on-set line, the Command Module should be oriented such that a positive lift vector orientation (lift vector up) exists in order to prevent excessive G buildup. However, if the entry trace slope becomes more positive than the nearest G off-set line then the Command Module should be oriented to produce negative lift (lift vector down) for entry.

The change of lift vector is achieved with a 180-degree roll maneuver of the RCS/SCS system.

The range potential lines, shown in hundreds of nautical miles, indicate the ranging potential of the Command Module at the present G level. The crew will compare the range display by the range-to-go counter with the range potential indicated by the entry trace. The slope and position of the entry trace relative to a desired ranging line indicates the need for lift vector up or down.

The image below is an example from an entry scroll used during a real Apollo mission (I drew the line by hand from a reference but it should show the trajectory).



Roll is used to fly the Command Module up from the denser atmosphere or down into it. The relative velocity vs. density is a function of the G-load. The scroll the EMS draws on shows the Velocity (counting down) and the current G-load. 0 G-load is on the top of the graph and 9 G’s is on the bottom.

The scroll is aligned with a marker on the EMS before entry interface, and is set to the entry velocity by moving the scroll so the planned entry velocity matches with the numbers on the lower side of the scroll.

4.5 EMS TEST MODES

The EMS system comes with a few test modes to increase its reliability when it's needed.

ΔV TEST MODE BEFORE SPS BURN

Before a flight and SPS burns, the EMS ΔV must be tested. This prodcedure is printed on the EMS scroll.

1. It is assumed that this test is done in weightlessness in space. To perform the test on the ground, the GTA switch needs to be set to the up position.
2. Set the EMS MODE switch to STBY
3. Enter the ΔV SET mode by setting the EMS FUNCTION knob to ΔV SET/VHF RNG and the EMS MODE switch to NORMAL.
4. Use the ΔV/EMS SET to set the ΔV/RANGE display to 1586.8 ft/s.
5. Go to the ΔV TEST function by setting the EMS FUNCTION knob to ΔV TEST. The SPS THRUST ON light is illuminated and the ΔV/RANGE will decrease.
6. When the ΔV/RANGE is negative, the SPS THRUST ON light is extuingished. The reading stops to decrease after 10 seconds, the ΔV/RANGE display shows -20.8 +/- 20.7 ft/s.
7. When the test is complete the EMS is turned off or switched to standby to reset it.

ΔV TEST MODE BEFORE REENTRY

Before performing a reentry, the EMS should again be tested. The tests are similar to those used during pre-launch by the backup crew (see ΔV TEST MODE DURING PRE-LAUNCH below)

Set EMS MODE to OFF
Set the two EMS circuit breakers on Panel 8 to CLOSE
Set the EMS MODE to STBY
Set EMS FUNC to TEST 1 (and wait 5 seconds)
Set the EMS MODE to NORMAL (and wait 10 seconds)

TEST 1
Wait 10 seconds
- SPS THRUST light OFF
- .05G light OFF
- Lift Vector UP light OFF
- Lift Vector DOWN light OFF
- Range indicator displays 0.0 NM

Use slew control to move the scroll to start of next test pattern
- it should by default be at the first line already

Set EMS FUNC to TEST 2 when ready

TEST 2
Wait 10 seconds
- .05G should illuminate after 10 seconds.
- All other lights are extinguished

Set EMS FUNC to TEST 3

TEST 3
Wait 10 seconds
- .05G light stays illuminated
- Lift Vector DOWN light illuminates after 10 seconds

Use slew controls to change RANGE to 58.0 NM
Set EMS FUNC to TEST 4 when ready

TEST 4
Wait 10 seconds
- .0.5G light is on
- G-V trace moves down within test pattern
- RNG counts down towards 0, stops at 0.0 +/- 0.2 NM

Set EMS FUNC to TEST 5 when ready

TEST 5
Wait 10 seconds
- .0.5G light is illuminated
- Lift Vector UP light illuminates after 10 seconds
- G-V trace moves up again from 9G to 0.28G and stops

ALIGN SCROLL TO ENTRY PATTERN
Set the EMS FUNC to V0 and slew the pattern scroll to the 37K ft/sec line

COMPLETING THE TEST
Set EMS FUNC to RNG SET
- G-V trace goes to 0.0G

Set EMS MODE to STBY

ΔV TEST MODE DURING PRE-LAUNCH

Before a launching, you can test the EMS by using a few dedicated TEST functions, as well as the general test above.

Since the EMS is relying on the wightlessness of space, it is not possible to use the EMS on the ground unless you set the GTA switch to the up-position.

The EMS can be tested on the ground using the following procedure:

GENERAL TEST
Set GTA to ON
Set EMS MODE to NORMAL
Set EMS FUNC to dV
- dV should increase
Set EMS FUNC to dV SET
- Use slew control to set dV to about 1586.8
Set EMS FUNC to dV
- dV will decrease and SPS THRUST light illuminates
- dV < 0, dV stops to decrease and SPS THRUST light extinguishes
Set EMS MODE to STBY

TEST 1
Set EMS FUNC to TEST 1
Set EMS MODE to NORM
- SPS THRUST light OFF
- .05G light OFF
- Lift Vector UP light OFF
- Lift Vector DOWN light OFF
- RNG ind displays 0.0 NM

Use slew control to move the scroll to start of next test pattern
- is should by default be at the first line already

Set EMS FUNC to TEST 2 when ready

TEST 2
Wait
- .05G should illuminate after 10 seconds
Set EMS FUNC to TEST 3 when ready

TEST 3
Wait
- .05G light stays illuminated
- Lift Vector DOWN light illuminates after 10 seconds

Use slew controls to change RANGE to 58.0 NM
Set EMS FUNC to TEST 4 when ready

TEST 4

Wait
- .0.5G lt is on
- G-V trace moves down within test pattern
- RNG counts down towards 0, stops at 0.0 +/- 0.2 NM

Set EMS FUNC to TEST 5 when ready

TEST 5
Wait
- .0.5G lt is on
- Lift Vector UP light illuminates after 10 seconds
- G-V trace moves up again from 9G to 0.28G and stops

Set EMS FUNC to RNG SET
Set EMS MODE to STBY
- G-V trace goes to 0.0G
- All lights out

Set EMS FUNC to OFF
Set GTA switch to OFF

5. PERFORMING A REENTRY

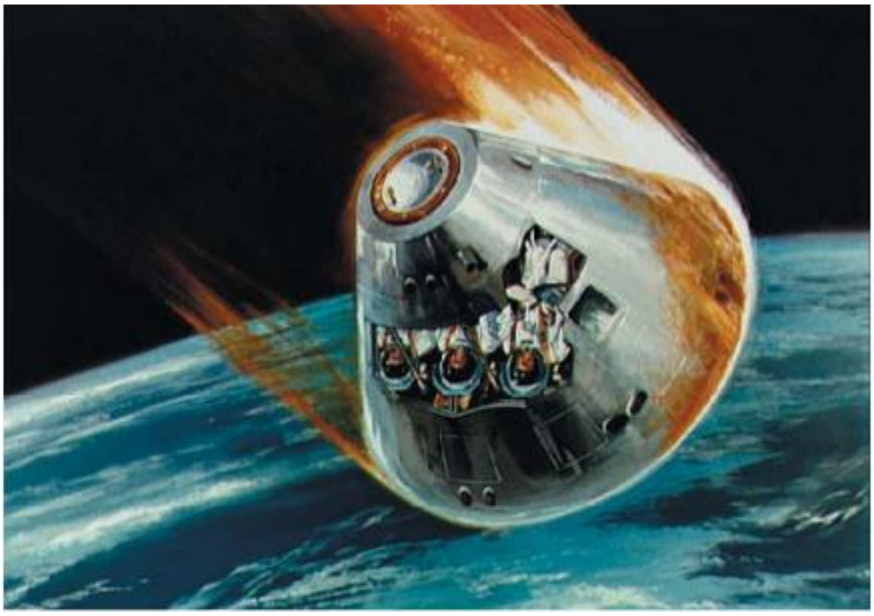
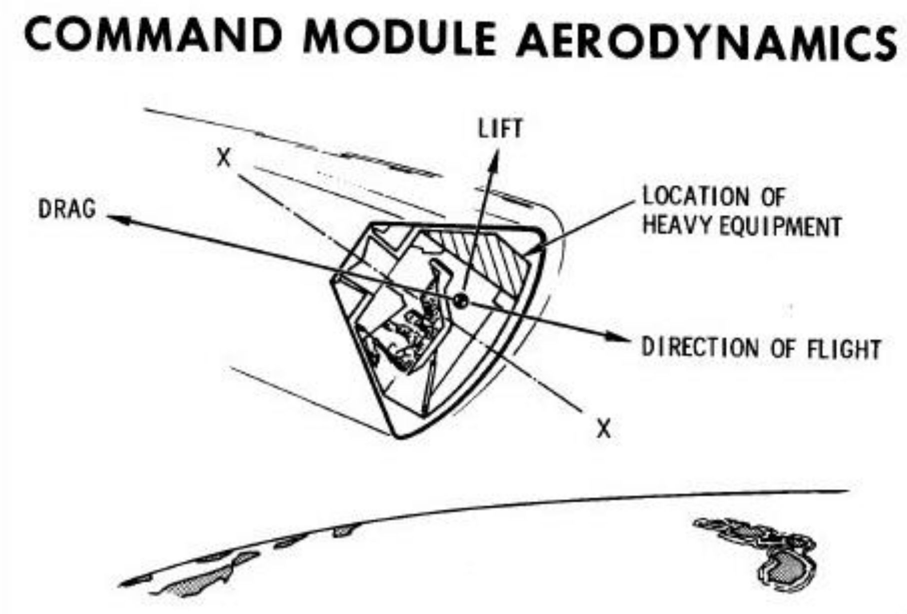


Image: Courtesy of NASA/Johnson Space Center

The Entry Monitor System is used to perform a reentry. The following section will describe how to perform a reentry, and how the aerodynamics of the Command Module is designed to steer through the atmospheric drag.

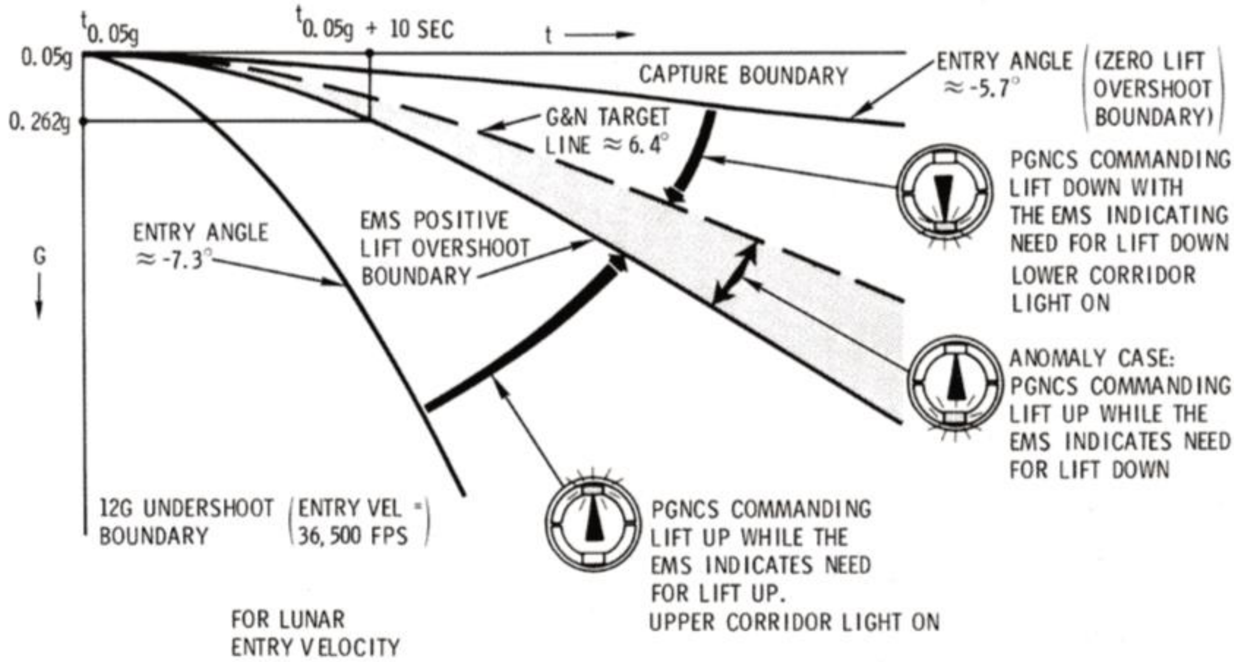
The Command Module is designed so its aerodynamic characteristics will stabilize it in the correct attitude due to its stable trim attitude; 21 degrees to the flight direction. The center of gravity is not directly in the center of the aerodynamic capsule, but rather so the capsule is producing lift using the heatshield in the direction of the feets. The reentry is started heads down towards Earth and faces in the retrograde direction to point the lift vector upwards.



Because of this, the lift can control the trajectory of flight just like an airplane. Roll is used to control the direction of lift, where the initial poisition will create an upward lift vector while rolling 180 degrees from the initial position will point the lift-vector down. This will make the capsule go down into the atmosphere, while up will take it upwards.

By adjusting the lift vector, one can control (slightly) the reentry profile.

Let's go back to the following image from the EMS section.



The entry angle as an upper and a lower limit. This defines the entry corridor. The lower limit, the overshoot boundry, is the angle where the Command Module will skip out of the atmosphere again. The upper limit, the overshoot boundry, is where the load-factor limits of the vehicle and the astronauts will be tested. Both directions are catastrophical as the crew will either burn up, or enter an orbit where the remaining life-support will be depleted before being able to perform another entry.

5.1 ATMOSPHERIC ENTRY FROM EARTH ORBIT

From an altitude of 300km, the perigee should be adjusted down to 6200km, so it intersects 170km below the Earth surface. This will give you an angle of entry of about 2 degrees when the re-entry phase start (400,000 ft).

At this point the the PGNCS, EMS or manual control is used to steer the capsule. The lift vector, if not pointing directly up or down, will also produce some cross range speed so take this into consideration. If you are too steep, set roll to 0 to go up a bit, or too shallow, set roll to 180 to dive down.

Once you are through the atmosphere and the capsule speed is less than 500 m/s, the capsule stops producing lift and will drop down. The landing system will help you through this.

5.2 ATMOSPHERIC ENTRY FROM LUNAR TRAJECTORY

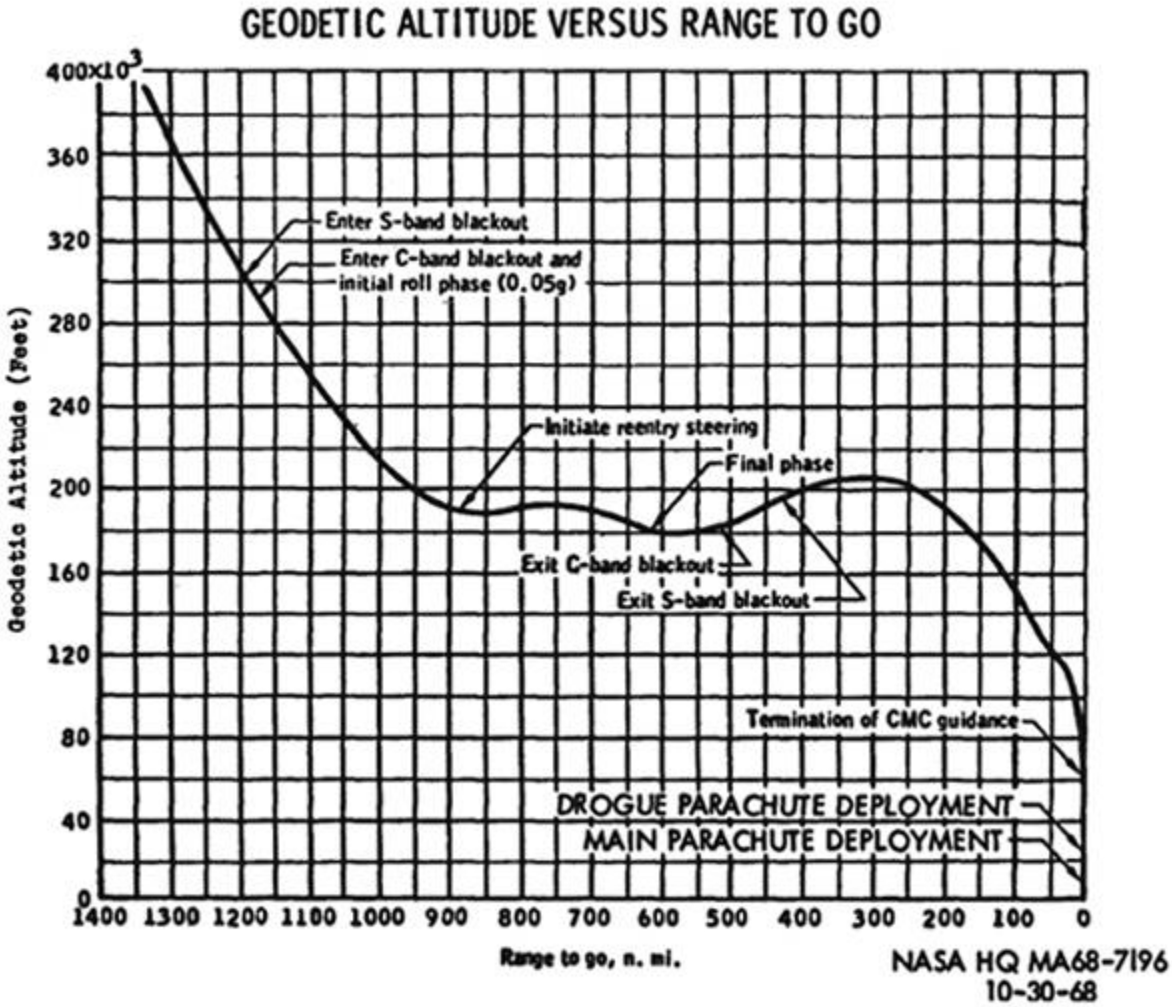
The perigee point is set to 6415 km for the lunar trajectory entry. This perigee is called the Vacuum Perigee Altitude (VPA), and will give an entry angle of 6.5 degrees. The velocity from a lunar trajectory is higher than during the Earth orbit entry. Entering the Earth at lunar return velocities will produce very high G-forces and it is hard to exactly hit the entry corridor. Due to the possibility to roll the lift vector, the accuracy of the reentry limits can be modified. To reduce the load, the lift will have to point up to start a longer breaking period (heads down) with less G-load. When altitude is increasing (lift vector magnitude becomes large due to density), the capsule is rotated to point the lift vector down and dive down for a while to prevent it to go back to space. When velocity is reduced to normal Earth entry velcotites (25500 ft/s), the roll is again set to 0 and the normal Earth orbital reentry procedures are followed.

5.3 REENTRY PROCEDURES

The entry procedures can be found in the Mission Pad checklist, but here is a detailed description.

- Separate the Service Module
- Align the Command Module with the stable trim attitude.
    - Computer provides this attitude
- Pitch and Yaw is stabilized by aerodynamic forces, roll is only controllable axis.
- Complete the EMS Entry Test
    - Test 1 – 5 will verify that EMS is operational
    - Test 5 will set the range to 37,000 ft/s.
    - Align the EMS scroll with this velocity in the entry pattern
        - Each entry pattern has a start line that is used to align it correctly
- RNG SET us used to set the range
- V0 is sett to the entry velocity in ft/s.
- Set the mode to ENTRY
    - The EMS will wait for .05G
    - The EMS will count down the range set
- At the point 05G mark, the point which deceleration can be sensed for the first time marks the entry phase
- Lift vector is pointed in the up direction, heads down towards Earth
- When the G’s build up to 2G – 2.5Gs, capture is achieved
- It continues in this attitude until it hits the dense part of the atmoshphere, with G’s climbing towards 7 G’s
- It will enter the first control period when the Command Module starts climbing
- The CM lift vector is rolled to point down within 70 seconds.
- This will move the entry to the second control part with G’s climbing up to 4 G’s.
- Use the EMS scroll and the EMS instruments to monitor the progress of the reentry.

The reentry profile will look something like this:



TIME FROM 400K FT	
TRAJECTORY EVENTS	MIN:SEC
400K FT (GET 304:18:00.5)	00:00
ENTRY S-BAND BLACKOUT	00:17
0.05G	00:29
KA-INITIATE CONSTANT DRAG	00:52
MAX HEATING RATE	01:12
RDOT = -700 FPS	01:20
PEAK G (FIRST)	01:23
SUBCIRCULAR VELOCITY	02:06
P64 TO P67	02:02
EXIT S-BAND BLACKOUT	03:36
PEAK G (SECOND)	05:32
GUIDANCE TERMINATION	06:44
DROGUE DEPLOYMENT	07:41
MAIN DEPLOYMENT	08:23
SPLASHDOWN	13:09

The parameters for the reentry is provided over the radio as a radio message.

V. ELECTRICAL POWER SYSTEM

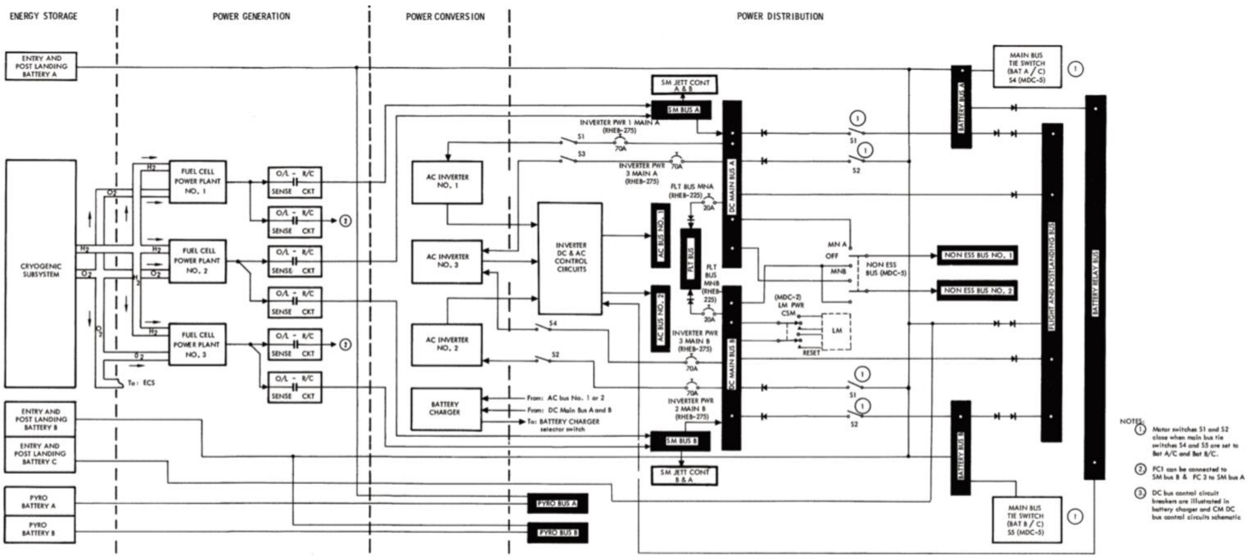
V. ELECTRICAL POWER SYSTEM

1. GENERAL

The electrical power subsystem (EPS) consists of the systems, reactants and equipment required to provide electrical power onboard the spacecraft. The main power sources are 3 Fuel Cells, 3 batteries and two pyro batteries. The power is distributed through several DC-busses and AC-busses. AC power is generated from DC through inverters.

The DC-busses in the CSM is the following:

- MAIN BUS A & B
- SM BUS A & B
- BAT BUS A & B
- BAT RELAY BUS
- FLIGHT BUS
- FLIGHT/POSTLANDING BUS
- NONESS BUS 1 & 2
- PYRO BUS



The EPS is mostly configured using the EPS switches on MDC-3.


FUEL CELL
FLOW
MODULE TEMP
SKIN
COND EXH
3
16
HAND HOLD
pH HI
FC RAD TEMP LOW
FUEL CELL RADIATORS
NORMAL
EMER BYPASS
FUEL CELL HEATERS
OFF
MASTER ALARM
FUEL CELL INDICATOR
DC AMPS
DC VOLTS
FUEL CELL MAIN BUS A
FUEL CELL PURGE
FUEL CELL REACTANTS
MAIN BUS B
RESET
DC INDICATORS
BAT BUS
MAIN BUS
BAT CHARGER
BAT C
FUEL CELL
PYRO BAT
BATTERY CHARGE
S BAND AUX
UP TLM
CMD RESET
PWR AMPL
TAPE MOTION
AC INVERTER
AC BUS 1
AC BUS 2
AC VOLTS
AC INDICATOR
VHF AM
DUPLEX
SIMPLEX
RCV ONLY
B DATA
VHF BCN
VHF RANGING
S BAND SQUELCH ENABLE
TAPE RECORDER
PCM/ANLG
RECORD
FWD
POWER
SCE
PMP
NORM
PCM BIT RATE
HIGH
LM PCM
PLAY
REWIND
AUX
LOW
MASTER VOLUME
POWER AUDIO / TONE
VOX SENS
PAD COMM
VOLUME
S BAND

2. ENERGY STORAGE

The primary source of energy is provided by the cryogenic gas storage system, named the Cryogenic Storage Subsystem. It provides hydrogen and oxygen to the power generating system, namely the Fuel Cells. Two hydrogen and two oxygen tanks are located in the service module, where they are controlled under cryogenic temperatures and pressure. This is controlled automatically, but manual control is also possible.

The two tanks are of sufficient size to provide a safe return from the furthest point of the mission on the fluid remaining in any one tank. The physical data of the cryogenic storage subsystem are as follows:

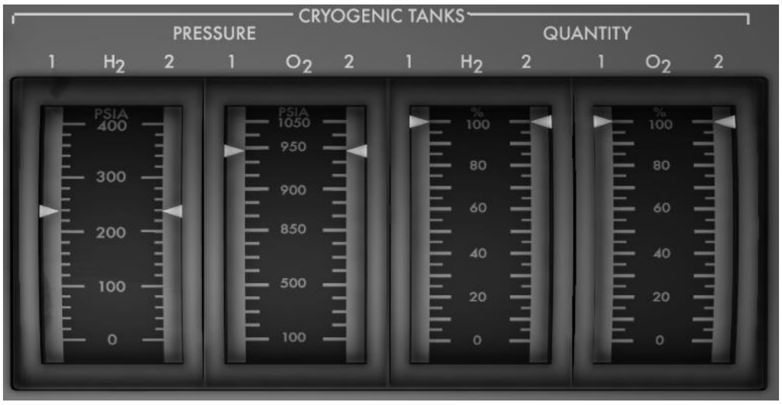
	Weight of Usable Cryogenics (lb/tank)	Design Storage Pressure (psia)	Minimum Allowable Operating Pressure (psia)	Approximate Flow Rate at Min dq/dm (+145°F environment) (lb/hr-2 tanks)	Approximate Quantities at Minimum Heater & Fan Cycling (per tank) (min dq/dm)
O_2	320 (min)	900±35	150	1.71	45 to 25%
H_2	28 (min)	245 (+15, -20)	100	0.140	53 to 33%

A secondary source of energy storage is provided by five silver oxide-zinc batteries located in the command module. Three of them are the rechargeable entry and postlanding batteries. They supply sequencer logic power at all times, supplemental d-c power for peak loads, and all the operating power required for reentry, landing and recovery.

Two pyro batteries provide energy for activation of pyro devices throughout all phases of a mission.

Each of the two oxygen tanks stores 320 lbs of cryogenic oxygen at 900+/-35 psia, and each of the two hydrogen tanks stores 28 lbs of hydrogen at 245+15/-20 psia.

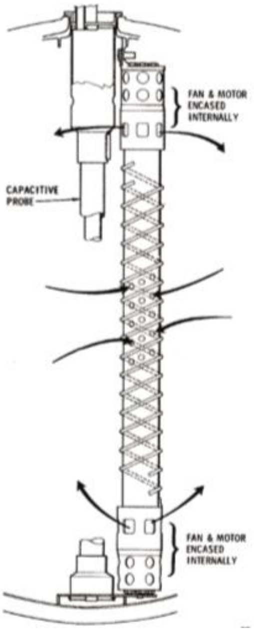
The quantity and pressure in each tank can be monitored on MDC-2.



It is imporant to often monitor the cryogenic power system. If something is wrong, it is important to detect this early so you can power down the non-essential systems to conserve the remaining power for as long as possible.

The CRYO PRESS warning light will illuminate when the pressure in one of the oxygen tanks falls below 800 psia, or exceeds 950 psia, or when hydrogen exceeds the 220 to 270 psia limits.
The MASTER ALARM will also come on when this warning is illuminated.

Heaters are used to maintain nominal pressure in each of the tanks. A heater and a fan is installed in each tank. The heater is adjusting the pressure by heating the substance, and the fan is used to circulate the substance to avoid stratification.



Two parallel d-c heaters in each tank supply the heat necessary to maintain design pressures. Two parallel 3-phase a-c circulating fans circulate the fluid over the heating helements to maintain a uniform density and decrease the probability of stratification.

The following table shows the flow rate at nominal pressure, and the repressurization time:

	Oxygen		Hydrogen	
Quantity (percent)	Repressurization Time (Minutes) (865 to 935 psia)	Flow at 865 psia	Repressurization Time (Minutes) (225 to 260 psia)	Flow at 225 psia
100	4.0	3.56	20.0	0.38
95	4.3	3.97	21.0	0.42
90	4.6	4.55	22.0	0.46
85	5.0	5.27	23.0	0.49
80	5.4	6.02	24.5	0.52
75	5.7	7.01	26.5	0.65
70	6.5	7.94	28.5	0.76
65	7.4	9.01	31.0	0.80
60	8.7	10.80	33.5	0.87
55	9.6	12.54	36.0	0.93
50	10.8	14.19	39.0	0.97
45	11.5	15.69	41.0	0.98
40	12.4	17.01	41.0	0.97
35	12.6	17.56	41.0	0.94
30	13.0	17.56	40.5	0.91
25	13.1	16.55	40.5	0.83
20	13.2	15.48	42.0	0.71
15	14.5	12.28	47.0	0.54
10	17.8	8.76	58.0	0.37
7.5	21.4	7.09	71.0	0.23
5	24.0	5.37	Continuous	0.16

The H2/O2 HEATERS switches (MDC-2), as well as the H2/O2 FANS (MDC-2) switches controls these system.

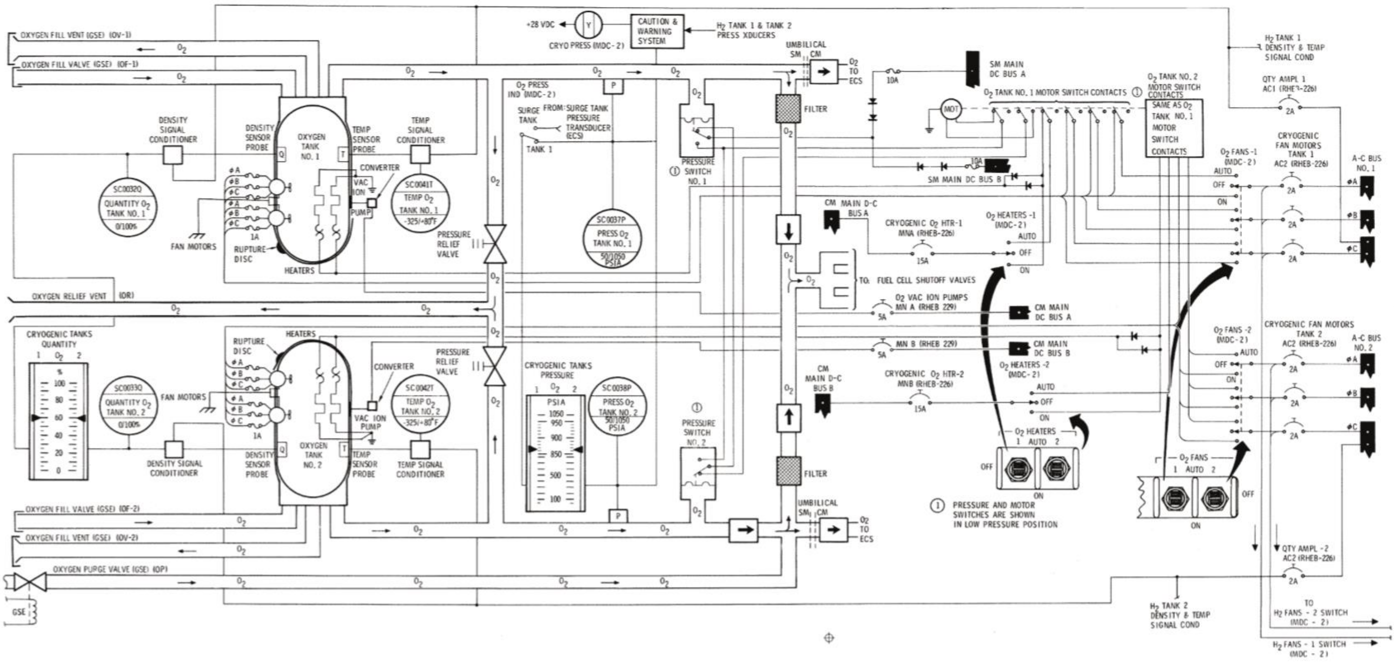
AUTO will control the heaters automatically and is the nominal setting. Manual control is obtained by setting them to either ON or OFF. There are no atuomatic detection systems if manual mode is used so ensure to monitor carefully in this mode. When in AUTO, the heaters will automatically be turned ON when both tanks are below 225 psia (H2)/865 psia (O2), and turn OFF when one of the tanks reaches 260 psia (H2)/935 psia (O2).

The spring-loaded FUEL CELL REACTANTS switches (MDC-3) controls the cryogenic flow to the fuel cells. They are noramlly open during the duration of the flight. Once they are opened during preflight, there is no way to restart them. This means that if you close the reactant valves, the fuel cells can't be restarted and will stay off for the rest of the mission.

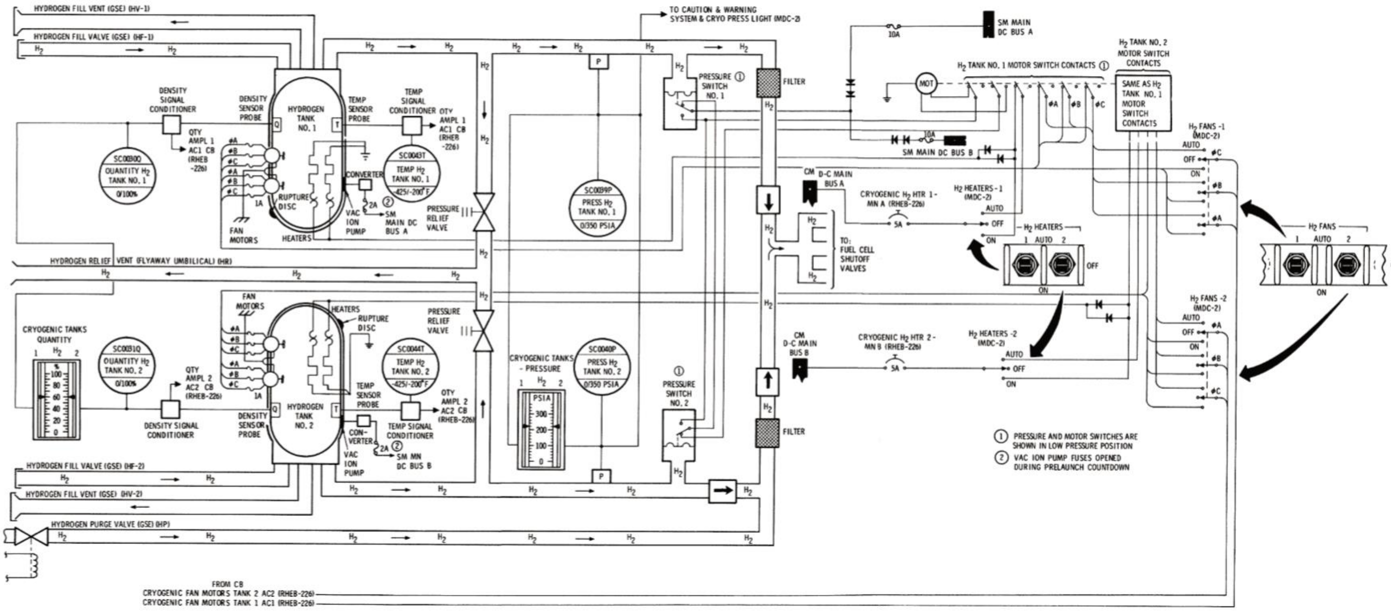
The talkbacks are grey when open and normal, and barberpoled when closed/shut off.

The FC REACS cbs on panel 226 enables or disabled the power to the FUEL CELL REACTANTS switches on MDC-2.

The Oxygen Cryogenic Storage Subsystem can be seen in the figure below.



The Hydrogen Cryogenic Subsystem can be seen in the figure below.



3. POWER GENRATION

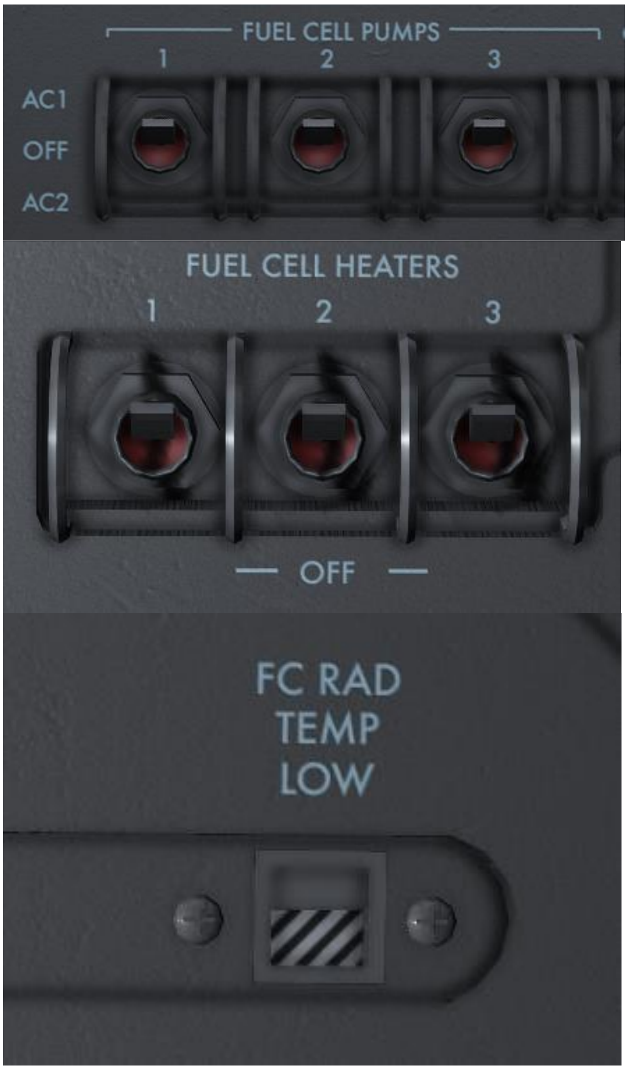
Three Fuel Cell (FC) power plants generates power through the electrochemical reaction of hydrogen (H2) and oxygen (O2). They provide the primary d-c power to the spacecraft systems until CM/SM separation. The electricity is generated by reacting O2 and H2 with H2O-steam.

Each Fuel Cell power plant is capable if normally supplying from 400 to 1420 watts at 27 to 31 vdc to the power distribution system.

All three fuel cells are normally generating power and are nominally used for the entire duration of the mission (until CM/SM separation), but two of them are adequate to complete the mission if power management is done right.

The fuel cells can be configured and connected to the power distribution system. The normal setup is that Fuel Cell 1 is connected to main d-c bus A; Fuel Cell 2 is connected to main d-c bus A and B; and Fuel Cell 3 is connected to main d-c bus B.

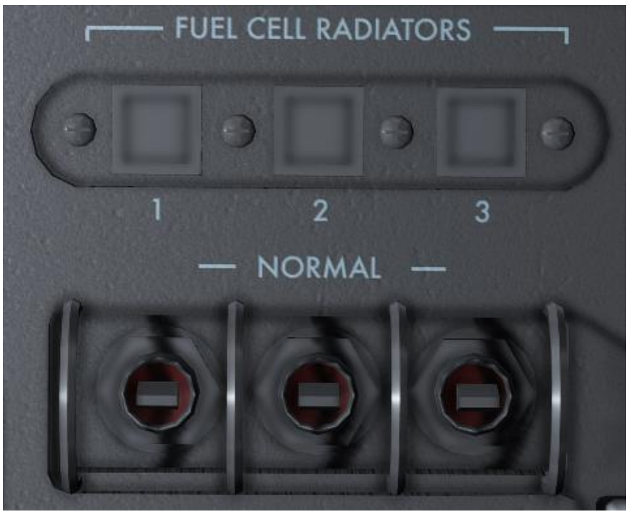
The reaction of Oxygen (O2) and Hydrogen (H2) generates the needed electricity, in additon to water (H2O) and heat. The excess heat is used by the Environmental Control System (ECS) and radiated to space. The water is also distributed to the ECS system. A shared cryogenic manifold and O2/H2 are shared between the otherwise fully independent Fuel Cell powerplants.



The water, through the ECS, ejects its heat through Fuel Cell radiators before entering the condencer again. The FUEL CELL PUMPS switches on MDC-5 controls the circulation loop. These are usually powered throughout the flight. The FUEL CELL HEATERS are controlling the heat in the system. The Fuel Cells are only funcional when the temperature is minimum 360 degrees F. The heaters will preheat the hydrogen. They are normally ON.

The FC RAD TEMP LOW talkback indicates if the Fuel Cell radiator temperature is low (< -30°F). The radiators are heated due to load on the Fuel Cells. It the FC load is low, the H2O/H2 exhaust temperature can be so low that it’s not possible to heat it back to the nominal temperature. If this happens, it is possible to avoid 3/8 of the radiator.

The longer the exhaust stays in the radiator, the lower the temperature.

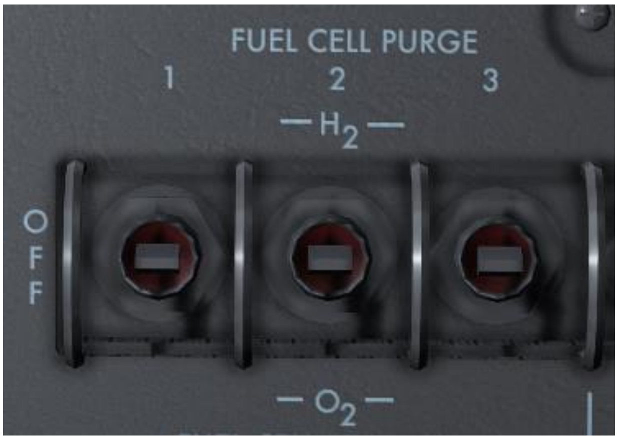


These three talkback-switches on MDC-3 controls the bypass of the radiators. If the talkbacks are gray, the bypass is closed and is the normal setting. If they are barberpole, the bypass is open, and the reactants are bypassing the radiator.

NORMAL will close the bypass, letting the substance go through the radiators normally.
EMER BYPASS will open the bypass of the selected fuelcell.

PURGING

Over time, impurities in the reactant will accumulate. Each of the Fuel Cells can be purged to flush out the impurities, correct hydrogen tank overpressurization or correct an overpressure condition in the oxygen system.

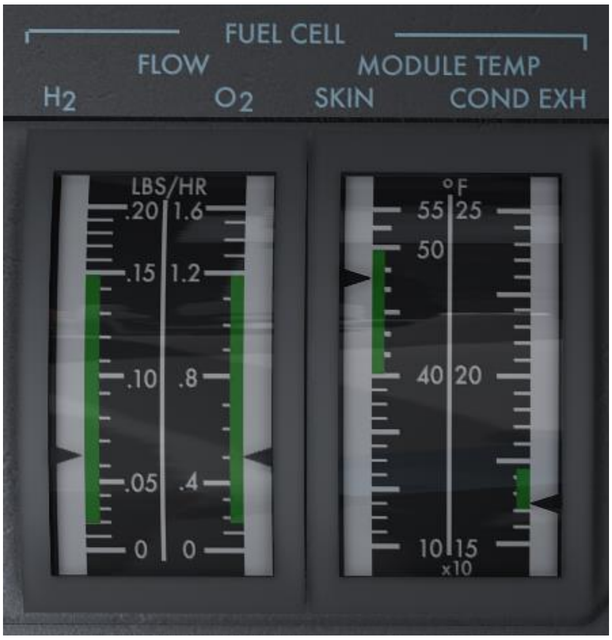


The FUEL CELL PURGE switches will purge the selecte Fuel Cell substance. The H2 purge selection will flush out impurities in the H2, while O2 will flush out the impurities in the O2. It will provide a high flow of the substance through the Fuel Cell; cleaning them.

Warning: Before the H2 PURGE, the H2 purge line needs to be heated in 20 minutes. (MDC-3)

The H2 PURGE LINE HTR needs to be ON for 20 minutes before performing a H2 purge. (MDC-3)

The fuel cell performance can be monitored on the Fuel Cell gauges. They provide information about the O2 and H2 flow, skin temperature and condensator outlet temperature of the selected fuel cell. The FUEL CELL INDICATOR-switch lets you choose what Fuel Cell to monitor.



The gauges above (MDC-3) provides monitoring information about the fuel cells. The green tape indicates that it's in the normal zone.

The Fuel Cell indicator (MDC-3) lets you choose what fuel cell you wish to monitor.

The pH HI-talkback indicates if the PH level in the selected Fuel Cell is high. If this is barberpole, the pH factor of the exhaust H_2O is over 9. This means the electrilyte of the fuel cell is leaking and needs to be shut down immediately.

The FC 1, FC 2 and FC 3 light will illuminate if the fuel cell is in a critical condition. A MASTER ALARM will sound with this warning. The following conditions are checked:

- H2 flow rate > 0.161 lb/h
- O2 flow rate > 1.276 lb/h
- Skin temperature below 360°F
- Skin temperature above 475°F
- Condenser exhaust temp below 155°F
- Condenser exhaust temp above 175°F
- pH Factor of the exhaust H20 > 9
- Radiator outlet temp < -30°F

BATTERIES

The three rechargable silver oxide-zinc entry & postlanding batteries power the CM after CSM separation, and is design to last during entry, landing and recover. During dV-maneuvers, they will also provide additonal power to the Fuel Cells. Battery A and Battery B are usually on during high power demands, but Battery C can also be used if needed.

They can also provide power during emergencies if two or more FCs are disabled, or if the EPS control circuitry, sequencer logic power, recovery aids or the pyro batteries fails.

A battery charger is available to recharge these batteries.

Two silver oxide-zinc batteries are supplying power to the SECS pyrotechnics. These are completely isolated.

Performance characteristics of each SC battery are as follows:

Battery	Rated Capacity per Battery	Open Circuit Voltage (max.)	Nominal Voltage	Minimum Voltage	Ambient Battery Temperature
Entry and Postlanding, A, B, and C (3)	40 amp-hrs (25 ampere rate)	37.8 vdc max. (37.2 vdc in flight)	29 vdc (35 amps load)	27 vdc (35 amps load)	50° to 110°F
Pyro A and B (2)	0.75 amp-hrs (75 amps for 36 seconds)	37.8 vdc max. (37.2 vdc in flight)	23 vdc (75 amps load)	20 vdc (75 amps load) (32 vdc open circuit)	60° to 110°F

NOTE Pyro battery load voltage is not measurable in the SC due to the extremely short time they power pyro loads.

4. POWER CONVERSION (A-C)

Primary d-c power is converted into a-c by solid state static inverters that provide 115/200-volt 400-cps 3-phase a-c power ip to 1250 volt-ampere each. A-C power is connected by motor switch controls to two a-c buses for distribution to the a-c loads. One inverter has the capability of supplying all spacecraft primary a-c power. One inverter can control both buses while the two remaining inverters act as redundant sources. However, throughout flight, each bus is powered by a separate inverter.

It is important to know that inverter outputs cannot by phase synchronized, so interlocked motorized switching circuits are incorporated to prevent the connection of two inverters to the same bus.

5. POWER DISTRIBUTION

Power is distributed by the following buses:

- MAIN BUS A & B, powered by the three fuel cells and/or entry & postlanding batteries A,B and C
- SM BUS A & B through the main d-c buses
- BAT BUS A & B, powered by its respective entry & postlanding battery A and B. Battery C can power either or both buses if battery A and/or B fail.
- BATTERY RELAY BUS, powered by entry & postlanding batteries through their battery buses.
- FLIGHT BUS, powered through both main d-c buses.
- FLIGHT/POSTLANDING BUS, powered through both main d-c buses, or directly by the three entry and postlanding batteries, A, B and C.
- NONESS BUS 1 & 2, powered through either d-c main bus A or B.
- PYRO BUSES, isolated from the main electrical power system. Can be powered by the entry batteries.

Distribution of d-c power is accomplished via two redundant d-c buses in the service module. These are again connected to two redundant buses in the command module through a SM deadface, the CSM umbilical, and a CM deadface. These are Main Bus A (MNA) and Main Bus B (MNB).

Two other d-c buses exist for servicing non-essential loads (the non-essential buses), another bus for servicing the inflight telecommunications equipment named the flight bus. Then we have two battery buses for distribuing power to sequencers, gimbal motor controls, and servicing the battery relay bus for power distribution switching. The last bus we have is the flight and postlanding bus for servicing some communications equipment and the postlanding loads.

Three-phase a-c is distributed via two redundant a-c buses, providing bus selection through switches in the a-c operated component circuits.

Power to the lunar module (LM) is provided through two umbilicals witch are connected after compeltion of transposition and docking (usually after the TLI phase of the mission).

A d-c sensing circuit monitors voltage on each main d-c bus and an a-c sensing circuit monitors voltage on each a-c bus. The d-c sensors provide an indication of an undervoltage (means that part of the energy sources is providing less voltage than assumed) by illuminating a warning light. The a-c sensors illuminate a warning light when high- or low-voltage limits are exceeded.

DC POWER

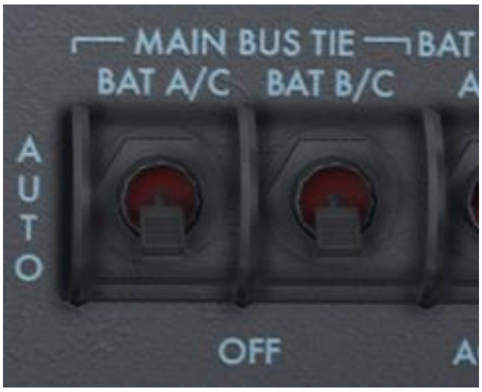
The MAIN BUSES (A & B) can be powered using the Fuel Cells and the Batteries. However, they are primarly powered by the Fuel Cells. Each Fuel Cell can be connected to either or both Main D-C Bus A and B.

The FUEL CELL MAIN BUS-switches connects the Fuel Cell to the main d-c buses. ON will connect the Fuel Cell to the main bus selected. The center position will arm the FC-BUS DISCONNECT light on the caution & warning panel.

The talkback indicator indicates if the Fuel Cell is connected to the selected main d-c bus. Gray means it is connected while barberpoled means it is disconnected.

The RESET switch controls the undervolt circuit. Middle position means it is armed. When armed, the sensor will illuminate the MAIN BUS A/B UNDERVOLT warning light and the MASTER ALARM. The UP/RESET position will reset this and extinguish the warning light. OFF will disarm the logic.

The batteries can also power the main d-c buses. Battery Bus A can power Main Bus A, and Battery Bus B can power Main Bus B. Battery Bus C can power either Main Bus A or Main Bus B.



The MAIN BUS TIE switches will connet the battery bus to the main bus. If BAT A/C is ON, BAT BUS A will be connected with MAIN BUS A and BATTERY BUS C is connected to MAIN BUS B. If BAT B/C is ON, the BAT BUS B will be connected to MAIN BUS B and BUS C is connected to MAIN BUS A.

Usually BATTERY C is disconnected so it won't acctually power the other bus (panel 275).

OFF will open the bus tie and isolates the BAT BUS and BAT C from MAIN BUS A/B.

AUTO will automatically switch to battery power in case of an EDS-abort.

The MAIN A – BAT C cbs and the MAIN B – BAT C on panel 275 enables or disables the battery C connection to the main bus selected above.

Backcurrent to the batteries are prevented using diodes between the BATTERY BUS A/B, MAIN BUS A/B and BAT C.

There are no diodes that prevent this between BAT C and BAT BUS A/B.

If BAT C is connected to a battery bus with BAT C TO BAT BUS A/B cbs on panel 250, the respective battery has to be disconnected from the bus.

This is done by opening the BAT A/B PWR ENTRY/POSTLANDING circuit breaker to avoid damage to both of the batteries.

The Battery Relay Bus powers the FUEL CELL MAIN BUS switches, FUEL CELL RADIATOR switches, FUEL CELL REACTANT swiches and the DC/AC sensing circuits

The FLIGHT/POSTLANDING BUS is powered by both MAIN BUSSES, both BAT BUSSES and BAT C over diodes. Normally, the FLIGHT & POST LANDING - BAT BUS A, - BAT BUS B and - BAT C circuit breakers are open, so that only both MAIN BUSSES power this bus.

During earth landing these cbs are closed, as both MAIN BUSSES are powered down after splashdown. The FLIGHT/POSTLANDING BUS powers the equipment necessary after splashdown, e.g. postlanding vent, dye marker, recovery bacon, VHF COM.

MONITORING

Monitoring over the electrical system is done over the DC AMPS-meter and DC VOLTS-meter.

DC AMPS monitors the LOAD on the main buses, battery buses, the fuel cells, battery C, the pyro batteries and the battery charger.

Monitors the VOLTAGE on the main buses, battery buses, the fuel cells, battery C, the pyro batteries and the battery charger.

Selects what to monitor on the DC AMPS/DC VOLTS gauge.

AC POWER

The AC busses provides a-c power to the spacecraft through inverters. Three inverters are available. Inverter 1 is powered by MNA, Inverter 2 is powered by MNB, and inverter 3 is powered by MNA or MNB. As mentioned earlier, only one inverter can be connected to an a-c bus at the same time, this is mechanically protected.

The switches for controlling a-c power is located on MDC-3. D-C power to the inverters is controlled by the AC INVERTER switches. As you can see in the image above, AC INVERTER 1 can be either OFF or in MNA, AC inverter 2 can be OFF or in MNB, while Inverter 3 can be OFF, MNA or MNB.

The two bottom rows of switches controls the inverter outputs. It can only output power to one AC bus at the time. UP will tie it to the selected bus, and down will disconnect it.

The inverters has temperature sensing, and the INV 1/2/3 TEMP HI warning light will illuminate with a MASTER ALARM.

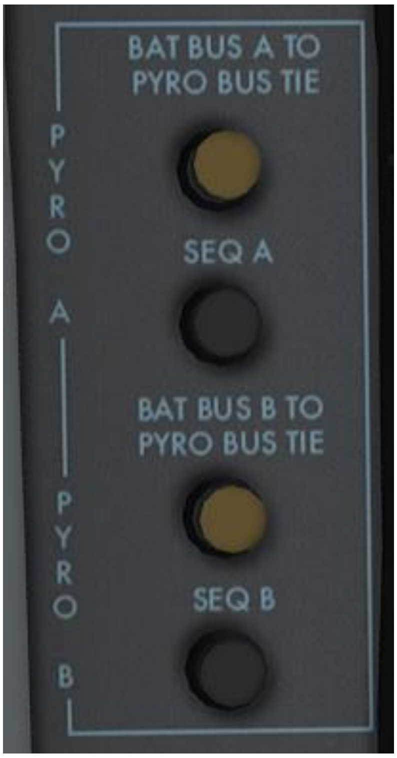
The RESET switch controls the over-/undervolt and overload circuit. Middle position means it is armed. When armed, the sensor will illuminate the AC BUS 1/2 OVERLOAD warning light and the MASTER ALARM. It will also illuminate the AC BUS 1/2 warning light with a MASTER ALARM switch if an under- or overvoltage occures. The UP/RESET position will reset this and extinguish the warning light. OFF will disarm the logic. The inverter powering the bus will be disconnected during an overvoltage. Reset will connect it again.

The AC VOLTS gauge shows the AC volts on the selected phase of the a-c bus.

Selects what phase to monitor in the AC VOLTS gauge

PYRO BATTERIES

The two pyro batteries provides power to the pyrotechincs of the sequencer. When the sequencer initiates a separation or jettison, the pyro batteries will charge the explosives needed.



The pyro batteries are powered by the PYRO A/B SEQ A/B circuit breakers.

BAT BUS A/B TO PYRO BUS TIE circuit breaker will power the respective pyro battery to the respective main d-c bus in case one or both fail. The above circuit breaker (PYRO A/B SEQ A/B) will need to be open for the pyro battery that you want to disable before doing this. If not, both the batteries will be damaged.

BATTERY CHARGER

There three main batteries (A,B and C) can be recharged by the battery charger. It uses d-c power from both MNA and MNB, as well as a-c power from one if the d-c busses.

The battery chargrs selector is used to recharge a battery.

Ensure there are no load on the battery before recharging. Battery A can only be recharged when the MAIN BUS TIE BAT A/C switch is OFF, and Battery B can only be recharged when the MAIN BUS TIE BAT B/C switch is OFF. To recharge Battery C, both the MAIN BUS TIE switches must be OFF.

The BAT CHGR switch selects what a-c bus that should provide power to it.

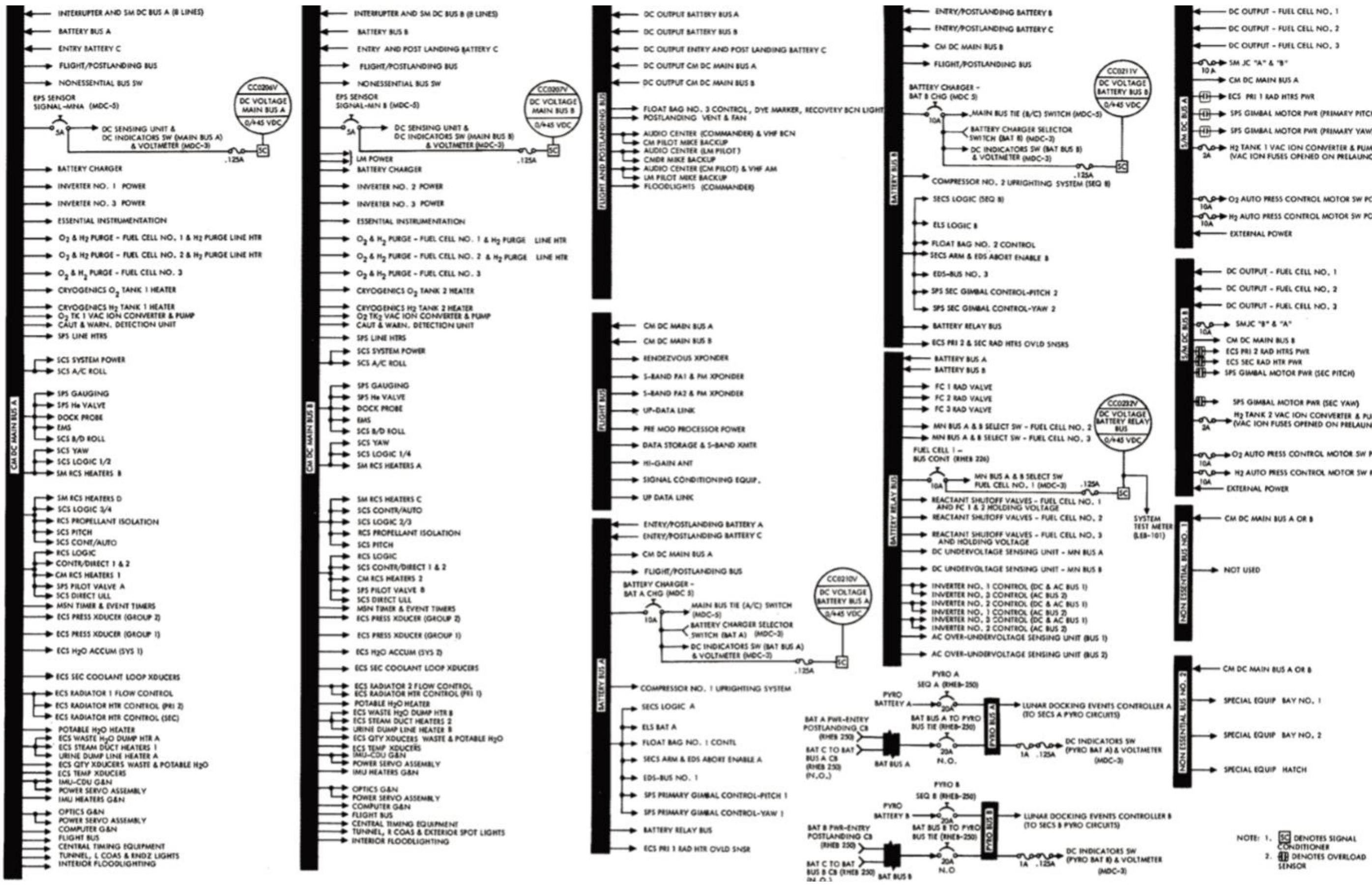
BAT RLY BUS – BAT A/B should be off when recharging battery A/B to isolate it from the loads on BAT RLY BUS.

Using the d-c selector setting BAT CHARGER, you can monitor the output voltage and amperes of the battery charger. The inner scale of the DC AMPS meter shows the output amps, and is ranging from 0 to 5 amps.

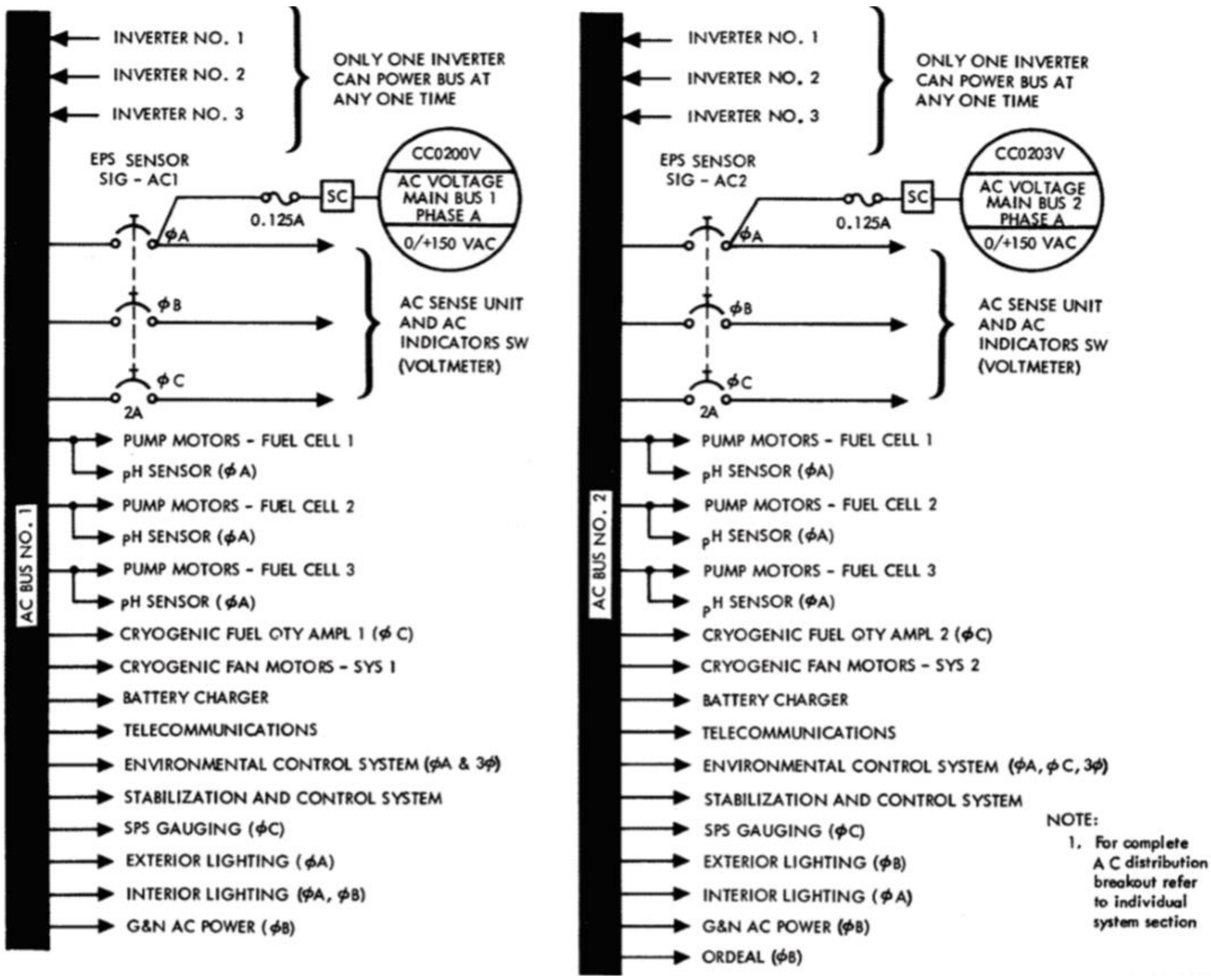
The battery is fully charged when the output voltage of the battery currently charging reaches 39.8 volts. Set the BATTERY CHARGE selector to OFF as soon as possible when the battery is fully charged.

ELECTRICAL COMPONENTS

D-C components are connected by following the chart below:

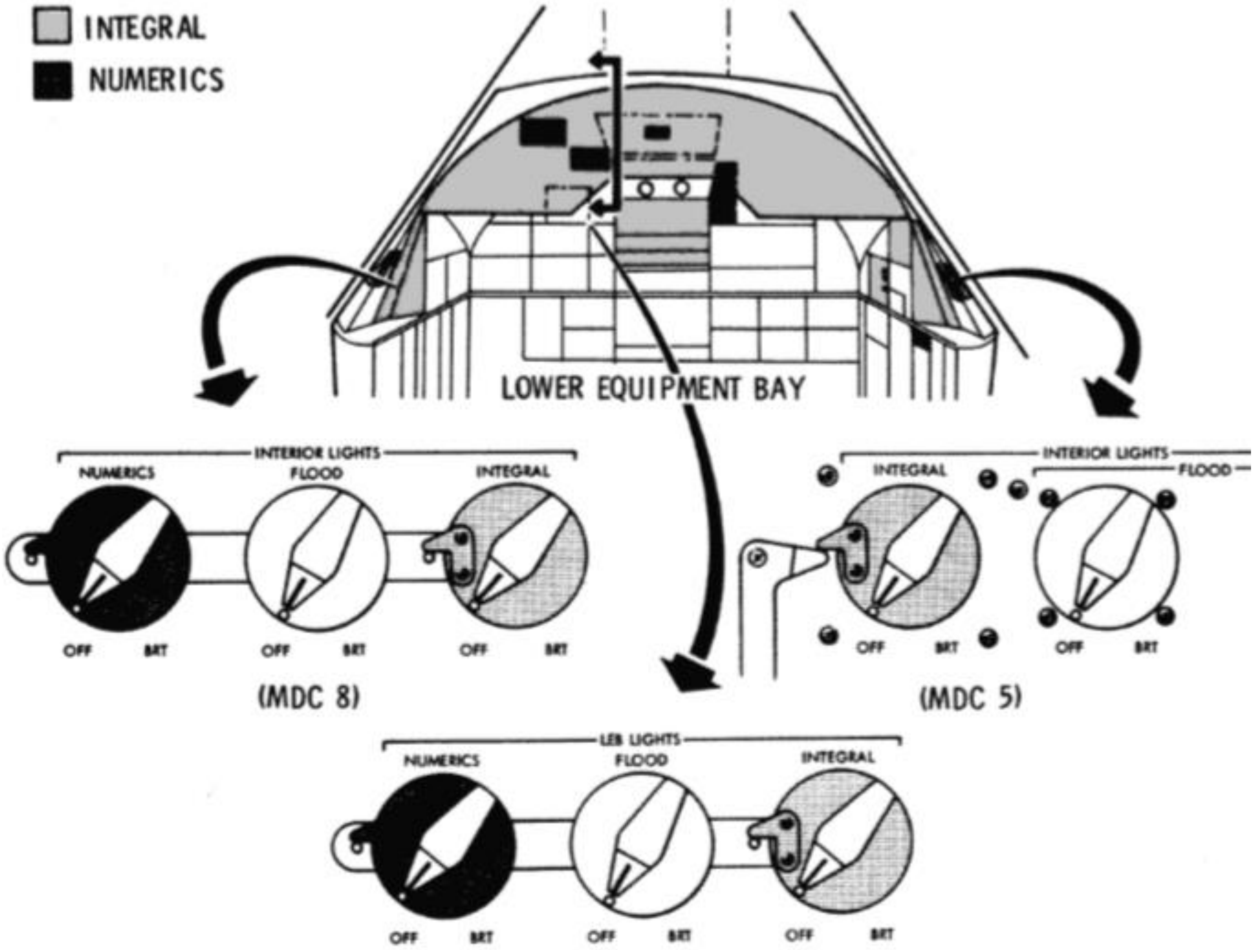


A-C components are connected following the chart below:



6. INTERIOR LIGHTING

There are three control panels to control the lights, one is on MDC-5, another on MDC-8 and another on LEB-100. These controls can dim the interior flood lights, integral instrument lights and the numerics.



VI. ENVIRONMENTAL CONTROL SYSTEM

VI. ENVIRONMENTAL CONTROL SYSTEM

1. GENERAL

The environmental control system (ECS) is designed to provide the flight crew with a conditioned environment that is both life-supporting, and as comfortable as possible. The ECS is aided in the accomplishment of this task through an interface with the electrical power system, which supplies oxygen and potable water. The ECS also interfaces with the electronic equipm ent of the several Apollo systems, for which the ECS provides thermal control, with the lunar module (LM) for pressurizing the LM, and with the waste management system to the extent that the water and urine dump lines can be interconnected.

The ECS is operated continosly throughout all Apollo mission phases. During this operating period the system provides the following three major functions for the crew:

- Spacecraft atmosphere control
- Water management
- Thermal control

Control of the spacecraft atmosphere consists of regulating the pressure and temperature of the cabin and suit gasses; maintaining the desired humidity by removing excess water from the suit and cabin gases; controlling the level of contamination of gases by removing CO2, odors, and particulate matter; and venting the cabin after landing. There are provisions for pressurizing the lunar module during docking and subsequent CSM/LM operations.

Water management consists of collecting, sterilizing, and storing the potable water produced in the fuel cells, and delivering chilled and heated water to the crew for metabolic consumption, and disposing of the excess potable water by either transferring it to the waste water system or by dumping it overboard. Provisions are also made for the collection and storage of waste water, delivering it to the glycol evaporators for supplemental cooling, and dumping the excess waste water overboard.

Thermal control consists of removing the excess heat generated by the crew and the spacecraft equipment, transporting it to the cabin heat exchanger, and rejecting the unwatned heat to space, either by radiation from space radiators, or in the form of steam by boiling water in the glycol evaporators.

Five subsystems operating in conjection with each other provide the required functions:

- Oxygen subsystem

- Pressure suit circuit (PSC)
- Water subsystem
- Water-glycol subsystem
- Post-landing ventilation (PLV) subsystem

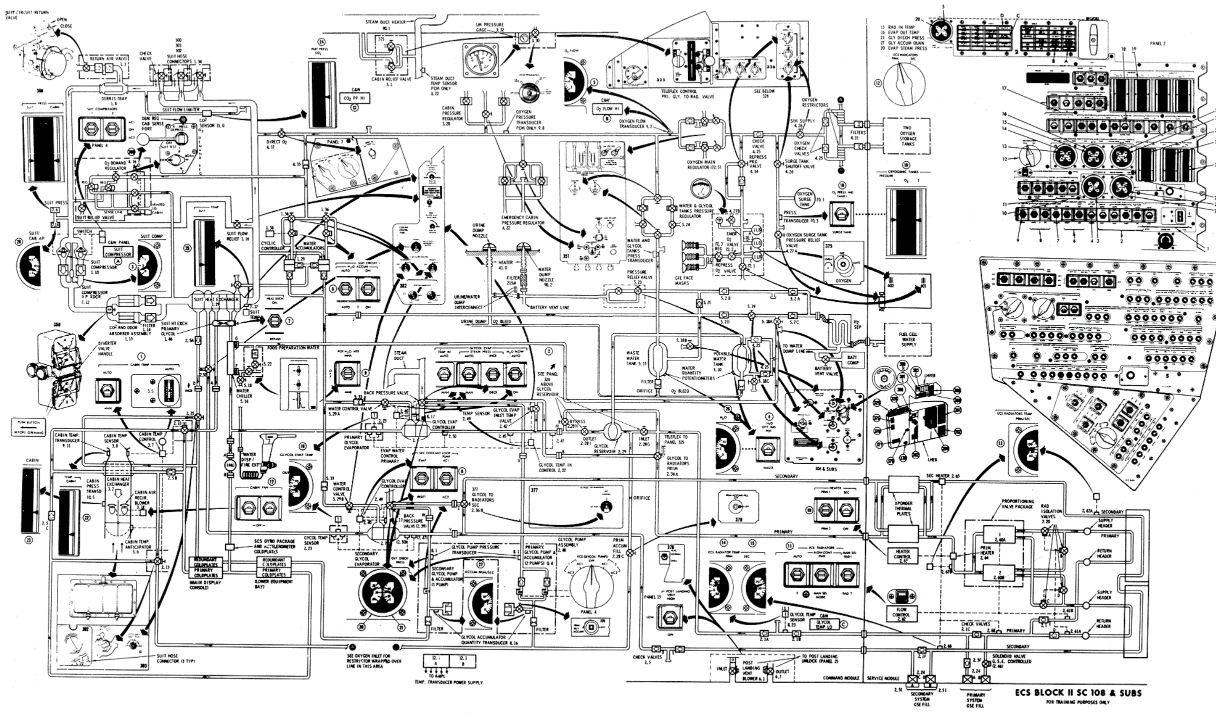
The oxygen subsystem controls the flow of oxygen within the command module (CM); stores a reserve supply of oxygen for use during entry and emergencies; regulates the pressure of oxygen supplied to the subsystem and PSC components; controls the cabin pressure in normal and emergencey (high flow-rate) modes; controls pressure in the water tanks and glycol reservoirs; and provides for PSC purging via DIRECT O2 valve.

The pressure suit circuit provides the crew with a continously conditioned atmosphere. It automatically controls suit gas circulation, pressure, and temperature; and removes debris, excess moisture, odors, and cabon dioxide from both the suit and cabin gases.

The water system (potable section) collects and stores potable water; delivers hot and cold water to the crew for metabolic copurposes; and augments the waste water supply for evaporative cooling. The waste water section collects and stores water extracted from the suit heat exchanger, and distributes it to the water inflow control valves of the evaporators, for evaporative cooling.

The water-glycol subsystem provides cooling for the PSC, the potable water chiller, and the spacecraft equipment; and heating or cooling for the cabin atmosphere.

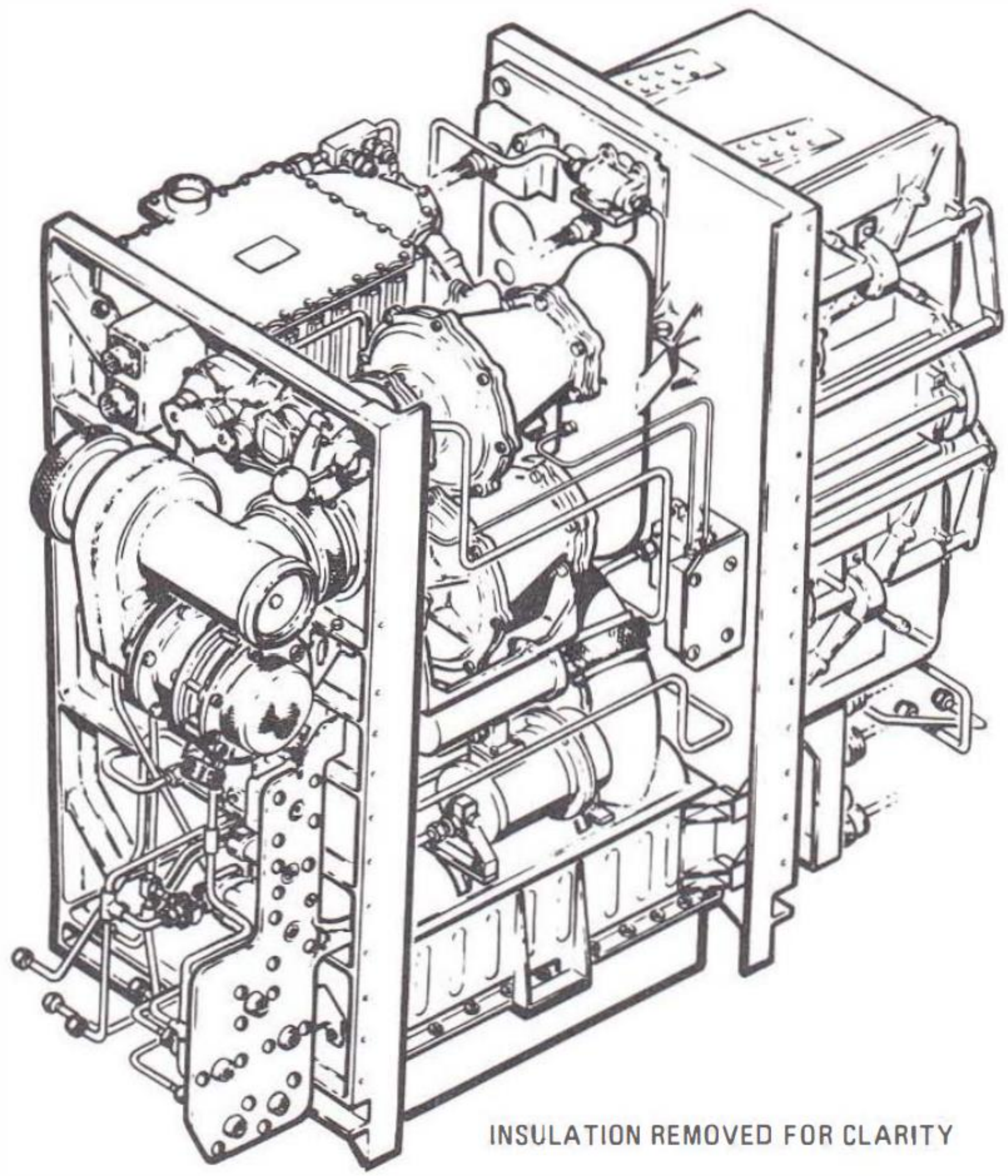
The postlanding ventilation subsystem provides a means for circulating ambient air through the command module cabin after landing.



In the subsequent sections in this chapter, we will demystify and explain the diagram above. It shows how all the ECS related systems work together, but the diagram is massive and requires a lot of studying to understand, and follow.

2. FUNCTIONAL DESCRIPTION & OPERATIONS

The environmental control system operates continously throughout all mission phases. Control begins during preparation for launch and continues through recovery. The following paragraphs describes the operating modes and the operational characteristics of the ECS from the time of crew insertion to recovery.



2.1. SPACECRAFT ATMOSPHERE CONTROL

During prelaunch operations the SUIT CIRCUIT RETURN VALVE is closed; and the DIRECT O2 valve is opened slightly (approximately 0.2 pound per hour flowrate) to provide an oxygen purge of the PSC. Just before prime crew insertion the O2 flowrate is increased to 0.6 pound per hours. This flow is in excess of that required for metabolic consumption and suit leakage. The excess flow causes the PSC to be pressurized slightly above the CM cabin. The slight overpressure maintains the purity of the PSC gas system by preventing the cabin gases from entering the PSC.

Any changes made in the pressure of composition of the cabin gas during the prelaunch period is controlled by the ground support equipment through the purge port in the CM side hatch.

As soon as the crew connects into the PSC, the suit gas becomes contaminated by CO2, odors, moisture, and is heated. The gases are circulated by the suit compressor through the CO2 and odor absorber assembly where a portion of the CO2 and odors are removed; then through the heat exchanger, where they are cooled and the excess moisture is removed. Any debris that might get into the PSC is trapped by the debris trap or on gelt pads on the upstream side of each LiOH cartridge.

When the crew is partially suited or in a shirtsleeve environment they contaminate the cabin gases. Since the contaminants can only be removed in the PSC, the crew must necessarily configure the PSC to allow for adequate flow of gases out of the PSC into the cabin and back into the PSC through the suit return hoses and the SUIT CIRCUIT RETURN VALVE. For the shirtsleeve mode it can be accomplished by disconnecting the inlet hoses and placing the flow control valve in the CABIN FLOW position in addition to the preceding steps.

During the ascent the cabin remains at sea level pressure until the ambient pressure decreases a nominal 6 psi. At that point the CABIN PRESSURE RELIEF valve vents the excess gas overboard, maintaining cabin pressure at 6 psi above ambient. As the cabin pressure decreases, a relief valve in the O2 DEMAND REGULATOR vents suit gases into the cabin to maintain the suit pressure slightly above the cabin pressure.

Sometime after attaining orbit it will be necessary to close the DIRECT O2 valve to conserve oxygen. After the DIRECT O2 valve is closed, make-up oxygen for the PSC is supplied by the DEMAND REGULATOR when the SUIT CIRCUIT RETURN VALVE is closed or from the cabin via the cabin pressure regulator when the SUIT CIRCUIT RETURN VALVE is open.

During normal space operations, the cabin pressure is maintained at a nominal 5 psia by the cabin pressure regulator, at flowrates up to 1.4 pounds per hour. In the event a high leak rate develops, the EMERGENCY CABIN PRESSURE regulator will try to supply oxygen at high flow rates to maintain cabin pressure above 3.5 psia for a short period of time.

When performing depressurized operations the suit circuit pressure is maintained above 3.5 psia by the O2 DEMAND REGULATOR; the cabin pressure regulator shuts off automatically to prevent wasting oxygen.

Prior to entry SUIT CIRCUIT RETURN VALVE is closed, isolating the suit circuit from the cabin; the O2 DEMAND REGULATOR then controls suit pressure. Cabin pressure is maintained during the descent by the cabin pressure regulator until the ambient pressure rises to a maximum of 0.9 psi above the cabin pressure. At that point the cabin relief valve will open, allowing ambient air to flow into the cabin. As the cabin pressure increases, the O2 DEMAND

REGULATOR admits oxygen into the suit circuit to maintain the suit pressure slightly below the cabin, as measured at the suit compressor inlet manifold.

After spacecraft landing, the cabin is vented with ambient air by postlanding ventilation fan and valves. When the CM is floating upright in the water, the POST LANDING VENT switch is placed in the HIGH (day) or LOW (night) positions. Either of those positions will supply power to open both vent valves and start the fan. In the HIGH position, the fan will circulate 150 cubic feet per minute (cfm); LOW, 100 cfm.

2.2. WATER MANAGEMENT

In preparing the spacecraft for the mission the potable and waste water tanks are partially filled to ensure an adequate supply for the early stages of the mission. From the time the fuel cells are placed in operation until the CSM separation, the fuel cells replenish the potable water supply. A portion of the water is chilled and made available to the crew through the drinking fixture and the food preparation unit.

From the time the crew connects into the suit circuit until entry, the water accumulator pumps are extracting water from the suit heat exchanger and pumping it into the waste water system. The water is delivered to the glycol evaporators through individual water control valves. Provisions is made for dumping excess waste water manually when the tank is full.

2.3. THERMAL CONTROL

Thermal control is provided by two water-glycol coolant loops (primary and secondary). During prelaunch operations ground servicing equipment cools the water-glycol and pumps it through the primary loop, providing cooling for the electrical and electronic equipment, and the suit and cabin heat exchangers. The cold water-glycol is also circulated through the reservoir to make available a larger quantity of coolant for use as a heat sing during the ascent. Additional heat sink capability is obtained by selecting maximum cooling on the CABIN TEMP selector, and placing both cabin fans in operation. This cold soaks the CM interior structure and equipment. Shortly before launch, one of the primary pumps are placed in operation, the pump in the ground servicing unity is stopped, and the unit is isolated from the spacecraft system.

During the ascent the radiators will be heated by aerodynamic friction. To prevent this heat from being added to the CM thermal load, the PRIMARY GLYCOL TO RADIATORS valve is placed in the PULL TO BYPASS position approximately 75 seconds before launch. The coolant then circulated within the CM portion of the loop.

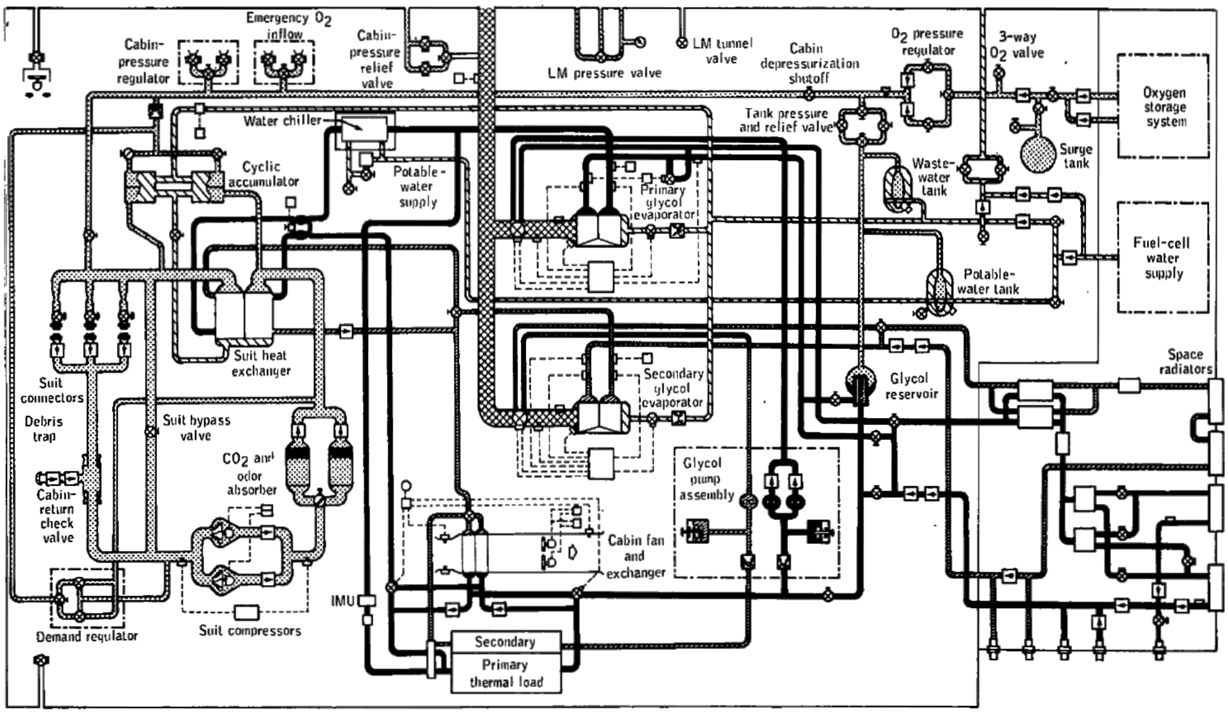
The heat that is generated in the CM, from the time that the ground servicing unit is isolated until the spacecraft reaches 110K feet it is possible to reject the excess heat by evaporating water in the primary glycol evaporator.

After attaining orbit the reservoir is isolated from the loop to maintain a reserve quantity of coolant for refilling the primary loop in case of loss of fluid by leakage. The PRIMARY GLYCOL TO RADIATORS valve is placed in the position (control pushed in) to allow circulation through the radiators and the radiator outlet temperature sensors. If the radiators have cooled sufficiently (radiator outlet temperature is less than the inlet) they will be kept on-stream; if not, the will be bypassed until sufficient cooling has taken place. After the radiators have been placed on-stream, the glycol temperatures control is activated (GLYCOL EVAP EMP IN switch in AUTO); and the CABIN TEMP selector is positioned as desired.

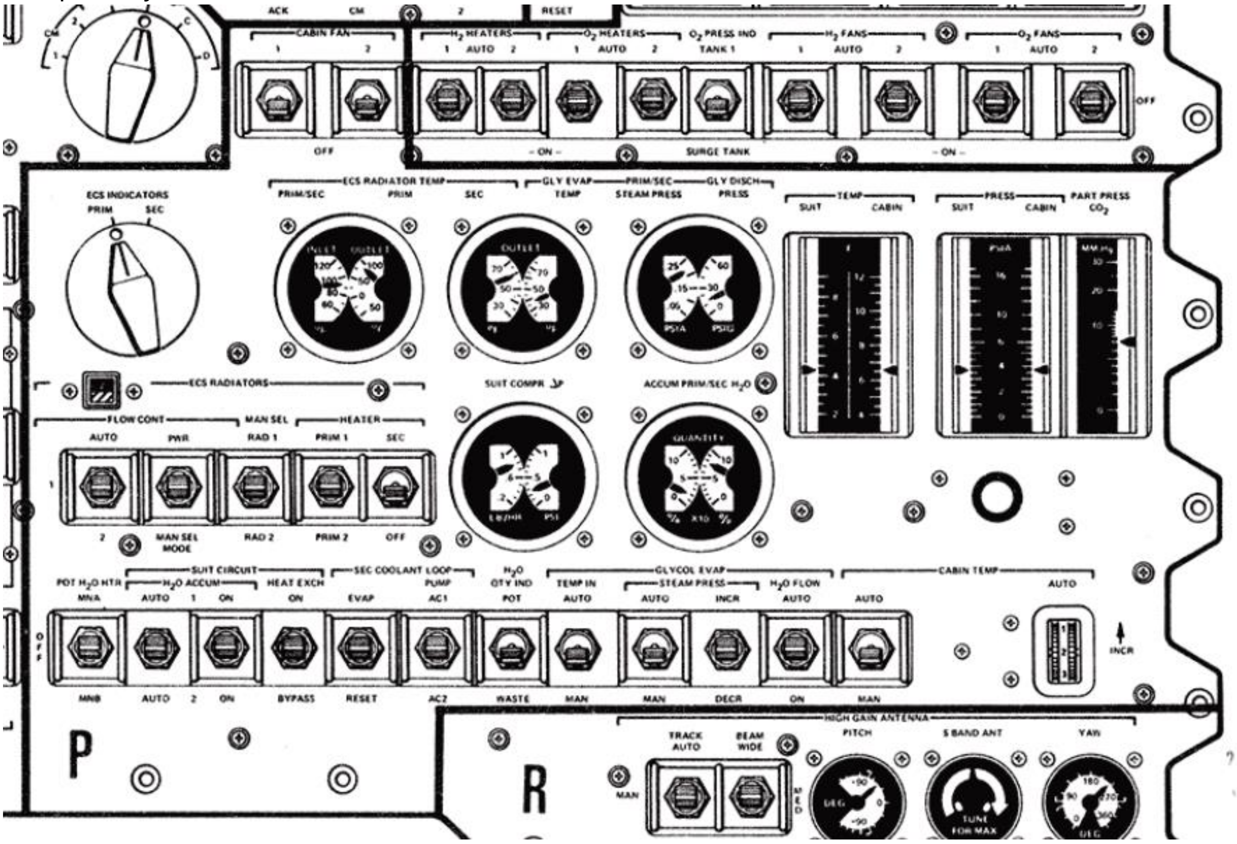
The primary loop provides thermal control throughout the mission unless a degradation of system performance requires the use of the secondary loop.

Several hours before CM-SM separation the system valves are positioned so that the primary loop provides cooling for the cabin heat exchanger, the entire cold plate network, and the suit heat exchanger. The CABIN TEMP control valve is placed on MAX COOL position, and both cabin fans are turned on to cold-soak in the CM interior structure.

Prior to separation the PRIMARY GLYCOL TO RADIATORS, and the GLYCOL TO RADIATORS SEC valves are placed in the BYPASS position to prevent loss of coolant when the CSM umbilical is cut. From that time (until approximately 110K feet spacecraft altitude) cooling is provided by water evaporation.

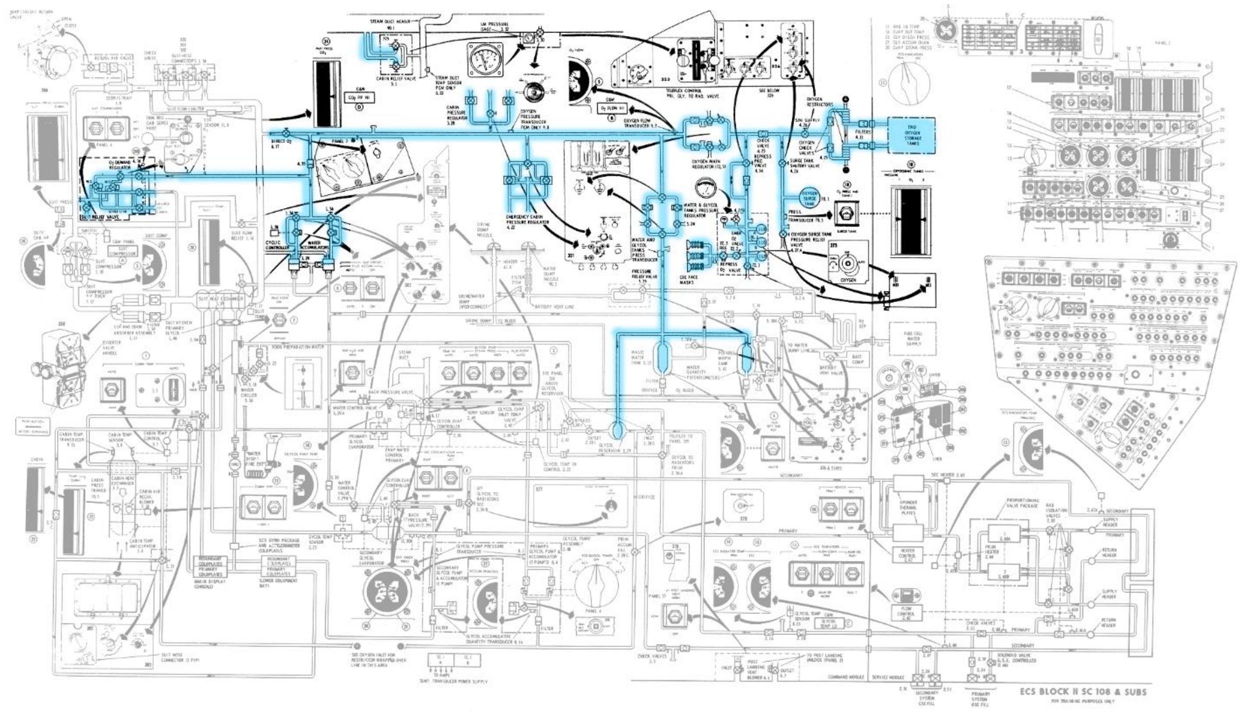


The primary controls of the ECS can be found on MDC-2.

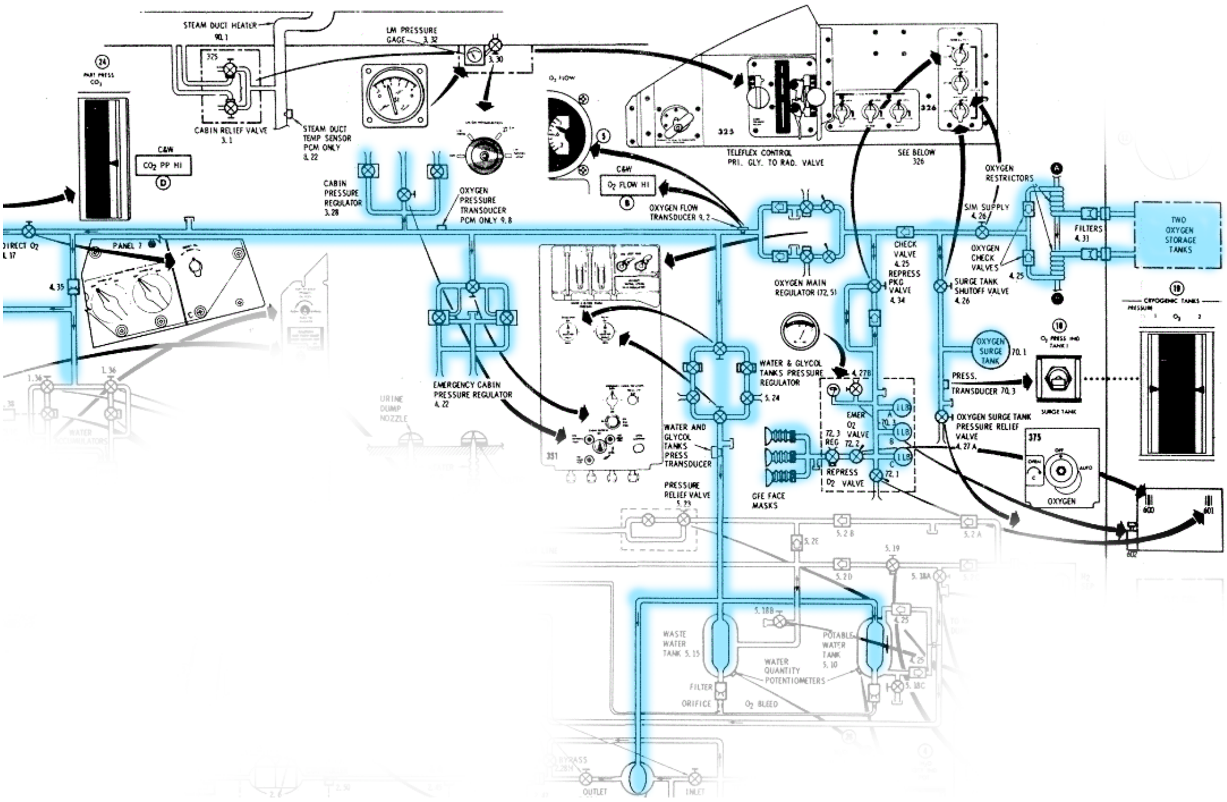


3. OXYGEN SUBSYSTEM

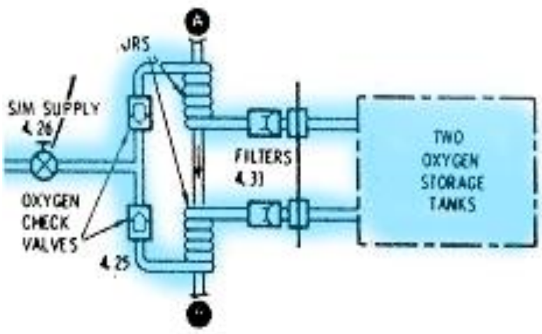
We will start this section with a quick look at the complicated diagram that was using in the introduction to the ECS. The oxygen supply loop, excluding the Pressure Suit Circuit is highlighted in blue below.



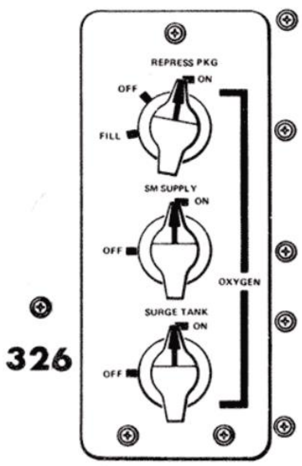
Now, if we zoom in a bit on the first part of the oxygen supply loop, it will become a bit simpler to reference as the OXYGEN SUBSYSTEM is described.



The oxygen subsystem shares the oxygen supply with the electrical power system. Approximately 640 pounds of oxygen is stored in two cryogenic tanks located in the service module. Heaters within the tanks pressurize the oxygen to 900 psig for distribution to the using equipment.

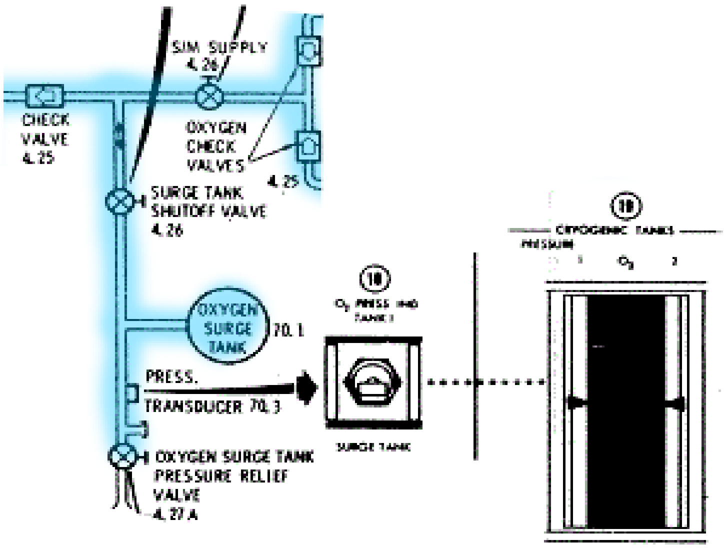


Oxygen is delivered to the command module through two separate supply lines, each of which enters at an oxygen inlet restrictor assembly. Each assembly contains a filter, a capillary line, and a spring-loaded check valve. The filters provide final filtration of gas entering the CM. The capillaries which are wound around the hot glycol line, serve two purposes; they restrict the total O2 flow rate to 7.5 pounds per hour maximum, and they heat the oxygen to prevent it from entering the CM in a liquid state. The check valves serve to isolate the two supply lines.



Downstream of the inlet check valves the two lines tee together and a single line is routed to the OXYGEN-S/M SUPPLY valve on panel 326. This valve is used in flight as a shutoff valve to back up the inlet check valves during entry. It is closed prior to CM-SM separation. You can see the valve in the figure above, named S/M SUPPLY 4.26.

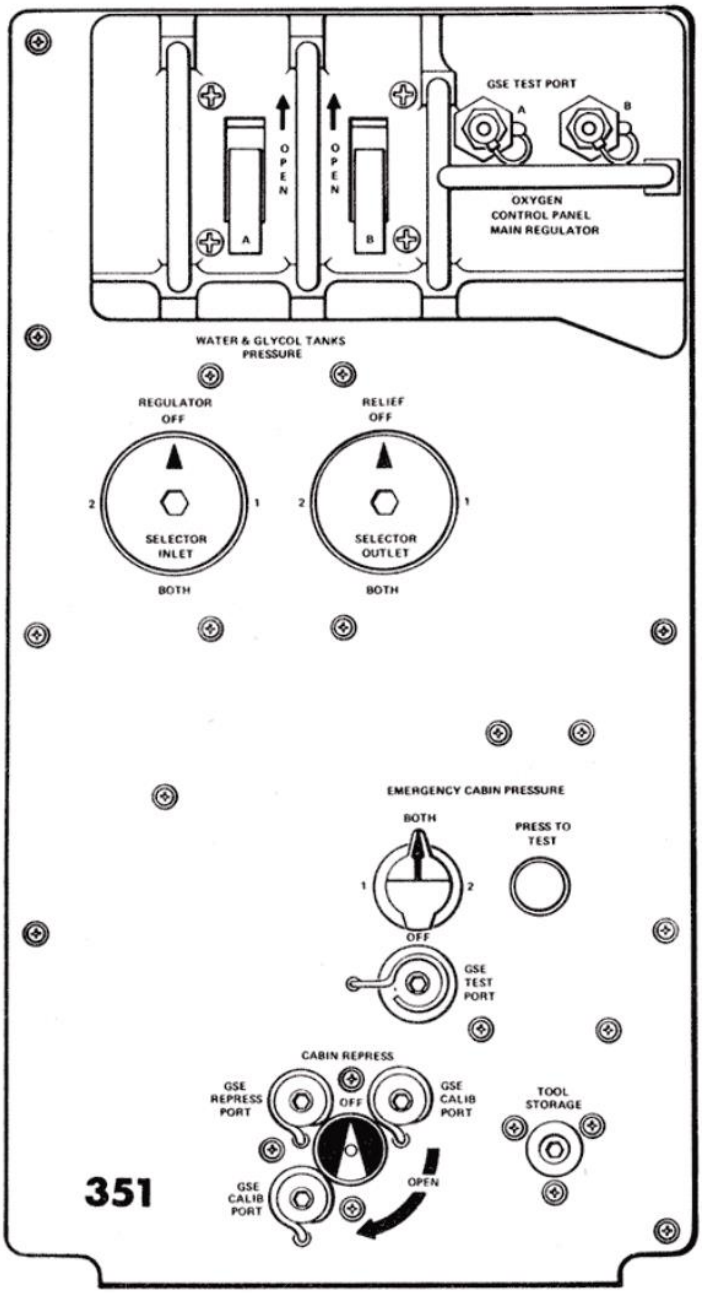
The outlet of the S/M SUPPLY valve is connected in parallel to the OXYGEN-SURGE TANK valve (panel 326) and to a check valve on the OXYGEN CONTROL PANEL (panel 351). The SURGE TANK valve is normally open during flight, and is closed only when it is necessary to isolate the surge tank from the system.



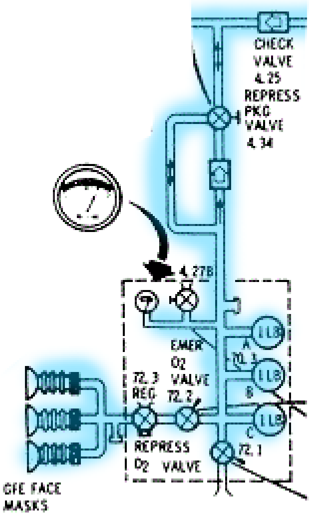
The surge tank stores approximately 3.7 pounds of oxygen at 900 psig for use during entry, and for augmenting the SM supply when the operational demand exceeds the flow capacity of the inlet restrictors. The OXYGEN SURGE TANK PRESSURE RELIEF and shutoff valve on panel 375 prevents overpressurization of the surge tank, and provides means for shutting off the flow in case of a relief valve failure.

The relief valve operates at a 1045+/- psid. A pressure sensor measures the pressure in the surge tank and can be seen on the O2 CRYOGENIC TANK #1 PRESSURE indicator on MDC-2. To see the value on the indicator, the O2 PRESS IND must be set to SURGE TANK, which is located beneath the indicator.

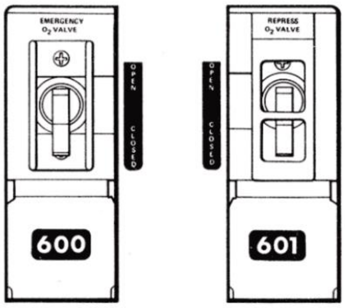
The outlet of the check valve (on the OXYGEN CONTROL PANEL) is connected to the OXYGEN-PLSS valve on panel 326, and the MAIN REGULATOR on panel 351.



So far we have covered the S/M SUPPLY inlet and the surge tank. As described above, the oxygen will venture further into the Oxygen subsystem. The next stop is the dedicated cabin repressurization system.



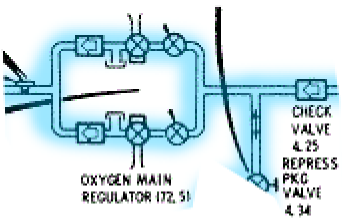
The Portable Life Support System (PLSS) valve is used for controlling the flow of oxygen to and from the cabin repressurization package. The package consits of three one-pound capacity oxygen tanks connected in parallel; a toggle-type fast acting REPRESS O2 valve on panel 601 for dumping oxygen into the cabin at a very high flowrate; a toggle valve and regulator on panel 600 for supplying oxygen to the emergency O2 face masks; a relief and shut-off valve on panel 602 to protect the package against overpressurization; and a direct-reading pressure gauge on panel 602 for monitoring package and pressure when the PLSS valve is closed.



The 600, 601 and 602 panels are located on the rear side of the side hatch.

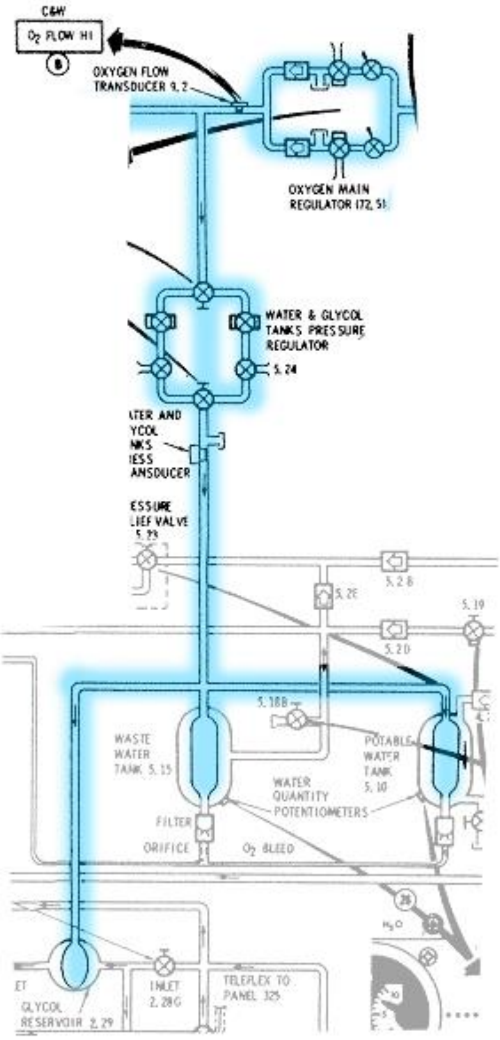
Opening the REPRESS O2 valve, with the PLSS valve (326) in the FILL position (O2 can only enter from the S/M supply line), will dump both the pacakge tanks and the surge tanks at a rate that will repressurize the command module from 0 to 3 psia in one minute. When the PLSS valve is in the ON position, the package tanks augment the surge tank supply for entry and emergencies. The package tanks are filled by placing the PLSS valve to the FILL position, and monitoring the surge tank pressure on the CRYOGENIC TANK PRESSURE O2 1 indicator. When the indicator reads 900+/-35 psi, both the surge tank and the package tanks are full.

As you can see, both the PLSS/Repress path and the Surge Tank paths deviate from the main S/M line and is controlled by valves. Passing the PLSS branch, the oxygen continues to the MAIN REGULATOR.



The MAIN REGULATOR reduces the supply pressure to 85-110 psig for use by the subsystem components. The regulator assembly is a dual unit which is normally operated in parallel. Two toggle valves at the inlet to the assembly provides a means of isolating either of the units in case of failure, or for shutting them both off. Integral relief valves limit the downstream pressure to 140 psig maximum. The output of the MAIN REGULATOR passes through a flowmeter located on MDC-2.

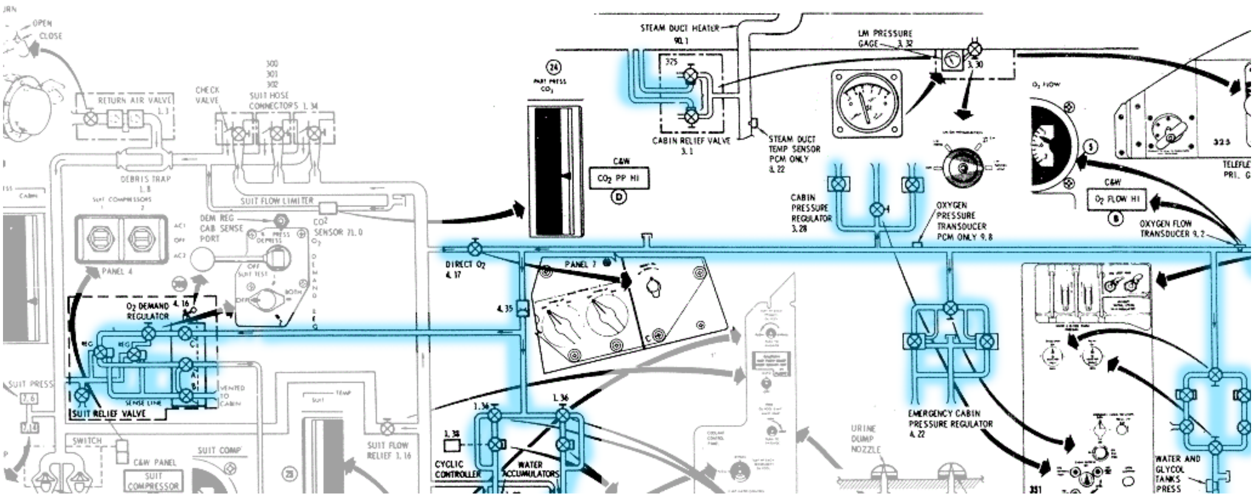
The output of the MAIN REGULATOR passes through the flowmeter, before being delivered to the WATER & GLYCOL TANK PRESSURE regulators, the cabin pressure regulator, EMERGENCY CABIN PRESSURE regulator (all on panel 351), the O2 DEMAND REGULATOR (panel 380), the DIRECT O2 valve (panel 7), and the WATER ACCUMULATOR valves (panel 382, described in the PSC section).



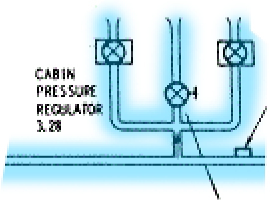
The output of the flowmeter is displayed on the O2 FLOW indicator, which ahs a range of 0.2 to 1.0 pound per hour. Nominal flow for metabolic consupmption and cabin leakage is approximately 0.43 pound per hour. Flow rates of 1 pund per hour or more with a duration of 16 seconds will illuminate the O2 FLOW HI light on the caution and warning panel. The warning is intended to alert the crew to the fact that the oxygen flow rate is greater than is normally required. It does not necessarily mean that a malfunction has occurred, since there are a number of flight operations in which a high-oxygen flow rate is normal.

The WATER & GLYCOL TANKS PRESSURE regulator assembly (panel 351) is a dual unit, normally operating in parallel, which reduces the 100-psi oxygen to 20 psig for pressurizing the positive expulsion bladders in the waste and potable water tanks, and in the glycol reservoir. INLET and OUTLET SELECTOR valves are provided for selecting either or both regulators and relief valves, or for shutting them down.

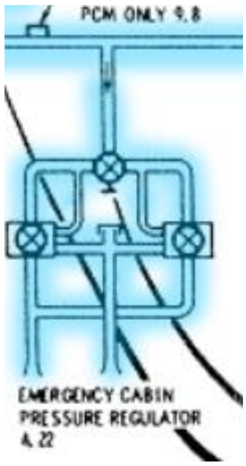
As we have passed the MAIN REGULATOR, the oxygen is as mentioned in a supply mode for many of the subsystem components. If we take a look at the overview again, this time with a focus on the latter part of the OXYGEN SUBSYSTEM, you will notice a straight line that goes towards the Pressurized Suit Circuit.



Having described the WATER & GLYCOL TANKS PRESSURE regulator above, it is time to continue the oxygen journey towards the other subsystems that requires it.

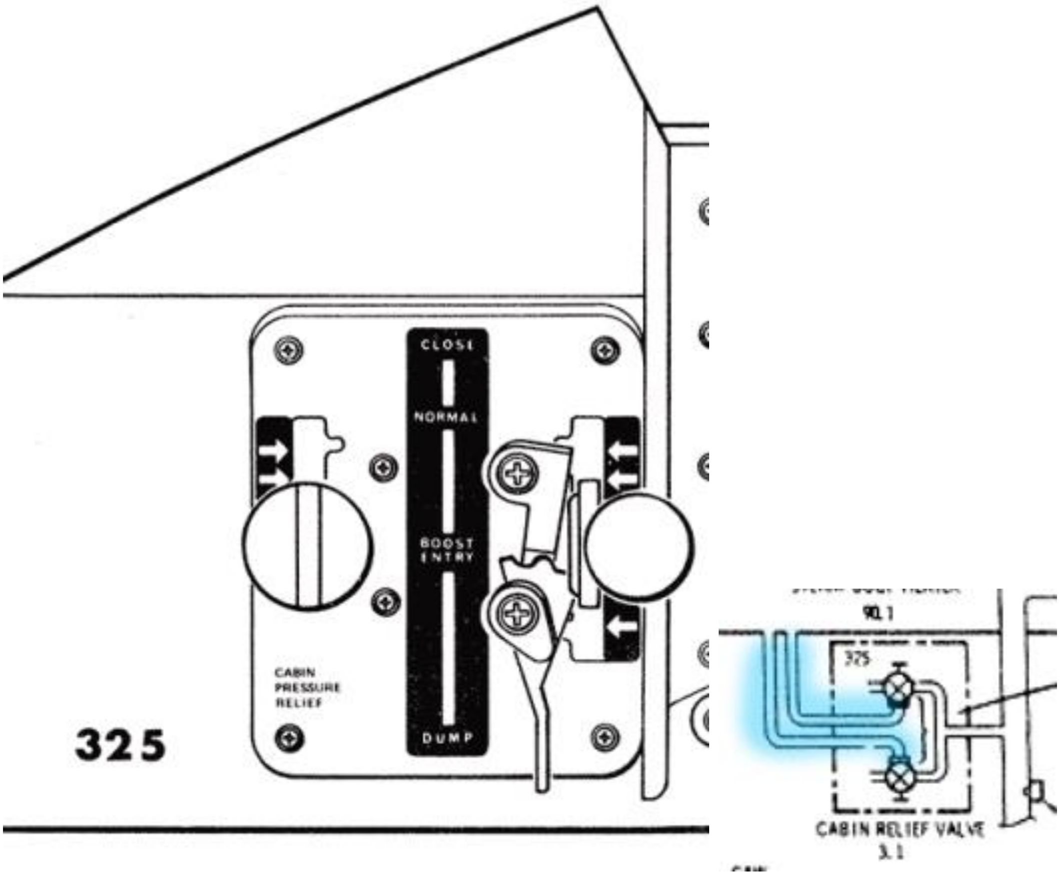


The cabin pressure regulator controls the flow of oxygen into the cabin to make up for depletion of gas due to metabolic consumption, normal leakage, or for repressurization. The assembly consists of two absolute pressure regulators operating in parallel, and a manually operated CABIN REPRESS valve. The regulator is designed to maintain a cabin pressure at 5 psia at flow rates up to 1.4 pounds per hour. Losses in excess of this value will result in a continual decrease in cabin pressure. When the cabin pressure falls to 3.5 psia minimum, the regulator will automatically shut off to prevent wasting the oxygen supply. Following depressurization, the cabin can be repressurized by manually opening the CABIN REPRESS valve. The CABIN REPRESS valve will flow at a minimum of 6 punds per hour. The O2 FLOW HI light will be on.

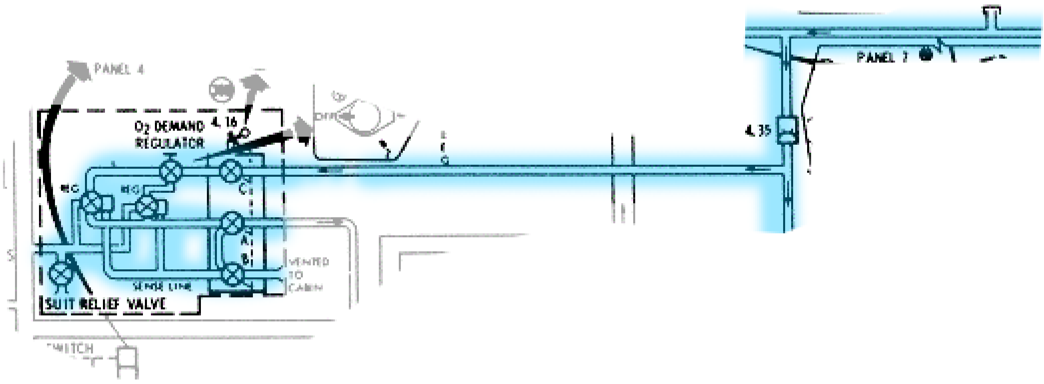


The EMERGENCY CABIN PRESSURE regulator provides emergency protection for the crew in the event of severe leak in the cabin. The assembly consists of two absolute pressure regulators, either of which can handle the maximum flow rate, and a selector valve for selecting either or both of the regulators, or for shutting the unit off. The regulator valve starts to open when cabin pressure decreases to 4.6 psia; and at 4.2 psia the valve is full-open, flooding the cabin with oxygen. The regulator can supply oxygen to the cabin at a flow rate of 0.67 pound per minute minimum (O2 FLOW HI light on), to prevent rapid decompression in case of cabin puncture. The regulator is capable of providing flow rates to try and maintain cabin pressure above 3.5 psia for a short period of time. This is a different emergency system than the cabin repress packages. The EMERGENCY CABIN PRESSURE system is designed to give time to the crew to suit up. During pressure suit operations, the regulator is shut off to prevent unnecessary loss of oxygen in case of unplanned cabin depressurization.

The CABIN RELIEF VALVE is used to relief the cabin of excess pressure, and will maintain cabin pressure at 5 psia. Excess pressure will be relieved overboard. The CABIN PRESSURE RELIEF valves are controlled on panel 325. During ascent and entry, this is set to BOOST/ENTRY. During normal operation, the valves are set to NORMAL.



The O2 DEMAND REGULATOR supplies oxygen to the suit circuit whenever the suit circuit is isolated from the cabin (return air SHUTOFF VALVE closed), and during depressurized operations. It also relived excess gas to prevent overpressurizing the suits. The assembly contains redundant regulators; a single relief valve for venting excess suit pressure; an inlet selector valve for selecting either or both regulators; and a SUIT TEST valve for performing suit integrity tests.



Each regulator section consists of an aneroid control, and adifferential diaphragm housed in a reference chamber. The diaphragm pushes agains a rod connected to the demand valve; the demand valve will be opened whenever a pressure differential is sensed across the diaphgragm. In operation, there is a constant bleed flow of oxygen from the supply into the refernece chamber, around the aneroid, and out through the control port into the cabin. As long as the cabin pressure is greater than 3.75 psia (nominal), the flow of oxygen through the control port is virtually unrestricted, so that the pressure within the reference chamber is essentially that of the cabin. This pressure acts on the upper side of the diaphragm, while suit pressure is applied to the underside of the diaphragm through the suit sense port. The diaphragm can be made to open the demand valve by either increasing the refernece chamber pressure, or by decresing the sensed suit pressure.

The increased pressure mode occurs during depressurized operations. As the cabin pressure decreases, the aneroid expands. At 3.7 psia the aneroid will have expanded sufficiently to restrict the outflow of the oxygen through the control port, this increasing the reference chamber pressure. When the pressure rises above the sensed suit pressure, the demand valve will be opened.

Decreased pressure mode occurs whenever the suit circuit is isolated from the cabin, and cabin pressure is above 5 psia. In the process of respiration, the crew will exhale carbon dioxide and water vapor. In circulating the suit gases through the CO2 and odor absober, and the suit heat exchanger, the CO2 and water are removed. The removal reduces the pressure in the suit circuit, which is sensed by the regulator on the underside of the diapgragm. When the pressure drops below the cabin, the diaphragm will open the demand valve.

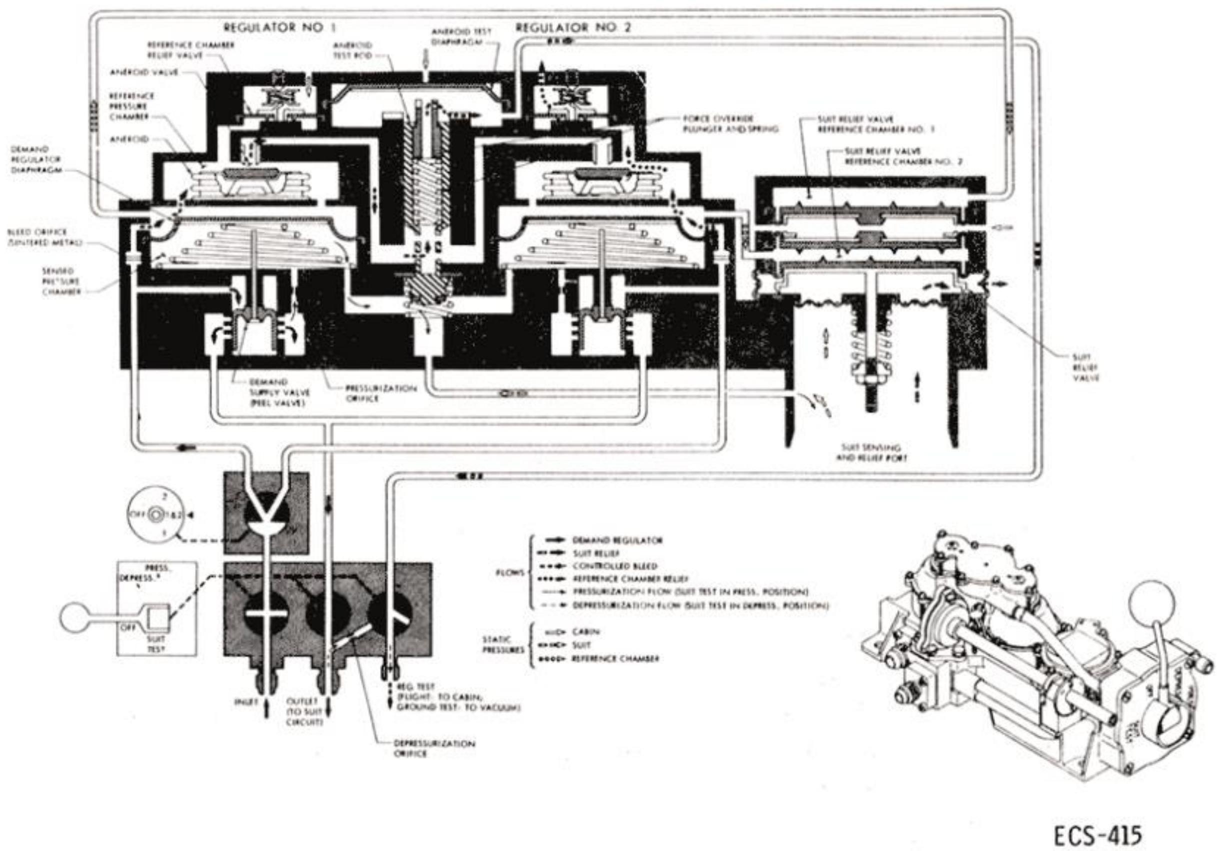


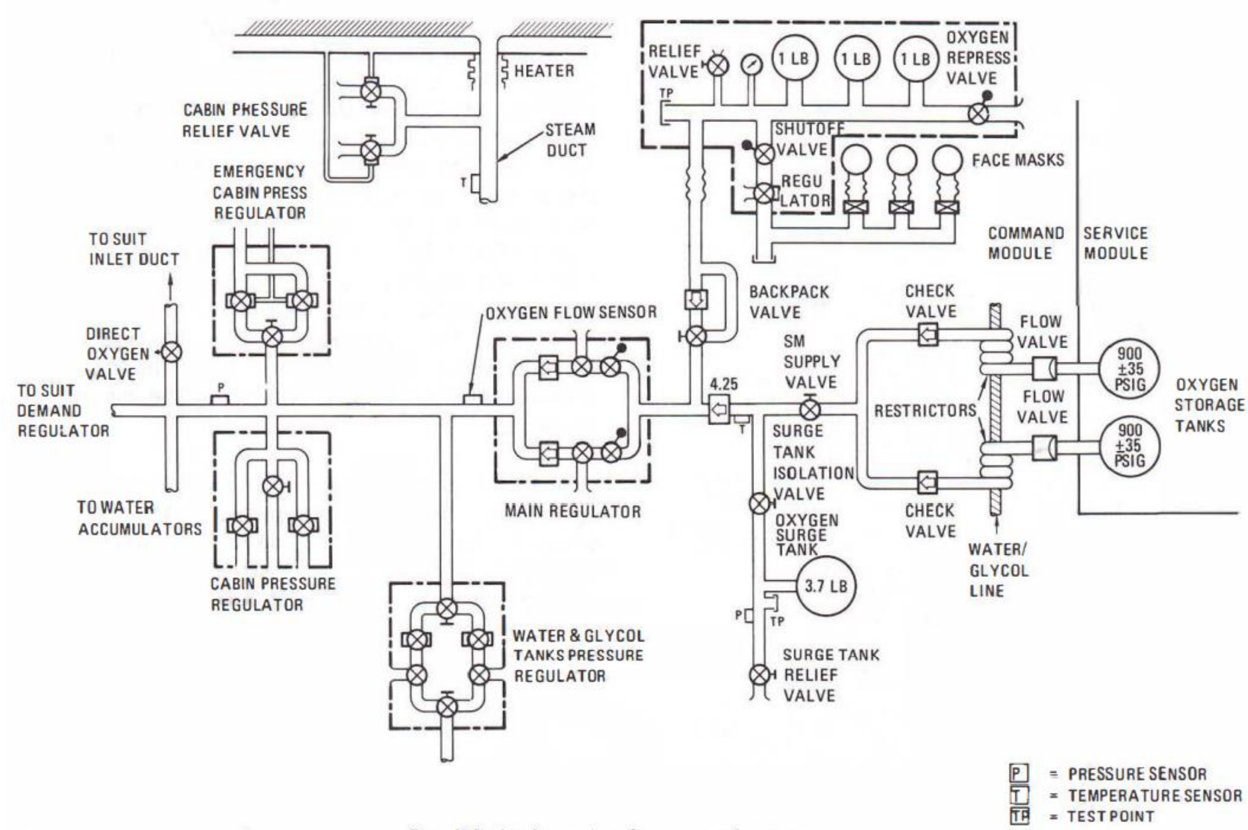
Figure 2.7-1. O_2 Demand Regulator

The regulator assembly contains a poppet-type relief valve which is integral with the suit pressure sense port. During operations where the cabin pressure is above 3.75 psia, the relief valve is loaded by a coil spring which allows excess suit gas to be vented whenever suit pressure rises above the cabin pressure. When the cabin pressure decreases to 3.75 psia, the reference chamber pressure is increased by the throttling effect of th expanding aneroid. The reference chamber pressure is applied, through ducts, to two relief valve loading chambers which are arranged in tandem above the relief valve poppet. The pressure in the loading chambers acts on tandem diaphgram which are focused agains the relief valve poppet. The relief value of the valve is thus increased to 3.75 psia.

The SUIT TEST valve provides a means for pressurizing and depressurizing the suit circuit, at controlled rates, for performing suit integrity tests. Placing the SUIT TEST valve in the PRESS position supplies oxygen through a restrictor to pressurize the suit circuit to a nominal 4 psi above cabin, in not less than 75 seconds, depending on cabin and suit pressures. Placing the SUIT TEST valve in the DEPRESS position will depressurize the suits in not less than 75 seconds. Moving the SUIT TEST valve from the PRESS position to OFF will dump the suite pressure immediately.

The DIRECT O2 valve on panel 7 is a screw-actuated poppet valve capable of metering oxygen into the suit circuit of flow rates from 0 to 0.67 pounds per minute.

To sum up, here is a simplified diagram of the ECS system from the CSM News Reference (NASA).

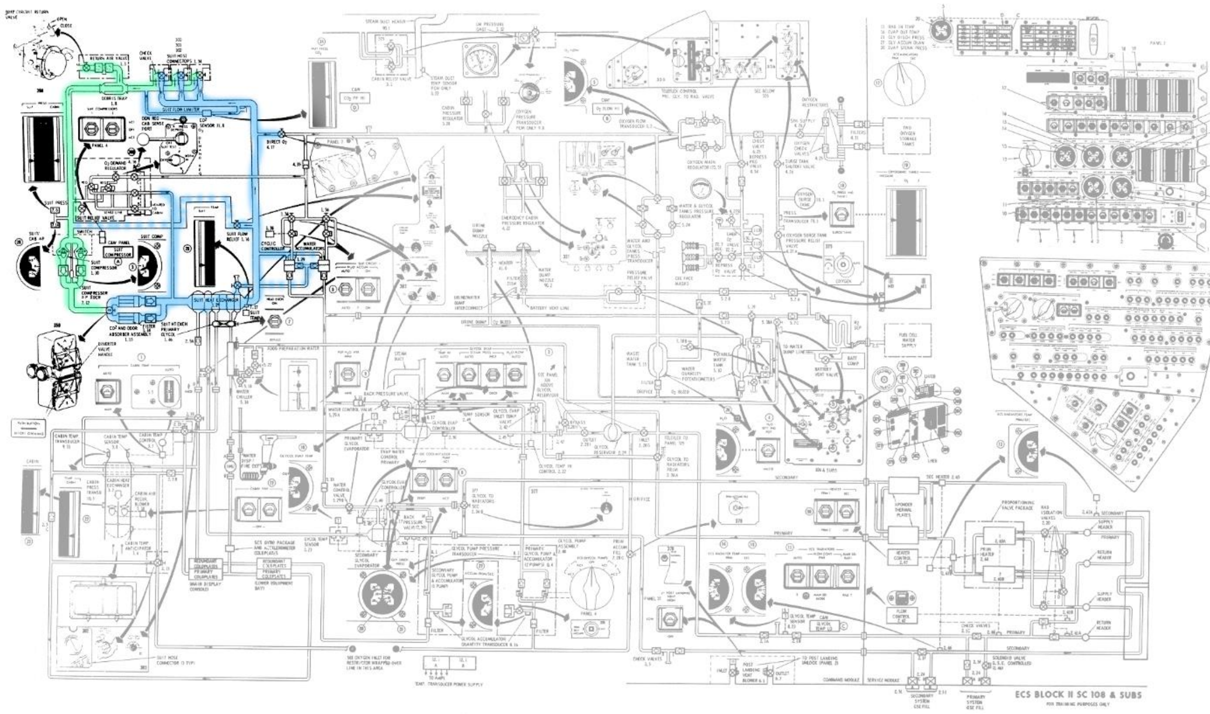


P-168

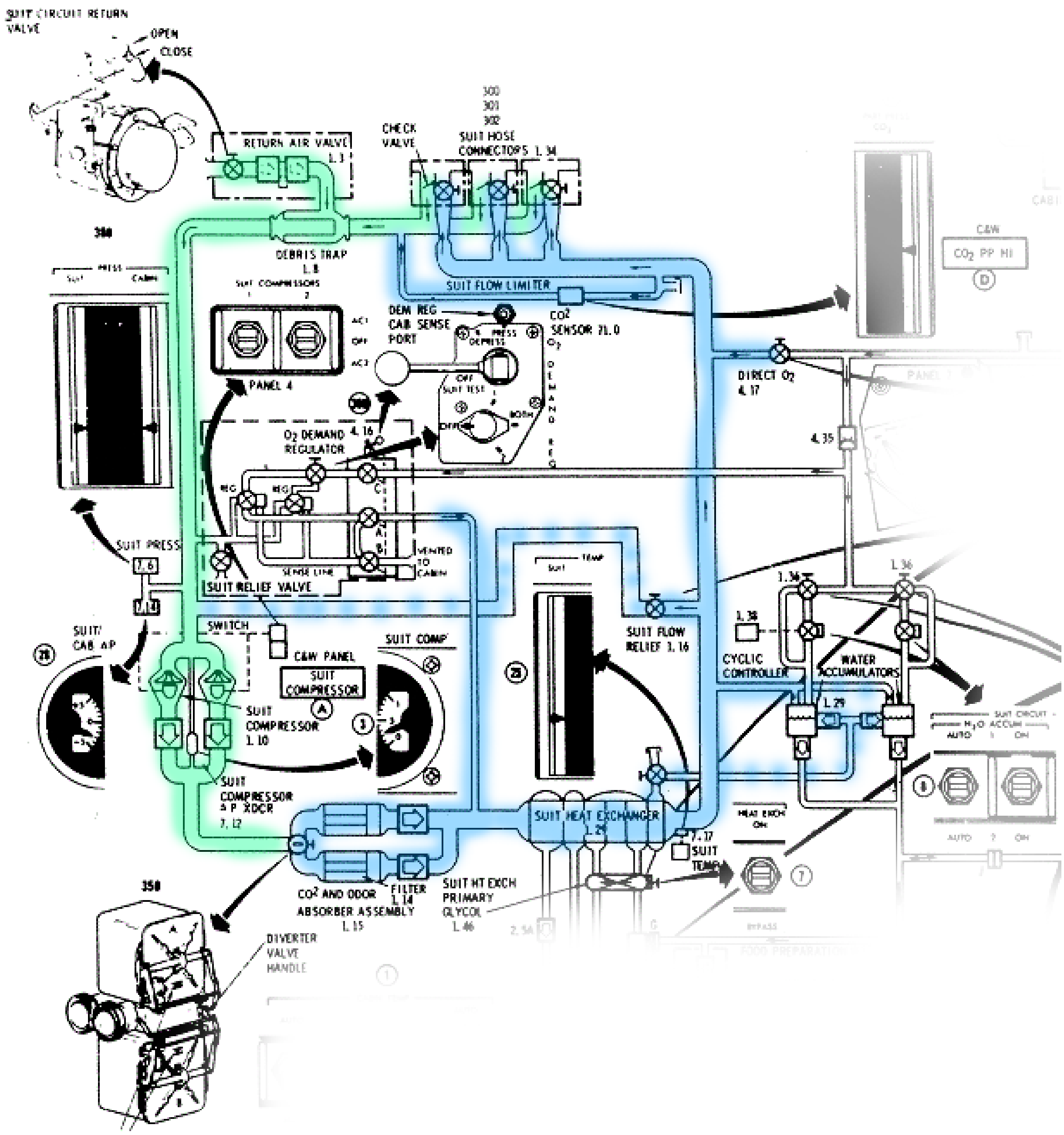
Simplified schematic of oxygen subsystem

4. PRESSURE SUIT CIRCUIT

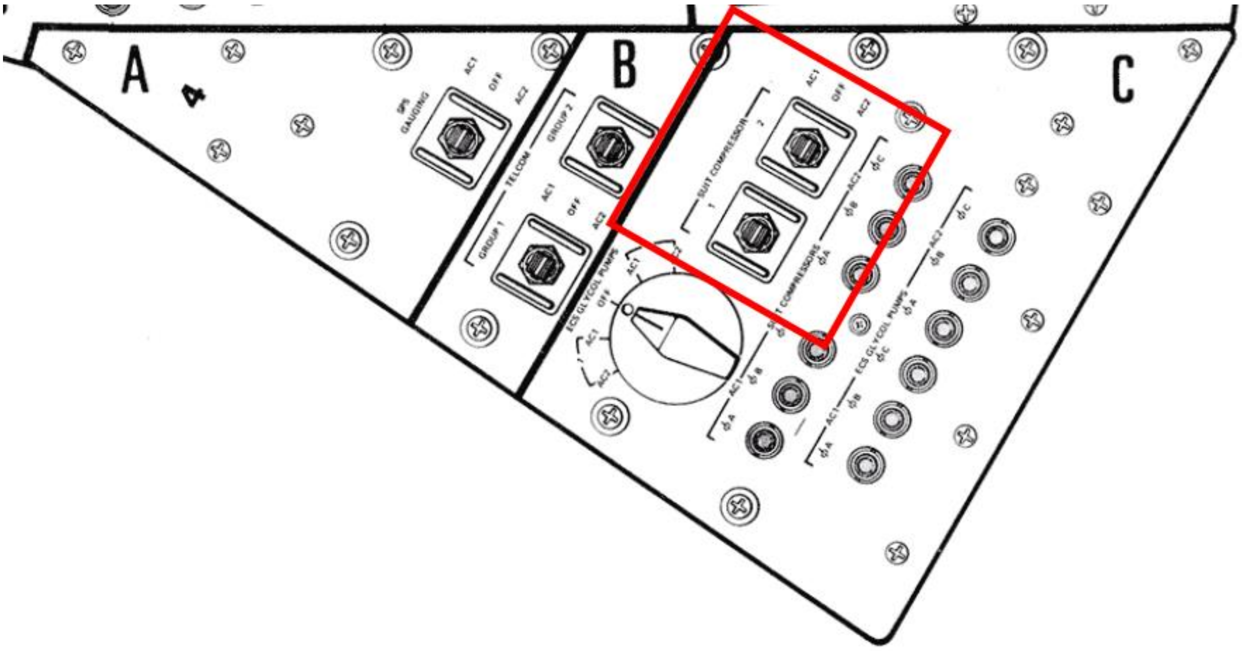
The oxygen subsystem provides oxygen to the pressure suit circuit, as seen in the diagram below. The loop is illustrated using a green color for the contaminated air, and blue for the filtered air.



I have created a zoomed in view of the PSC as well used for reference as the sytem is described below.



The pressure suit circuit (PSC) is a circulating gas loop which provides the crew with continuously conditioned atmosphere throughout the mission. The gas is circulated through the PSC by two centrifugal compressors, which are controlled by individual switches on panel 4. Normally only one of the compressores is operated at a time; however, the invidvidual switches provides a means for connection either or both of the compressores to either a-c bus.

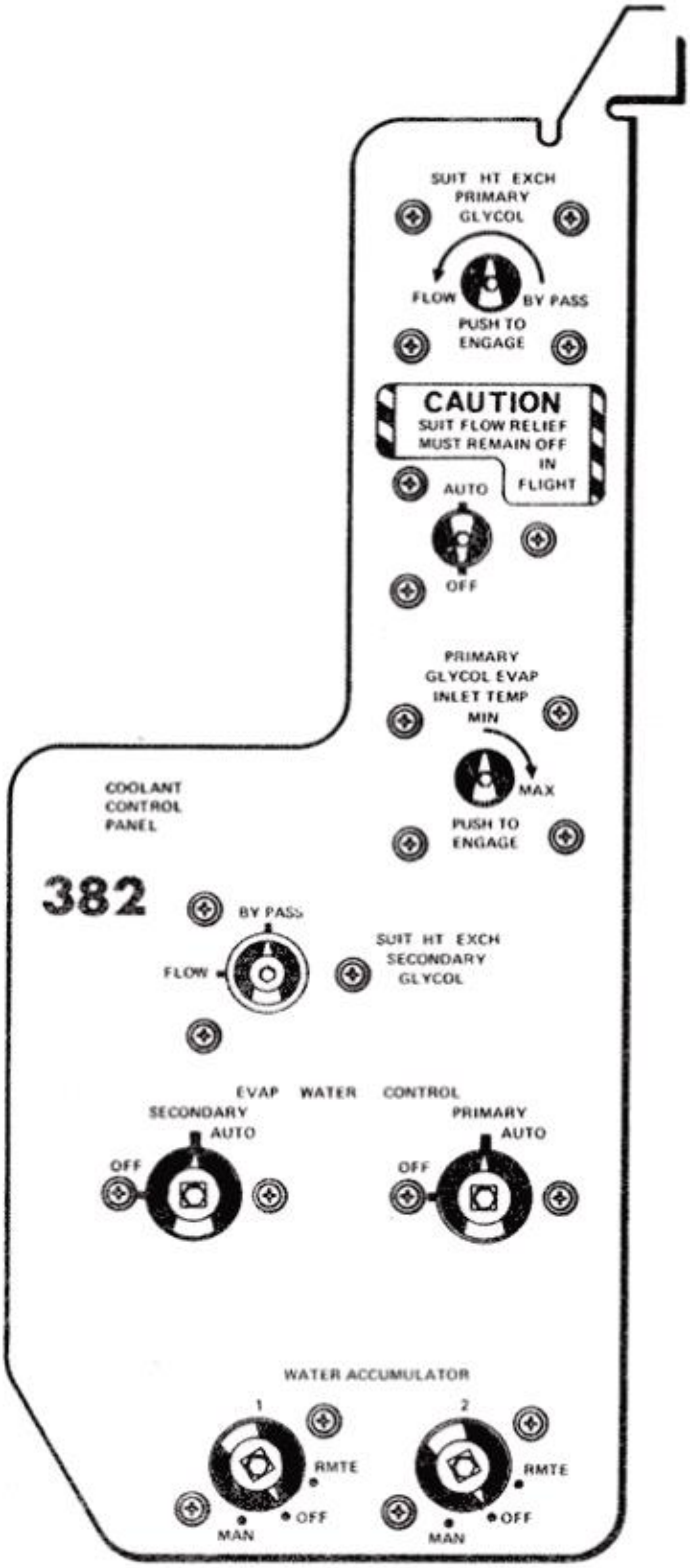


A differential pressure transducer connected between the compressor inlet and outlet manifolds provides a signal to the SUIT COMPR ΔP indicator (MDC-2) and to the caution and warning system, which will illuminate SUIT COMPRESSOR light at a ΔP of 0.22 or less. Another differential pressure transducer connected between the compressor inlet manifold and the cabin, provides a signal to the SUIT-CAB ΔP indicator (MDC-2). An absolute pressure transducer connected to the compressor inlet manifold provides a signal to the PRESS SUIT indicator (MDC-2) to measure the suit pressure.

The gas leaving the compressor flows through the CO2 and odor absorber assembly. The assembly is a dual unit containing two absorber elements in separate compartments with inlet and outlet manifolds common to both. A diverter valve in the inlet manifold provides a means of isolating one compartment or the other (without interrupting the gas flow) for the purpose of replacing a spent absorber. One absorber lasts for about 12 hours to stay below the 7.6 mm Hg CO2 level. The absorber element contains lithium hydroxide and activated charcoal for removing carbo dioxide and odors from the suit gases. Orlon pads on the inlet and outlet sides trap small particles and prevent absorbent materials from entering the gas stream.

From the filter the gas flows through the suit heat exchanger where the gases are cooled and the excess moisture is removed. The heat exchanger assembly is made up of two sets of broad flat tubes through which the coolant from the primary and secondary loops can be circulated. The coolant flow/bypass is controlled by the two valves located on the coolant control panel (382).

The SUIT HT EXCH PRIMARY GLYCOL valve is a motor-driven valve with manual override; the motor is controlled bu the SUIT CIRCUIT-HEAT EXCH switch on MDC-2. The SUIT HT EXCH SECONDARY GLYCOL valve must be positioned manually. The space between the tubes forms passages through thich the suit gases flow. The coolant flowing through the tubes absorbs some of the heat from the suit gases. As the gases are cooled to about 55 °F, the excess moisure condenses out and is removed from the heat exchanger by one or both of a pair of water accumulator pumps.

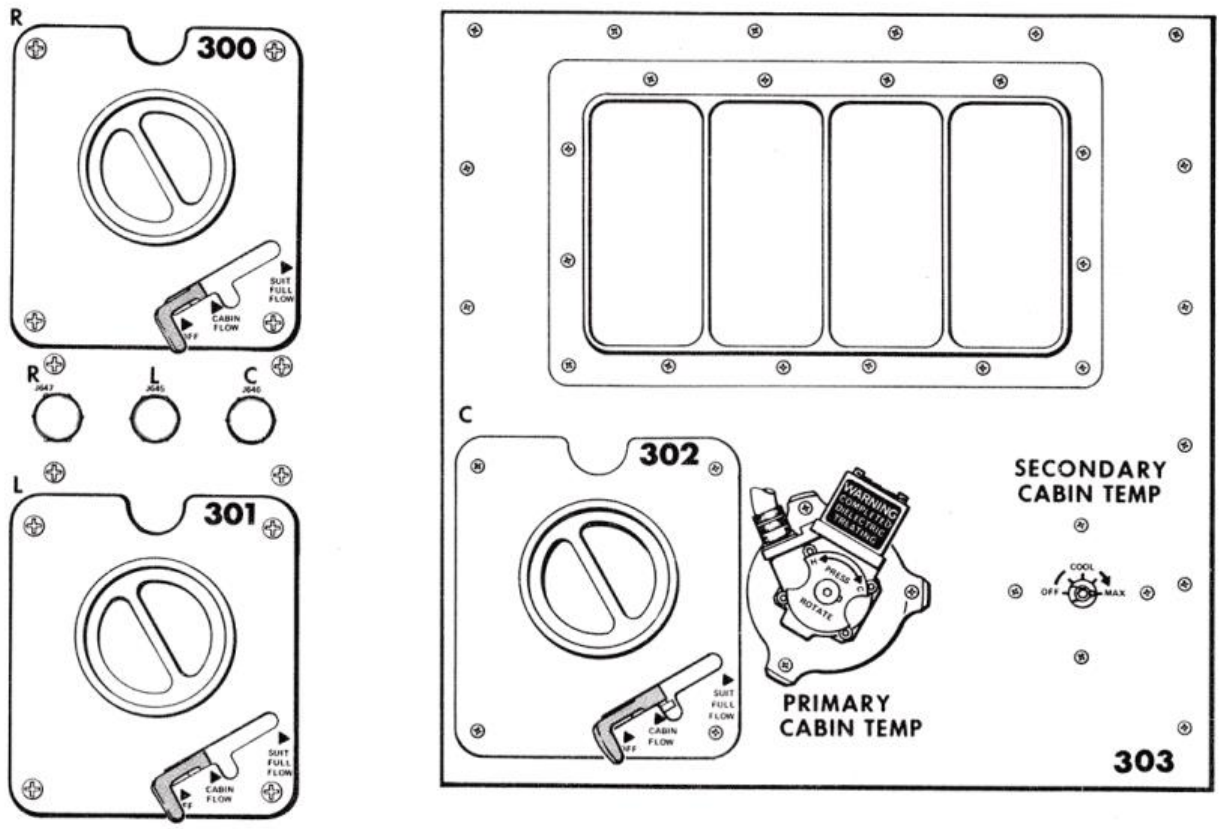


The water accumulators are piston-type pumps, which are actuated by oxygen pressure (100 psi) on the discharge stroke, and by a return spring for the suction stroke. The oxygen flow is controlled by the two WATER ACCUMULATOR selector valve assemblies located on the COOLANT CONTROL PANEL (382). Each valve assembly contains a selector valve, a solenoid valve, and an integral bypass. When the selector valve is in the RMTE position, oxygen flow is controlled by the solenoid valve; when in the MAN position, the oxygen flows through the bypass directly to the pump. The solenoid valve can be controlled automatically by signals from the central timing equipment by placing the SUIT CIRCUIT-H2O ACCUM switch (panel 2) in either AUTO 1 or

AUTO 2. In the automatic mode the central timing equipment signal will cause one of the accumulators to complete a cycle every ten minutes. If it becomes necessary to cycle the accumulators at more frequent intervals the solenoid valve can be controlled manually by placing the AUTO switch in the OFF position, and placing the adhacent H2O ACCUM switch to ON position for either No.1 or 2 accumulator. When excersising manual control, either by meins of switch or the selector valve, it is necessary to hold that particular control on for 10 seconds then return it to the OFF position.

The cool gas (55 °F nominal) flows from the heat exchanger through the suit flow limiters and the flow control valves, into the suits. The suit temperature is measured at the heat exchanger outlet, and is displayed on the SUIT TEMP indicator (panel 2).

A suit flow limiter is installed in each suit supply duct to restrict the fas flow rate through any one suit. The flow limiter is a tube with a Ventri section, sized to limit the flow to 0.7 pound per minute.

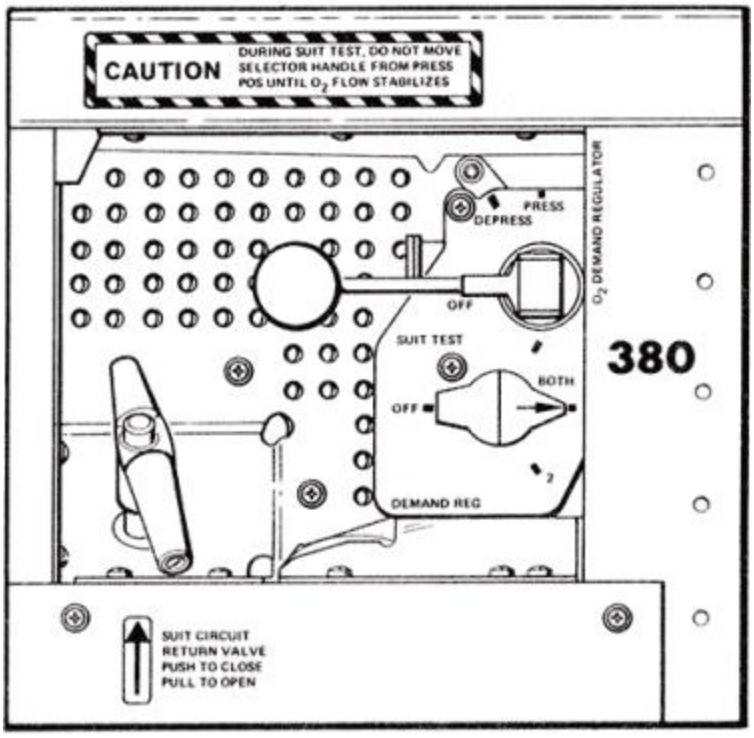


The flow control valves (panels 300, 301, 302) are part of the suit hose connector assembly. These valves provide a means for adjusting the fas flow through each suit individually, and are fully modulating from OFF to the FULL FLOW position. When operating in a shirtsleeve environment with the inlet hose disconnected from the suit, placing the flow control valves in the CABIN FLOW positoin will allow approximately 12 cubic feet of suit gas per minute to flow into the cabin.

A suit flow relief valve is installed between the suit heat exchanger outlet and the compressor inlet, and is intended to maintain a relatively constant pressure at the inlets to the three suits by relieving transient pressure surges. The SUIT FLOW RELIEF valve control (panel 382) provides a means for manually closing the valve by placing the control in the OFF position. Placing the control in AUTO removes the restraint and allows the valve to operate as a relief valve. There are no provisions for manually opening the valve. It should remain in the OFF position during the entire mission to ensure maximum flow through the SUIT CIRCUIT.

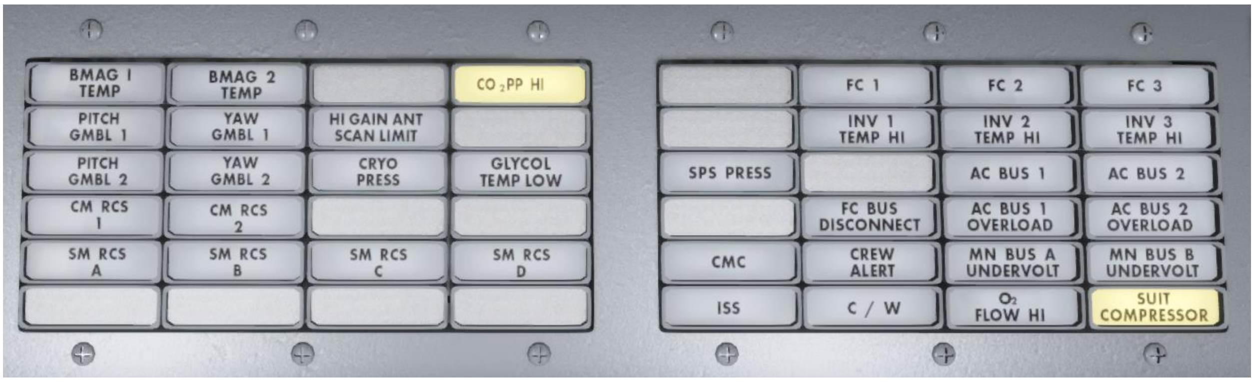
The gas leaving the suits flows through the debris trap assembly, into the suit compressor. The debris trap is a mechanical filter for screening out solid matter that might otherwise clog or damage the suit compressors.

The SUIT CIRCUIT RETURN VALVE (panel 380) is installed on the debris trap upsteam of the screen. The valve permits the cabin gases to enter the suit circuit for scrubbing. The valve consists of two flapper-type check valves, and a manual shutoff valve, all in series. The manual VALVE provides a means for isolating the suit circuit from the cabin manually by means of a remote control located on panel 380. This is done to prevent inducting cabin gases into the suit circuit, in the event the cabin gases become contaminated.

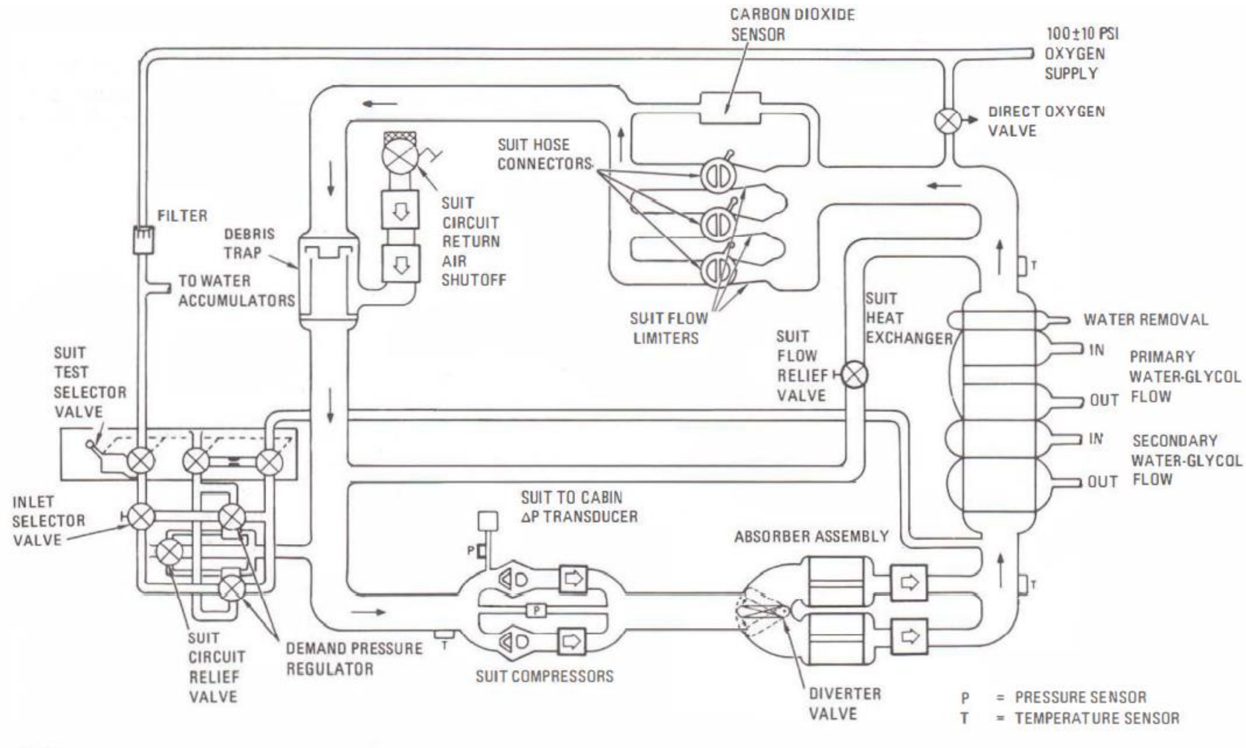


The SUIT CIRCUIT RETURN VALVE is located at the suit compressor inlet manifold, which is normally below cabin pressure. The differential pressure cases cabin gases to flow into the suit circuit when the manual valve is open. The reconditioned cabin gases are resirculated through the suits and/or cabin. During emergency operation, the check valve prevets gases from flowing into the deepressurized cabin from the suit circuit.

A CO2 sensor is connected between the suit inlet and return manifold. The output signal is delivered to the PART PRESS CO2 indicator on panel 2, and to the caution and warning system. At a CO2 partial pressure of 7.6 nn Hg, the CO2 PP HI light on panel 2 will be illuminated.



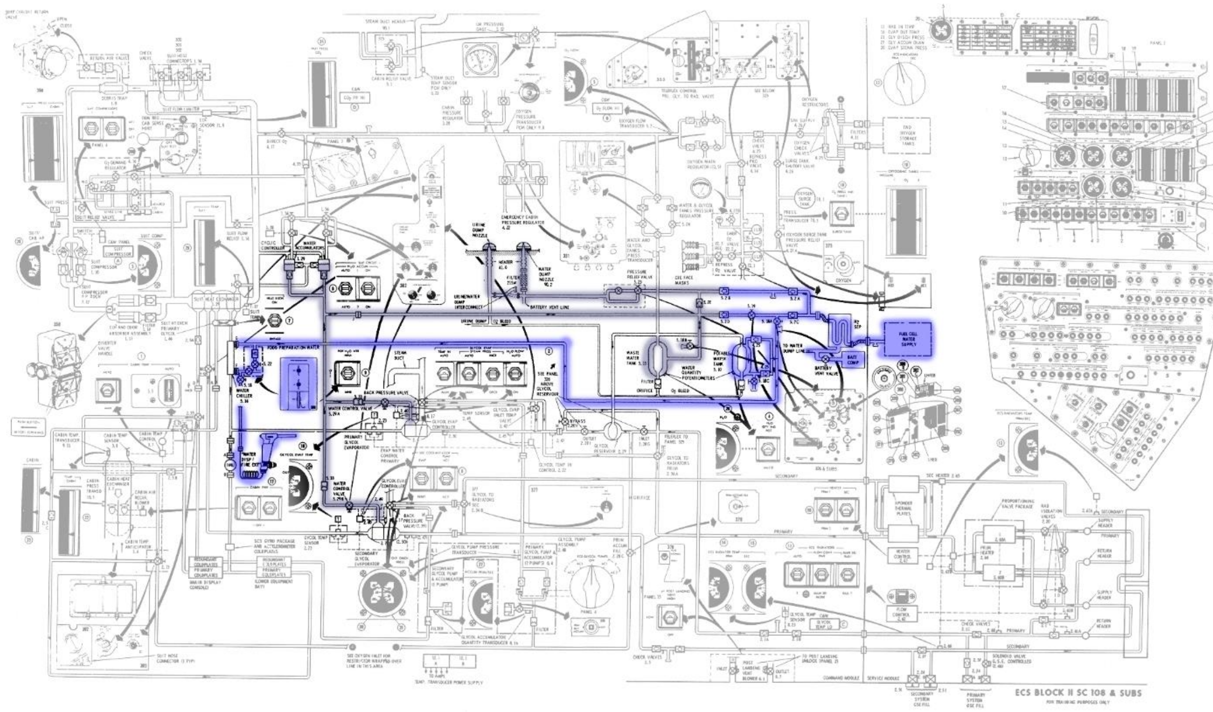
Here is a simplified view of the PSC from the CSM News Reference (NASA).



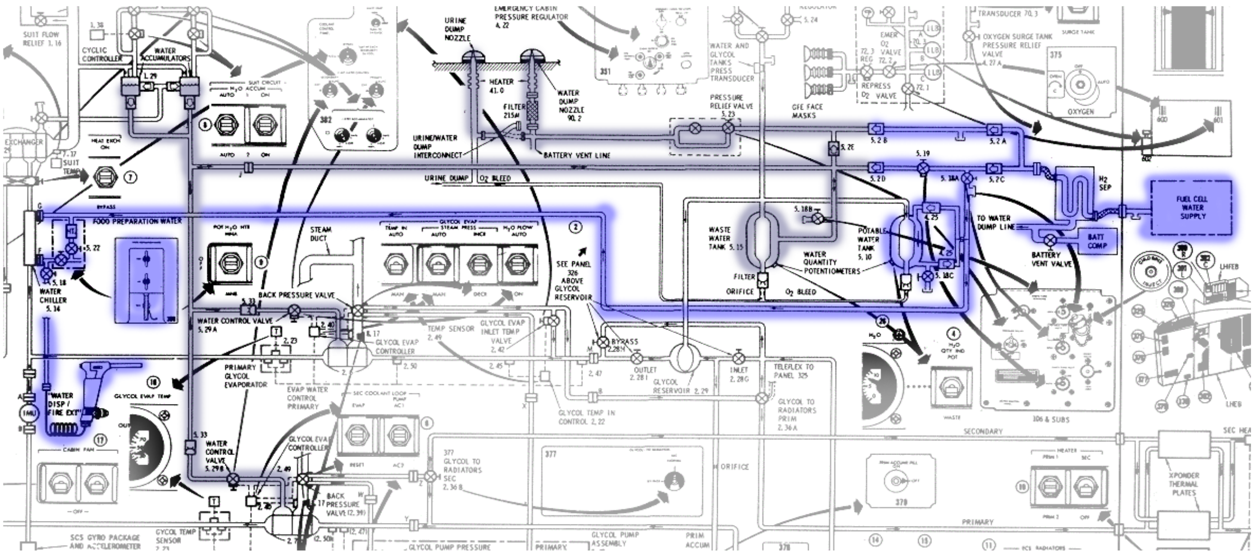
Simplified schematic of suit circuit

5. WATER SUBSYSTEM

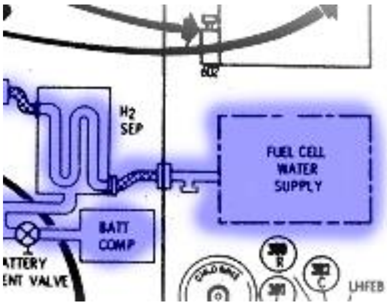
The location of the water subsystem in the ECS diagram is highlighted in the drawing below.



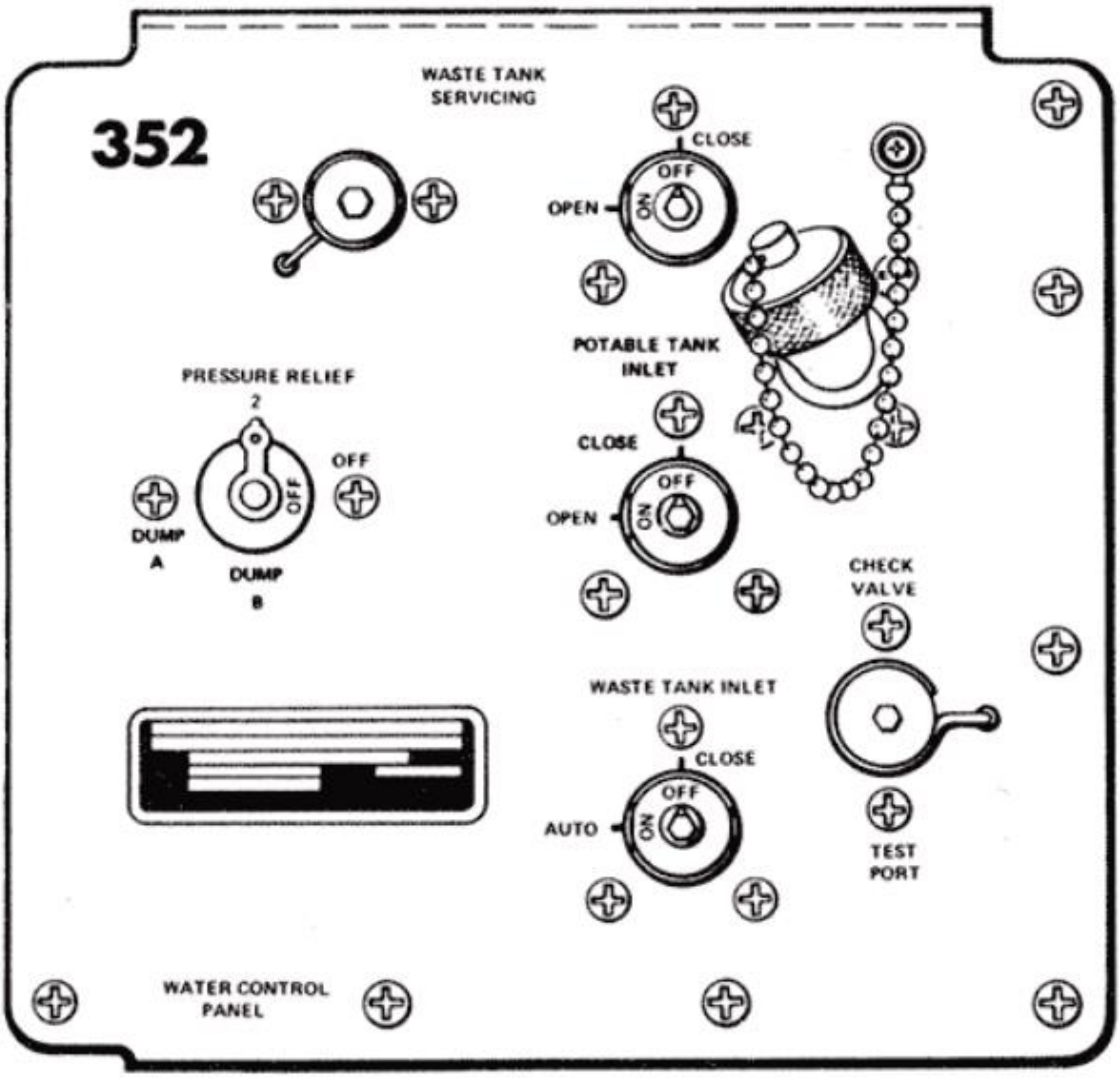
For reference during this section, I have created a zoomed in version of it as well. Potable water is drawn in blue, and waste water is drawn in dark blue/violet.



The water subsystem consists of two individual fluid management networks which control the collection storage, and distribution of potable and waste water. The potable water is used primarily for metabolic purposes. The waste water is used solely as the evaporator in the primary and secondary glycol evaporators. Although the two networks operate and are controlled independently, they are interconnected in a manner which allows potable water to flow into the waste water system under certain conditions.

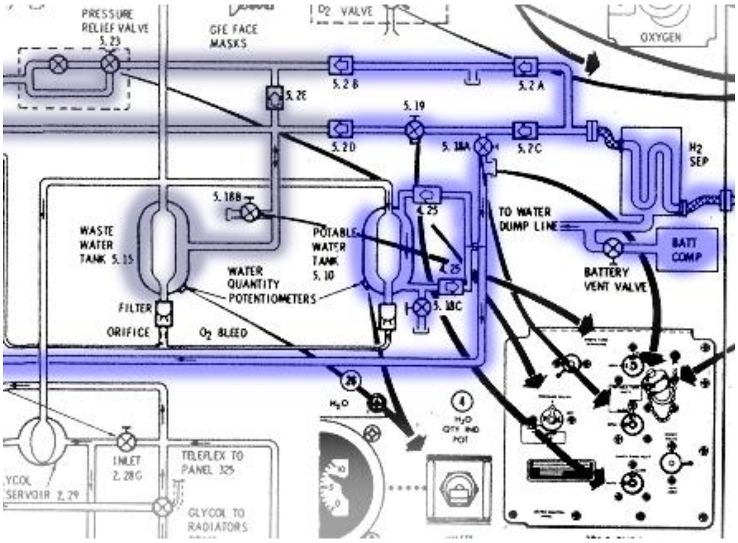


Potable water produced in the fuel cells is pumped into the CM at a flow rate of approximately 1.5 pounds per hour. The water flow through the hydrogen separator (H2 SEP) to a check valve, on the WATER CONTROL PANEL (352), and to the inlet ports of the POTABLE TANK INLET and WASTE TANK INLET valves (panel 352).



The hydrogen separator consists of a series of tubes (made of 25 percent silver and 75 percent palladium) through which the water flows, encased in a can which is vented to space. Hydrogen, in both the dissolved and free states, passes through the walls of the tubing into the can and flows overboard. The separator is installed in the right-hand equipment bay behind the waste management panel. The check valve at the inlet prevents loss of potable water after CM-SM separation.

In the diagram below you can see panel 352 in a miniature version. You can follow the arrows from the controls (reference the detailed panel above) to see where the valves are as we discuss the below section.

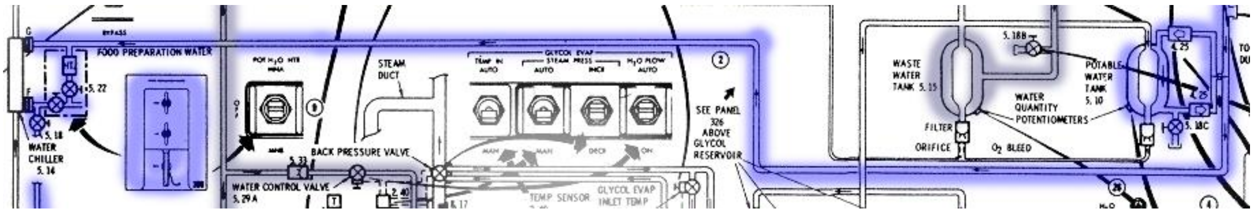


The POTABLE TANK INLET is a manual shutoff valve used for preventing the flow of fuel cell water into the potable system in the event the fuel cell water becomes contaminated. The pH HI talkback (panel 3) shows a "barberpole" when the water pH factor exceeds a value of 9.

The WASTE TANK INLET is an in-line relief valve, with an integral shutoff valve. The relief valve allows potable water to flow into the waste water tank. This can happen if the fuel cells are pumping water while the potable water tank is full, or the POTABLE TANK INLET valve is closed, or when the glycol evaporators are demanding water for cooling and the waste water tank is completely empty. The shutoff valve provides a means of blocking flow in case the relief valve fails. If such as failure occurs, potable water can flow through the valve until the two pressures are equal. Reverse flow is prevented by a check valve downstream of the WASTE TANK INLET valve.

In the event that both water tanks are full at the time the fuel cells are pumping, the excess potable water will be dumped overboard through the PRESSURE RELIEF valve on panel 352. During flight the waste water tank will be maintained below 75 percent by manually dumping the excess water. This means that normally an ullage will be maintained to receive the potable water, instead of dumping it overbard.

Water flows from the control panel to the potable water tank, the FOOD PREPARATION WATER unit (panel 305), and the water chiller.

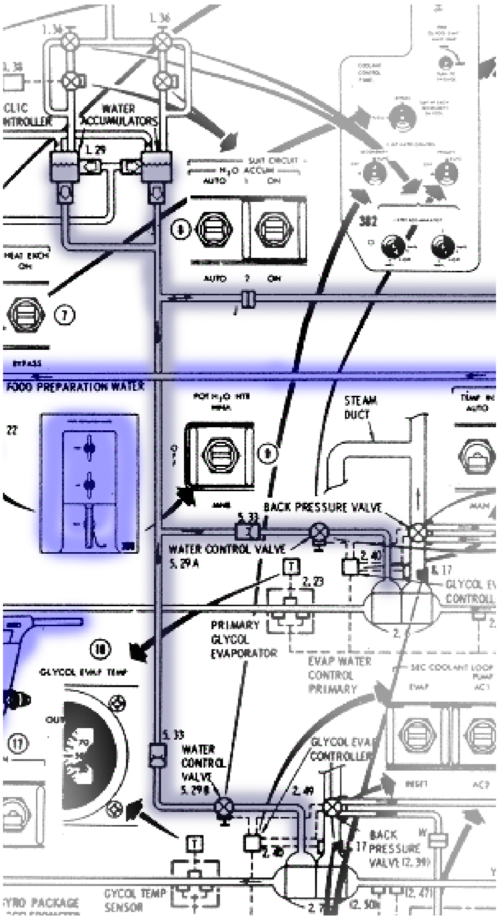


The water chiller cools and stores 0.5 pound of potable water for crew consumption. The water chiller is designed to supply 6 ounces of 50 °F water every 24 minutes. The water is chilled by the cool glycol.

The FOOD PREPARATION WATER unit heats potable water for use by the crew, and allows manual selection of hot or cold potable water. The cold potable water is supplied by the water chiller. The unit consists of an electrically heated water reservour and two manually operates valves. The insulated reservoir has a capacity of 1.9 pounds of water. Thermostatically controlled heating elements in the reservior heat the water and maintain it an 154 °F nominal.

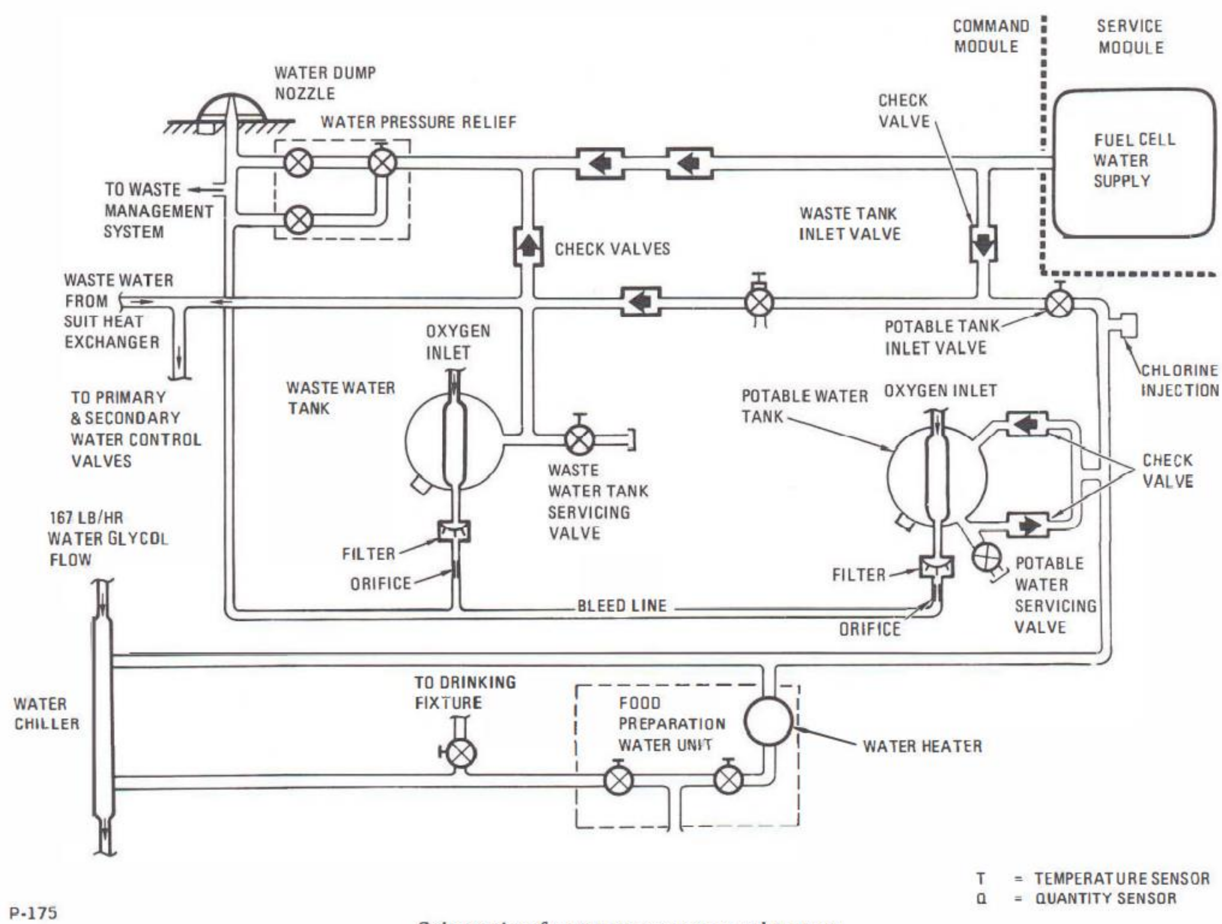
The DRINKING WATER SUPPLY valve on panel 304 provides a means for shutting off the flow of water to the drinking water dispenser (water pistol), in case of a leak in the flex hose.

The waste water and potable water is stored in positive expulsion tanks, which with the exception of capacity, are identical in function, operation, and design. The positive expulsion feature is obtained by an integrally supported bladder, installed longitudinally in the tank. Water collector channels, integral with the tank walls, prevent water from being trapped within the tank by expanding bladder. Quantity transducers provides signals to the H2O QUANTITY indicator on panel 2. The signal source is selected by the H2O QTY IND switch located below and to the left of the indicator on panel 2.



Waste water extracted from the suit heat exchanger is pumped into the waste water tank, and is delivered to the EVAP WATER CONTROL-PRIMARY and SECONDARY valves on panel 382. When the tank is full, excess waste water is dumped overboard through the water PRESSURE RELIEF valve. The EVAP WATER CONTROL valves consist of a manually operated inlet valve and a solenoid valve. When the inlet valves are in AUTO, the solenoid valves control water flow to the evaporators. The PRIMARY solenoid valve is controlled automatically when the GLYCOL-EVAP-H2O FLOW switch (panel 2) is in AUTO, and manually when the switch is ON. The SECONDARY solenoid valve is controlled automatically when the SEC COOLANT LOOP EVAP switch is in EVAP. There is no manual control provided.

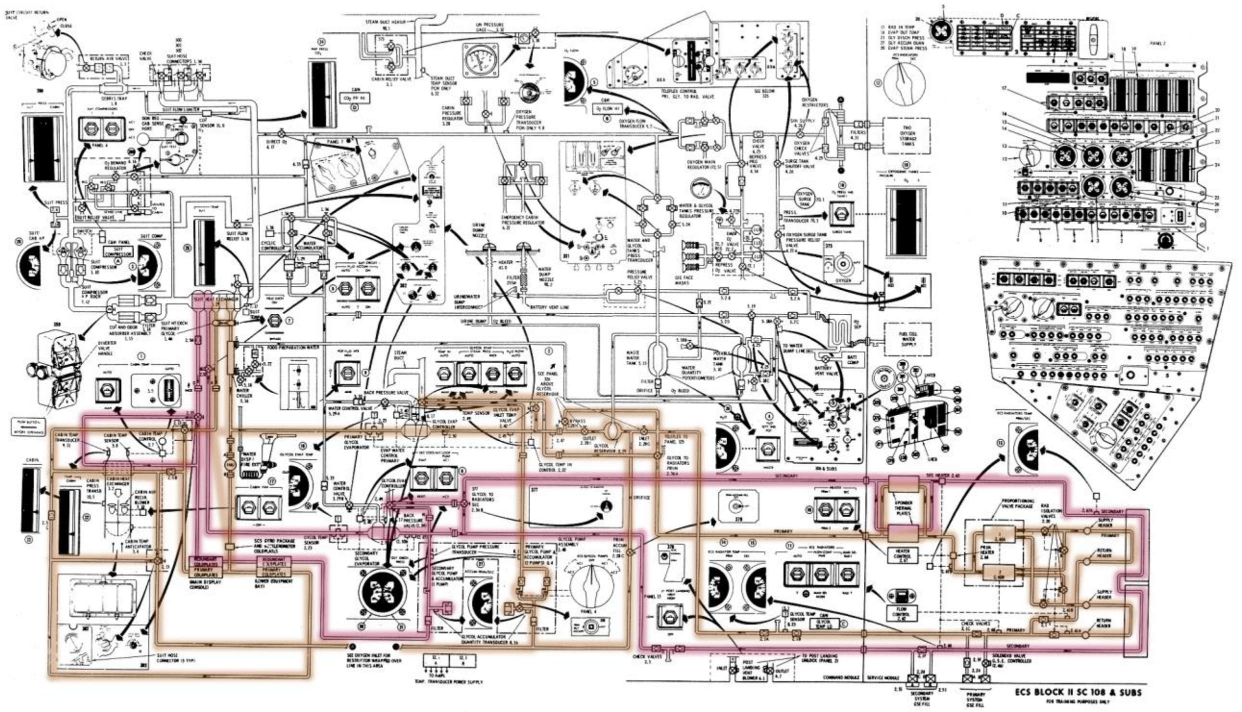
Here is a simplified diagram of the water subsystem from the CSM News Reference (NASA).



Schematic of water management subsystem

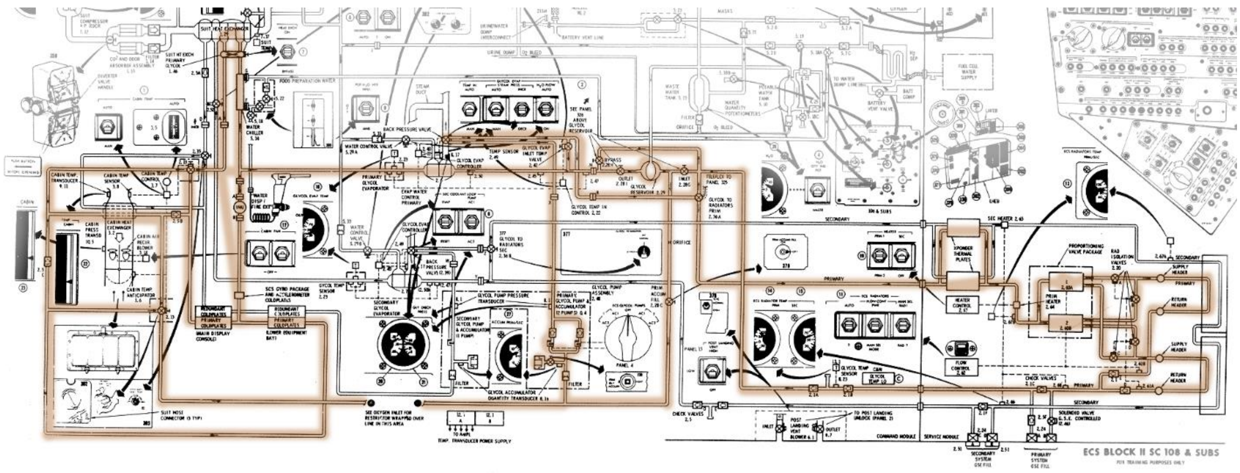
6. WATER-GLYCOL COOLANT SUBSYSTEM

The water-glycol subsystem is highlighted in the ECS diagram below.

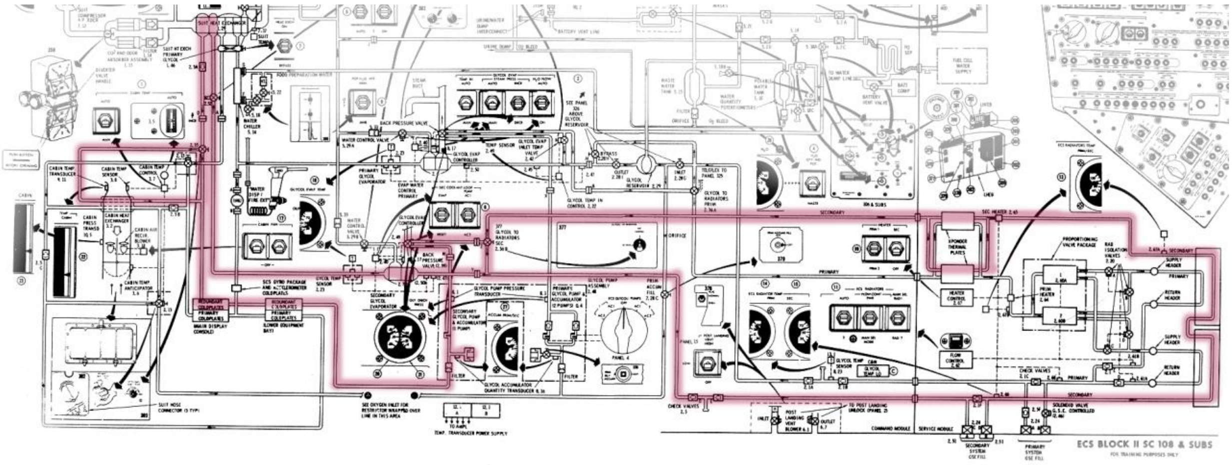


It consists of two independently operated closed coolant loops. I have created a separate diagram for each of the two loops. The primary loop has a brown color, and the secondary loop has a “red” color.

The primary loop is operated continuously throughout the mission, unless damage to the equipment necessitates shutdown.



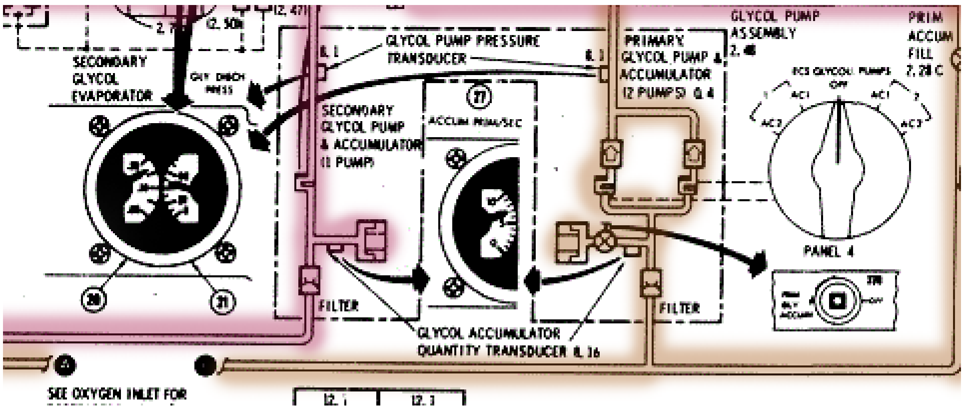
The secondary loop is operated at the discretion of the crew, and provides a backup for the primary loop.



Both loops provide cooling for the suit and cabin atmosphere, the electric equipment, and a portion of the potable water supply. The primary loop also serves as a source of heat for the cabin atmosphere when required.

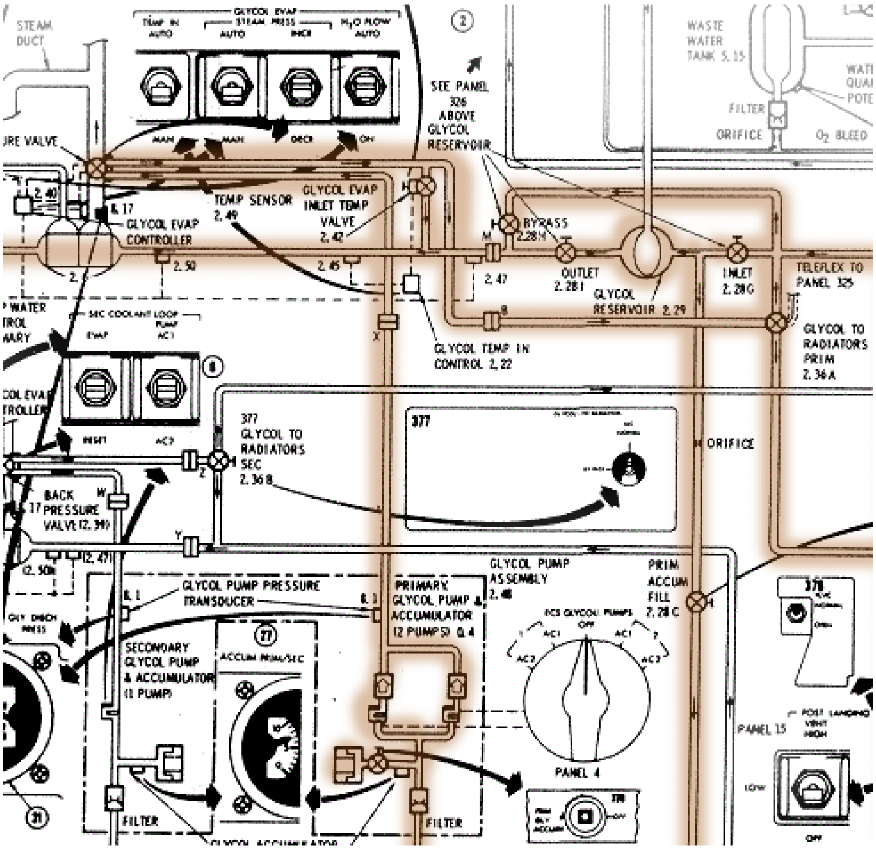
6.1. COOLANT FLOW

The coolant is circulated through the loops by pumping unit consisting of two pumps, a full-flow filter, and an accumulator for the primary loop; and a single pump, filter, and accumulator for the secondary loop.

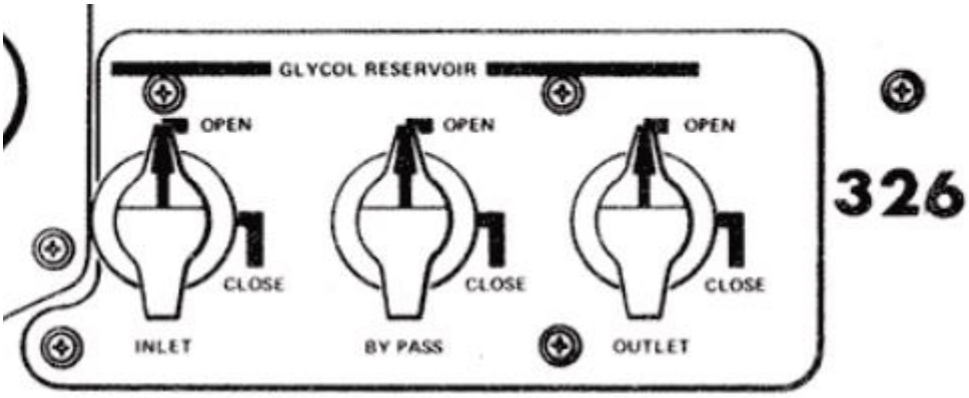


The purpose of the accumulators is to maintain a positive pressure at the pump inlets by accepting volumetric changes due to changes in coolant temperature. If the primary accumulator leaks, it can be isolated from the loop by means of the PRIM GLY ACCUM (panel 378). Then the reservoir must be placed in the loop to act as an accumulator. Accumulator quantity is displayed on the ACCUM PRIM/SEC indicator on panel 2. The signal source is selected by the ECS INDICATORS rotary switch on panel 2. The primary pumps are controlled by the ECS GLYCOL PUMPS rotary switch on panel 4, which permits either of the pumps to be connected to either a-c bus.

The output of the primary pump flows through a passage in the evaporator steam pressure control valve to de-ice the valve throat. The coolant next flows through the GLYCOL TO RADIATORS-PRIM valve (panel 325), through the radiators, and returns to the CM. The GLYCOL TO RADIATORS-PRIM valve is placed in the BYPASS position; prior to launch to isolate the radiators from the loop, and prior to CM-SM separation to prevent loss of coolant when the CSM umbilical is cut. During space operations the valve is in the NORMAL position.

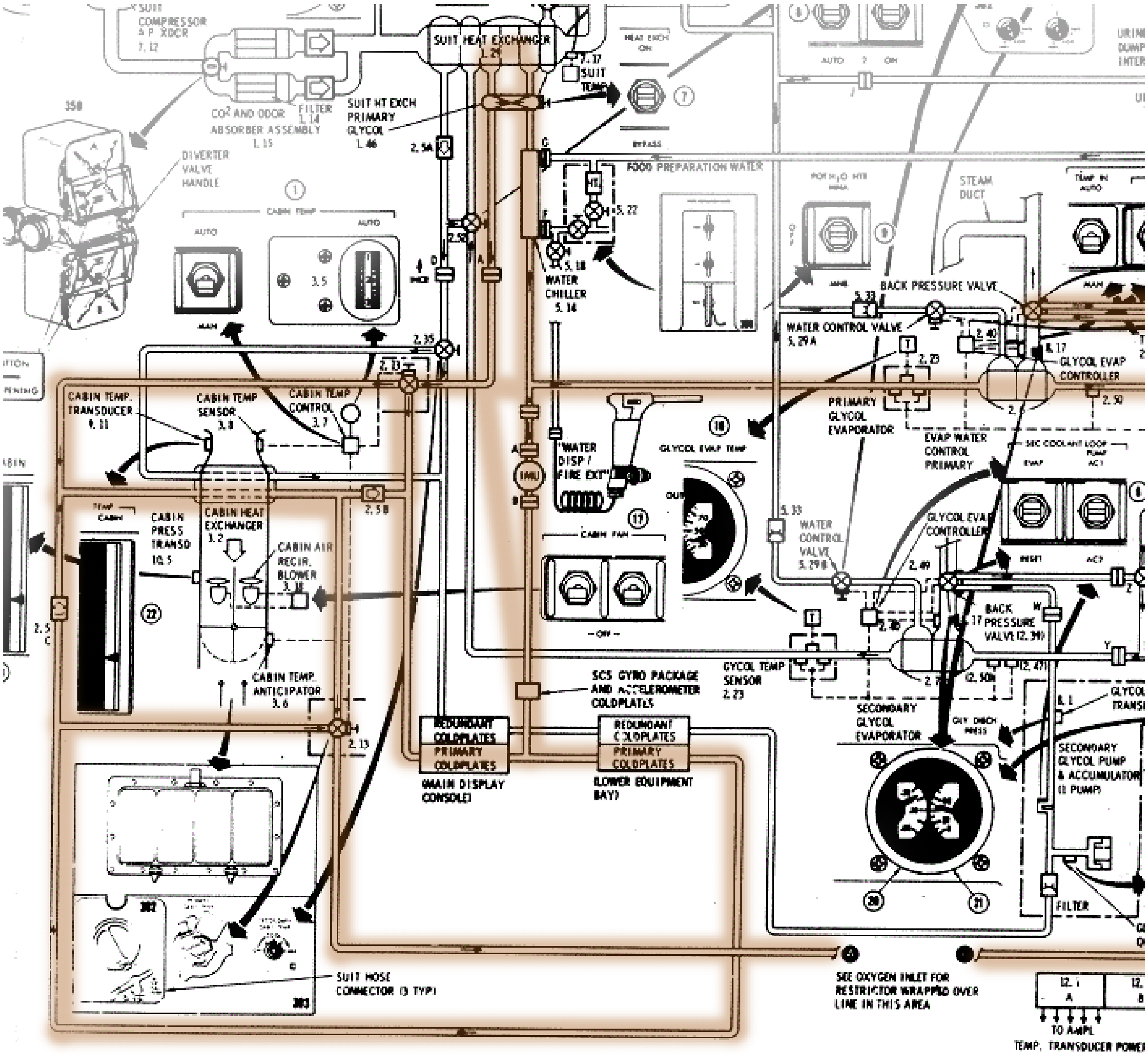


Coolant returning to the CM flows to the GLYCOL RESERVOIR valves (panel 326). From prelaunch until after orbit insertion, the reservoir INLET and OUTLET valves are open and the bypass valve is closed, allowing coolant to circulate through the reservoir.



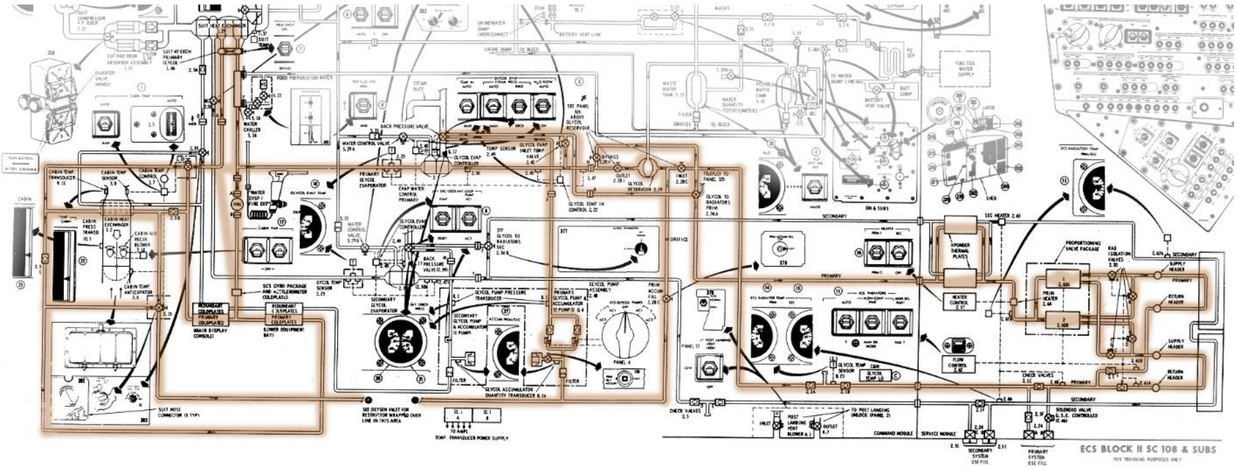
This provides a quantity of cold coolant to be used as a heat sink during the early stage of launch. After orbit insertion, the reservoir is isolated from the primary loop (by opening the BYPASS valve, and closing the INLET and OUTLET valves) to provide a reserve supply of coolant for refilling the loop in the event of a leak occurs. Refilling is accomplished by the means of the PRIM ACCUMR FILL valve (panel 379). Prior to entry, the reservoir is again placed in the loop. From the outlet or bypass valve, the coolant will go to the glycol evaporator.

The coolant flow from the evaporator divides into two branches. One branch carries a flow of 33 pounds per hour to the inertial measurement unit (IMU), and into the coldplate network. The other branch carries a flow if 167 pounds per hour to the water chiller, then through the SUIT HT EXCH PRIMARY GLYCOL valve (panel 382) and the suit heat exchanger to the PRIMARY CABIN TEMP control valve (panel 303).

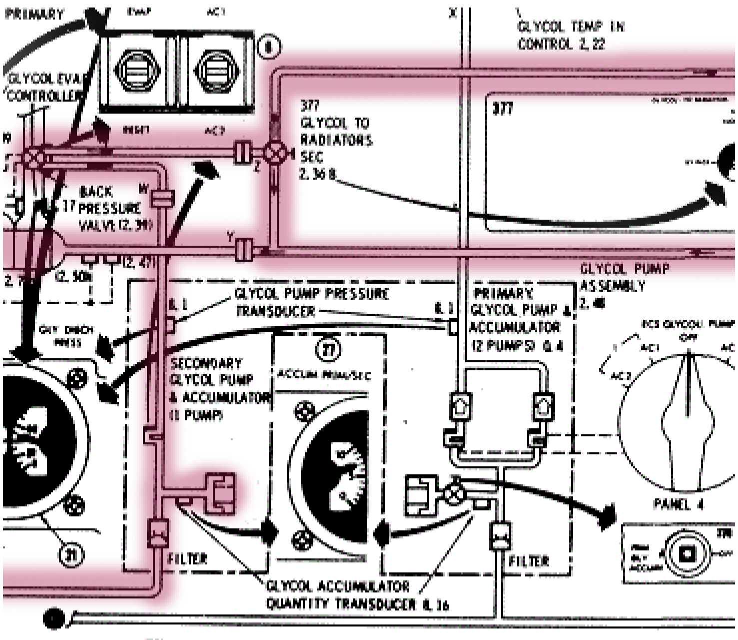


The PRIMARY CABIN TEMP control valve routes the coolant to either the cabin heat exchanger or the coldplate network. The valve is positioned automatically by the cabin temperature control, or manually by means of an override control on the face of the valve. The valve is so constructed that in the cabin full cooling mode, the flow of coolant from the suit heat exchanger (167 pounds per hour) is routed first through the cabin heat exchanger and then through the thermal coldplates where it joins the flow (33 pounds per hour) from the IMU. In the cabin full heating mode, the total flow (200 pounds per hour) is routed through the thermal coldplates first, where the water-glycol absorbs heat; from there it flows through the cabin heat exchanger. In the intermediate valve positions, the quantity of cool or warm water-glycol flowing through the heat exchanger is reduced in proportion to the demand for cooling or heating. Although the amount of water-glycol flowing through the cabin heat exchanger will vary, the total flow through the thermal coldplates will always be total system flow.

An orifice restrictor is installed between the cabin temperature control valve and the inlet to the coldplates. Its purpose is to maintain a constant flow rate through the coldplates by reducing the heating mode flow rate to that of the cooling mode flow rate. Another orifice restrictor, located in the coolant line from the IMU, maintains a constant flow rate through this component regardless of system flow fluctuations. The total flow leaving the PRIMARY CABIN TEMP valve enters the primary pump and is recirculated.

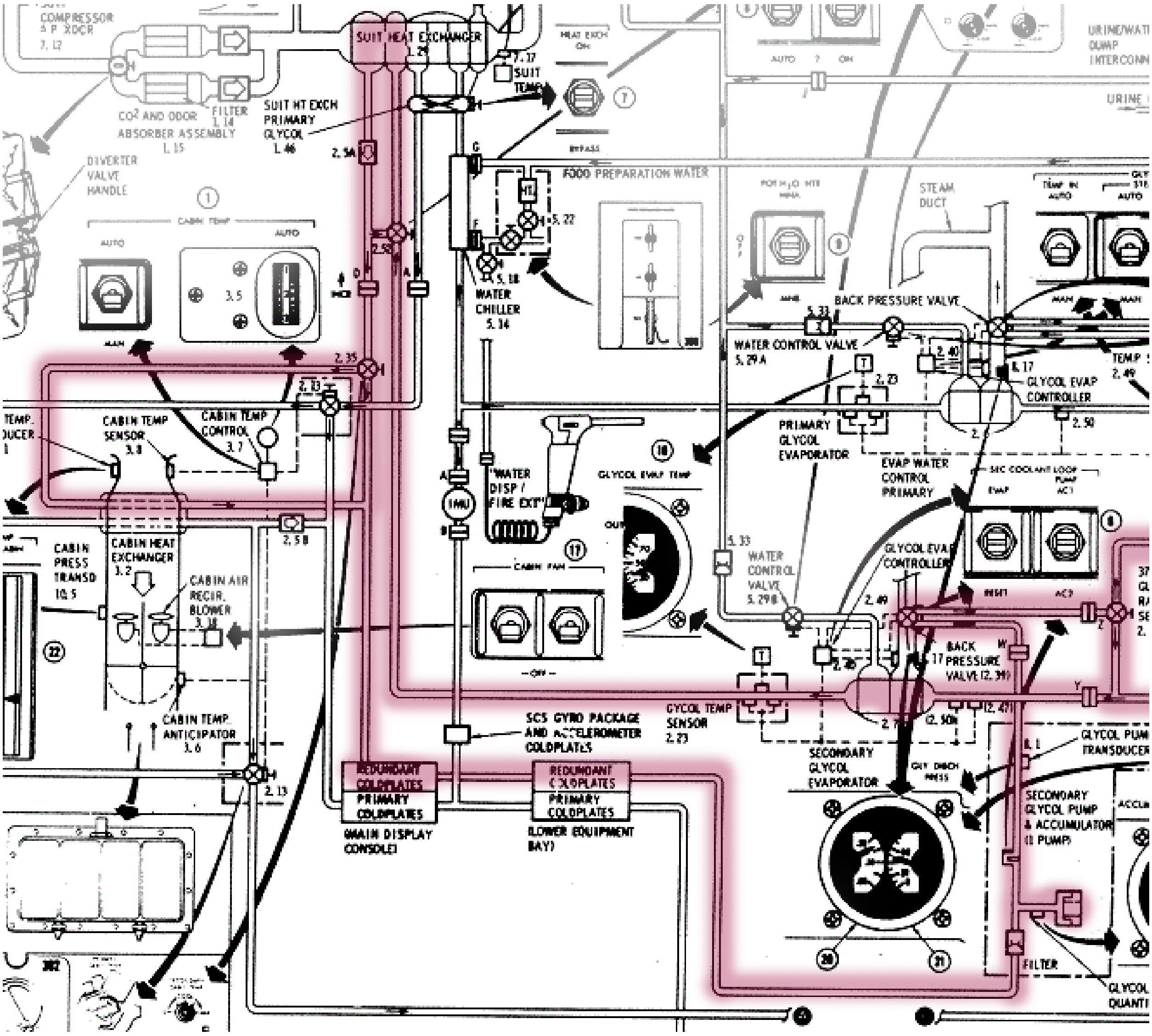


The output of the secondary pump flows through a passage in the secondary evaporator steam pressure control valve for de-icing the valve throat.



The coolant next flows through the GLYCOL TO RADIATORS-SEC valve (panel 377), through the radiators, and returns to the CM. The GLYCOL TO RADIATORS-SEC valve is placed in the bypass position, prior to CM-CM separation to prevent loss of coolant when the CSM umbilical is severed.

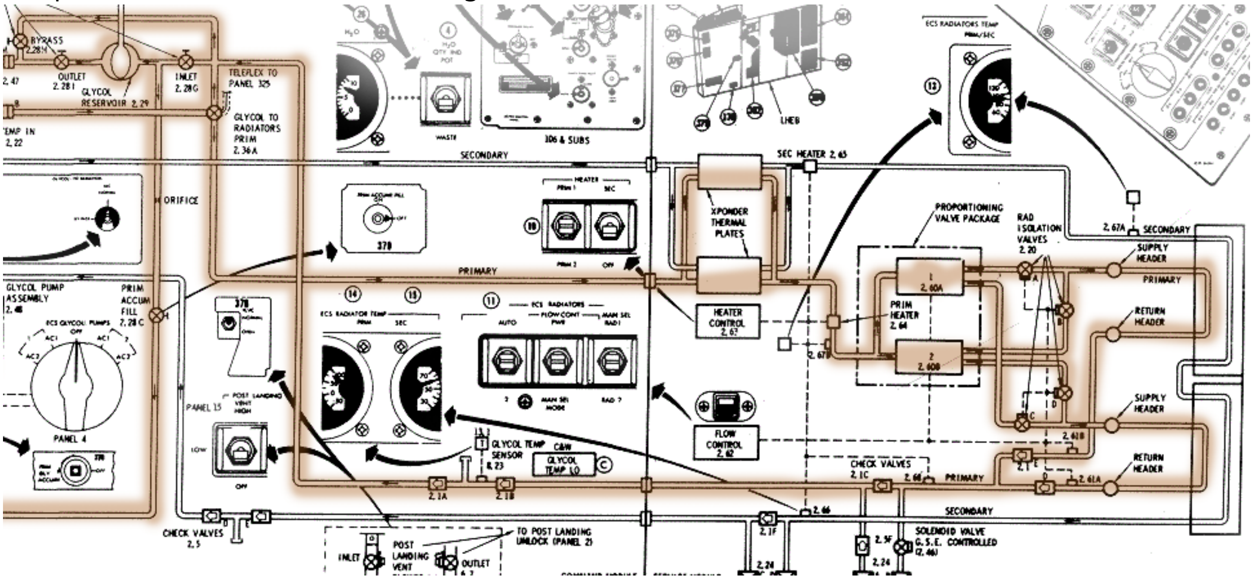
After returning to the command module, the coolant flows through the secondary evaporator, the SUIT HT EXCH SECONDARY GLYCOL valve, and the suit heat exchanger to the SECONDARY CABIN TEMP control valve (panel 303).



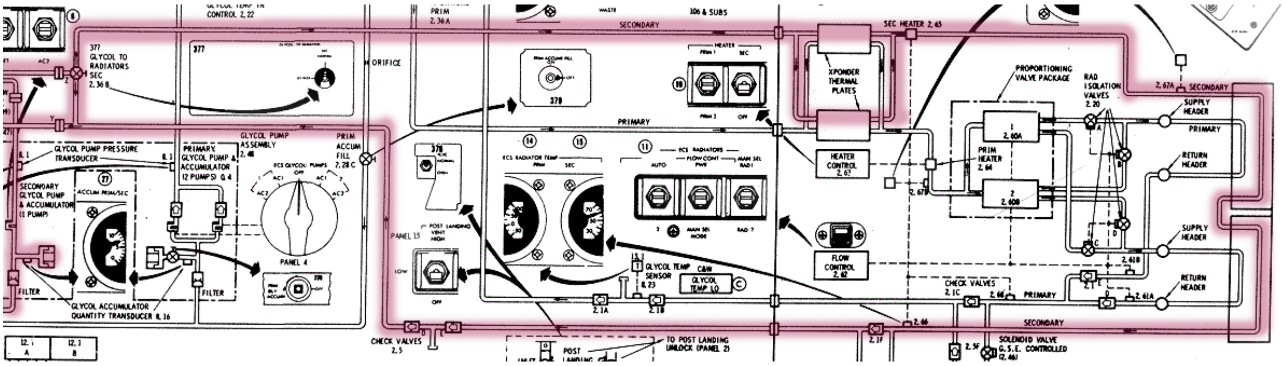
The SECONDARY CABIN TEMP control valve regulates the quantity of coolant flowing through the cabin heat exchanger in the cooling mode (there is no heating capability in the secondary loop). The coolant from the secondary cabin temp control valve and/or cabin heat exchanger then flows through redundant passages in the coldplates for the flight critical equipment and returns to the secondary pump inlet

6.2. GLYCOL TEMPERATURE CONTROL

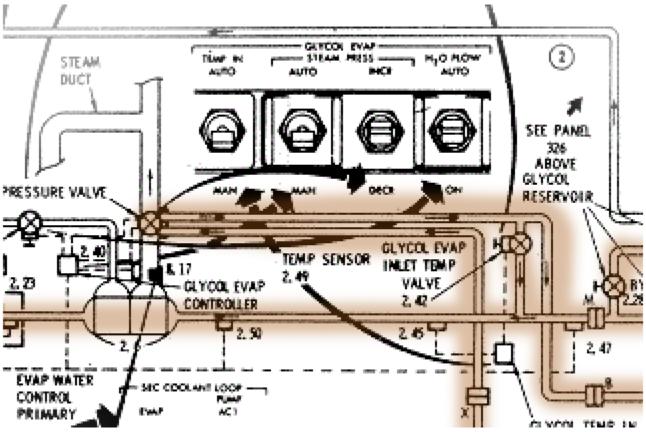
The heat absorbed by the coolant in the primary loop is transported to the radiators where a portion is rejected to space. If the quantity of heat rejected by the radiators is excessive, the temperature of the coolant returning to the CM will be lower than desired (45 °F nominal).



If the temperature of the coolant entering evaporator drops below a nominal 43 °F, the mixing mode of temperature control is initiated. The automatic control (GLYCOL EVAP-TEMP IN switch, AUTO position) opens the PRIMARY GLYCOL EVAP INLET TEMP valve (panel 382), which allows a sufficient quantity of hot coolant from the pump to mix with the coolant returning from the radiators, to produce a mixed temperature at the inlet to the evaporator between 43° and 48 °F. There is no mixing mode in the secondary loop. If the temperature of the coolant returning from the secondary radiator is lower than 45 °F nominal, the secondary radiator inlet heater will be turned on to maintain the outlet temperature between 42° and 48 °F.

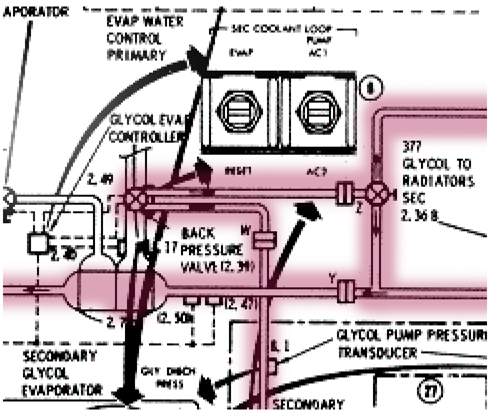


If the radiators fail to radiate sufficient quantity of heat, the coolant returning to the CM will be above the desired temperature. When the temperature of the coolant entering the



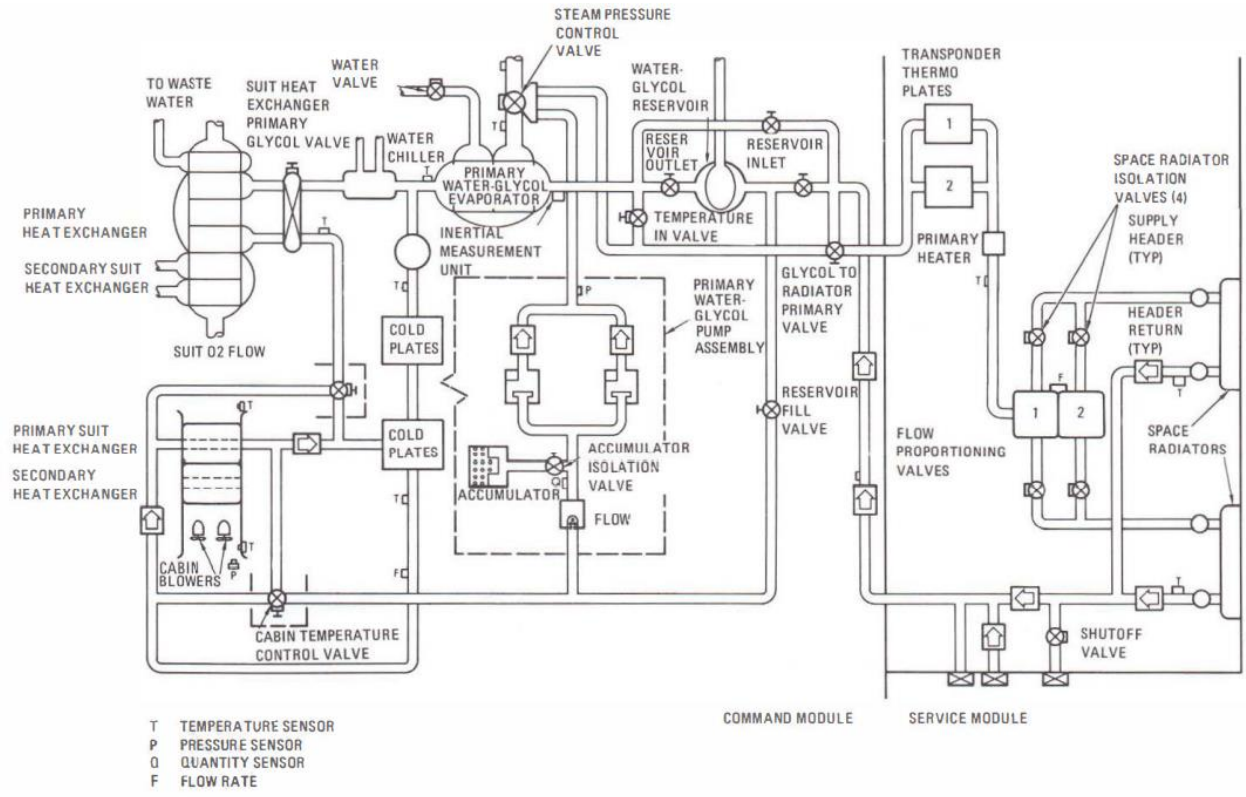
evaporator rises to 48° to 50.5 °F, the evaporator mode of cooling is initiated. The glycol temperature control (GLYCOL EVAP-STEAM PRESS switch, AUTO position) opens the steam pressure valve allowing water in the evaporator wicks to evaporate, using some of the heat contains in the coolant for the heat of vaporization. A glycol temperature sensor at the outlet of the evaporator controls the position of the steam pressure valves to establish a rate of evaporation that will result in a coolant outlet temperature between 38° to 45 °F.

The evaporator wicks are maintained in a wet condition by the wetness control (GLYCOL EVAP-H2O FLOW switch, AUTO position), which uses the wick temperature as an indication of water content. As the wicks become dryer, the wick temperature increases, and the water control valve is opened. As the wicks become wetter, the wick temperature decreases, and the water valve closes. The evaporative mode of cooling is the same for both loops, except that there is backup control for the primary loop only. The PRIMARY GLYCOL EVAP INLET TEMP valve can be positioned manually when the TEMP IN switch is in the MAN position. The steam pressure valve can be controlled remotely by placing the STEAM PRESS switch to the MAN and using the INCR/DECR switch to position the valve. The water control valve can be opened remotely by placing the H2O FLOW switch to ON.



The secondary evaporator is controlled automatically when the SEC COOLANT LOOP switch is in the EVAP position; placing the switch in RESET causes the control to close the secondary steam pressure valve. The OFF position removes power from the control.

Here is a schematic for the primary water-glycol loop from the CSM News Reference (NASA).

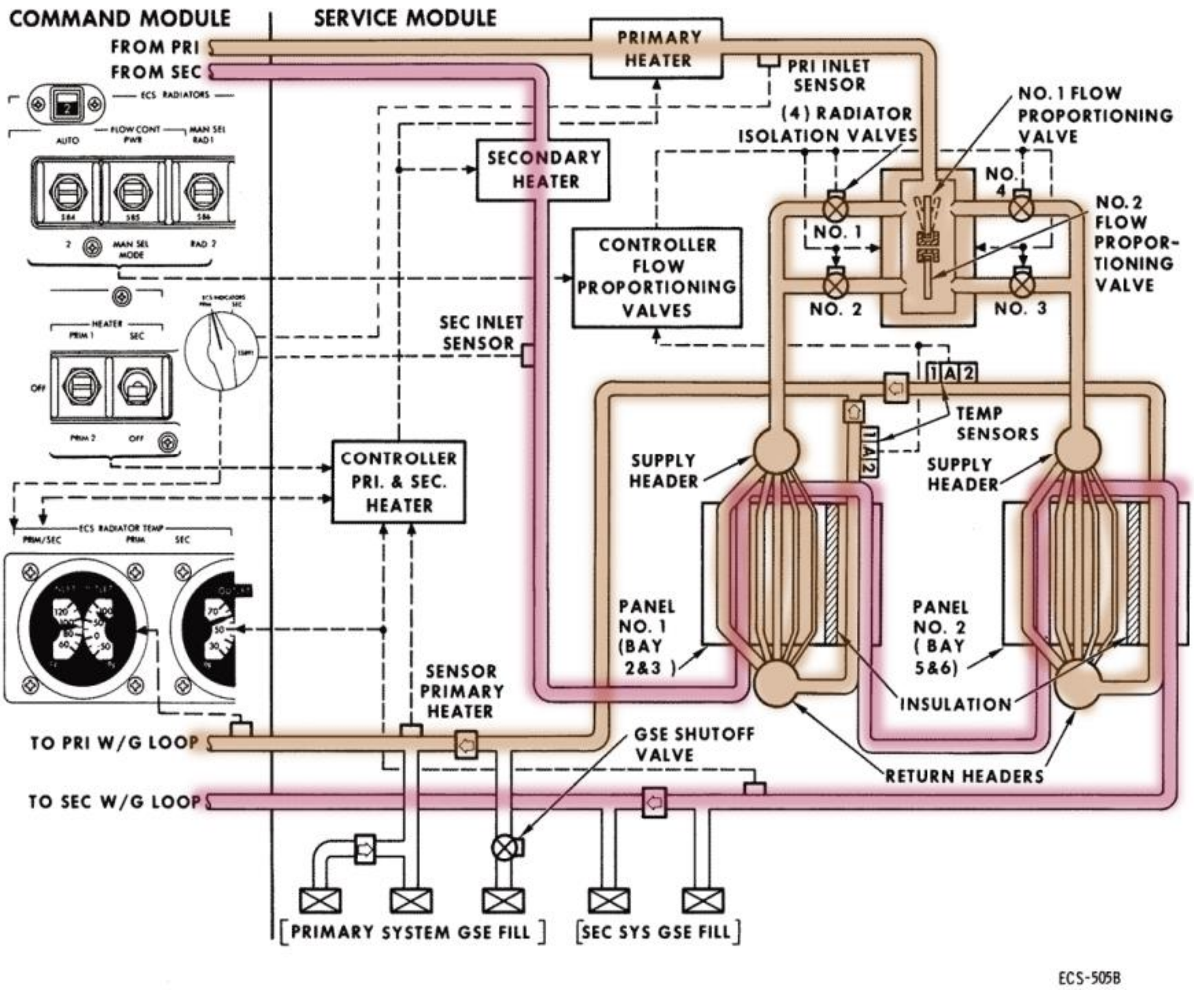


P-179

Schematic of primary water-glycol subsystem

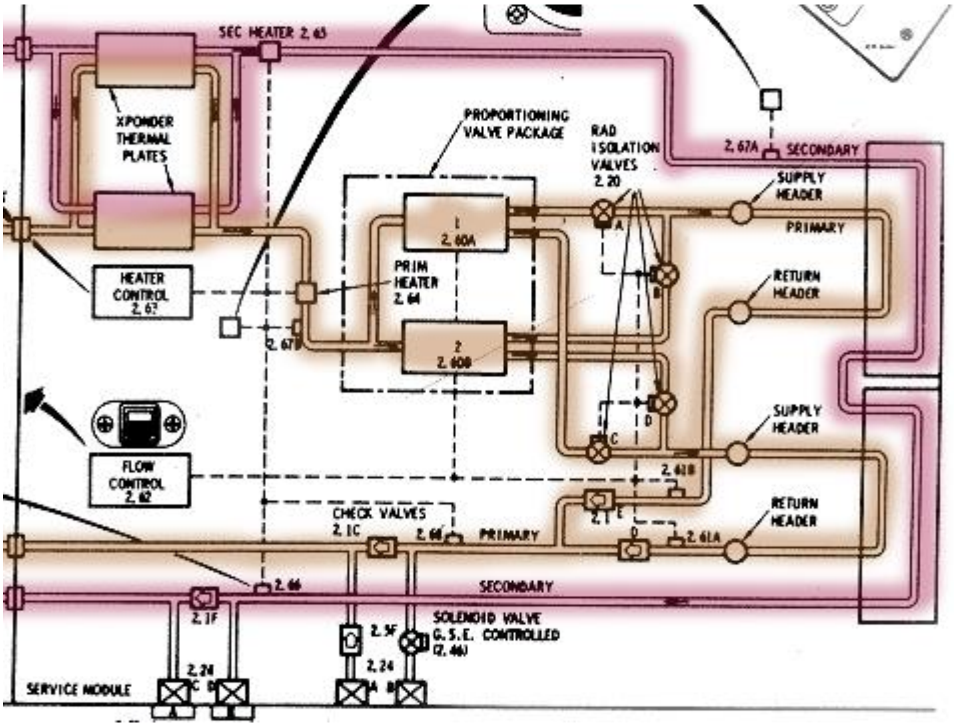
6.3. ECS RADIATOR CONTROL

Each coolant loop includes a radiator circuit.

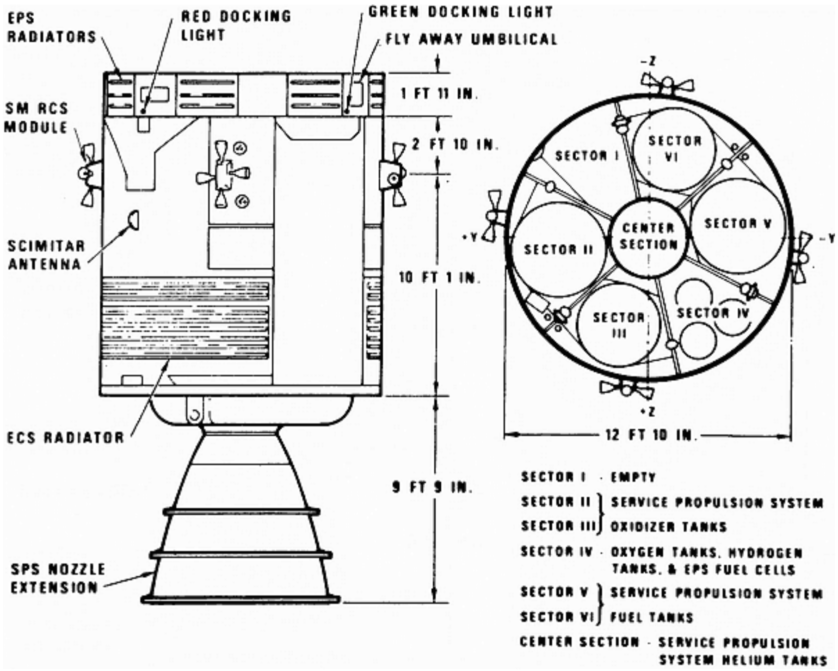


The primary radiator circuit consists basically of two radiator panels, in parallel with a flow-proportioning control for dividing the flow between them, and a heater control for adding heat to the loop.

The secondary circuit consists of a series loop utilizing some of the area of both panels, and a heater control for adding heat to the loop. The drawing above can be seen on the ECS overview diagram too, see reference below.

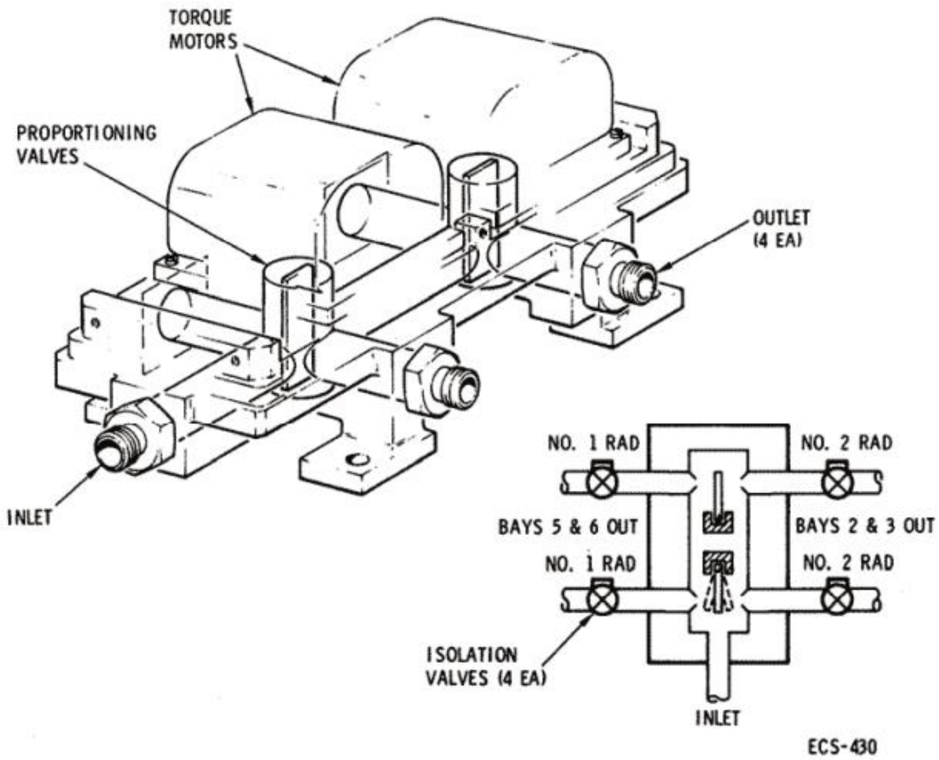


The radiator panels are an integral part of the SM skin and are located on the opposide sides of the SM (panel 1 in bays 2 and 3; panel 2 in bays 5 and 6). With the radiators being diametrically opposite, it is possible that one primary panel may “see” deep space while the

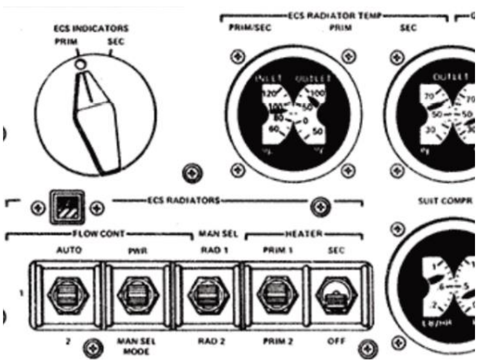


other “sees” the sun, earth, or moon. These extremes in environments, provide for large differences in panel efficiencies and outlet temperatures. The panel seeing deep space can reject more heat than the panel receiveing external radiaton; therefore, the overall efficiency of the subsystem can be improved by increasing the flow to the cold panel. The higher flow rate reduces the transit time of the coolant through the radiator, which decreases the quantity of heat radiated.

Flow through the radiator is controlled by a dual flow-proportioning valve assembly, four radiator isolation valves, and a solid-state electronic controller. The flow-proportioning valve assembly consists of two vane-type proportioning valves each driven by an individulla controlled torque motor. The assembly has a common inlet port, and each of the valves has two outlet ports, one going to the supply lines for radiator panel No. 1, and the other going to panel 2. A radiator isolation valve is installed between each of the valve outlet ports and the supplu line for each of the radiator panels.



The controller not only contains the circuits for controlling the position of the flow-proportioning valves, it also contains radiator isolation valve selection logic, a failure-sensing logic, and redundant power supplies.



Power is supplied to the controller through the two FLOW CONT switches in the ECS RADIATORS switch group on panel 2.

Placing the PWR-MAN SEL MODE switch in the PWR positoini, routes d-c power to the AUTO-1-2 switch, which is used for selecting the opoerating mode of the controller. When the AUTO-1-2 switch is placed in the AUTO position, and the PWR-MAN SEL MODE switch is in PWR, 28 vdc is applied to the No. 1 power supply of the controller through the internal automatic transfer circuit. The output of the power supply goes to the No. 1 operational amplifier which controls the No. 1 flow-proportioning valve; the failure-sensing logic circuit, which controls the electrical state of the auto transfer circuit; and to the control circuit for the four radiator isolation valves, which will position the valves for operation on the No. 1 flow-proportioning system. Thee temperature sensors are located in the outlet line from each of the primary radiator panels. The first pair of sensors are connected to the temperature bridge of the No. 1 operatioal amplifier, the second pair to the No. 2 amplifier, and the third pair to the failure-sensing logic amplifier.

During operation, if a difference in radiator panel outlet temperature occurs, the flow-proportioning valve will be positioned to increase the coolant flow to the cooler radiator panel. At a temperature differential of 10 °F the flow-proportioning valve will be "hard over", divirting approximately 95 percent of the flow to the cold radiator. The failure-sensing logic is monitoring radiator panel outlet temperatures and the magnitude and polarity of the flow-proprotioning valve torque motor current. If a temperature differential of 15 °F occurs, and the torque motor current is less than 90 percent of maximum or the wrong polarity, the failure-sensing logic will trigger the automatic transfer circuit. The transfer from the No. 1 to the No. 2 system is effected by removing the input power from the No. 1 power supply and applying power to the No. 2 power supply. The output of the No. 2 power supply then caues the radiator isolation valves to be positioned for operation with the No. 2 flow-proportioning valve, and applies power to the No. 2 operational amplifier. The failure-sensing logic does not operate with the No. 2 system.

When the AUTO-1-2 switch is in the 1 or 2 position, power is applied to the corresponding power supply, which will set up the system for operation as described previously, except for the failure-sensing and transfer circuit. Transfer in this case is by means of the AUTO-1-2 switch.

In situations where the radiator inlet temperature is low and the panels have faborable environment for heat rejection, the radiator outlet temperature start to decrease and thus the bypass (flow through the PRIMARY GLYCOL EVAP INLET TEMP valve) ratio starts to incrase. As more flow is bypassed, the radiator outlet temperature decreases until the -20 °F minimum desired temperature would be exceeded. To prevent this from occuring, an in-line heater upstream of the radiator is automatically turned on when radiator mixed outlet temperature drops to -15 °F and remains on until -10 °F is reached. The controller only provides on/off heater control. Power for the controller comes form the ECS RADIATORS HEATER switch in the PRIM 1 or PRIM 2 position. Switching to the redundant heater system is accomplished by the crew, if temperautre decreases to -20 °F.

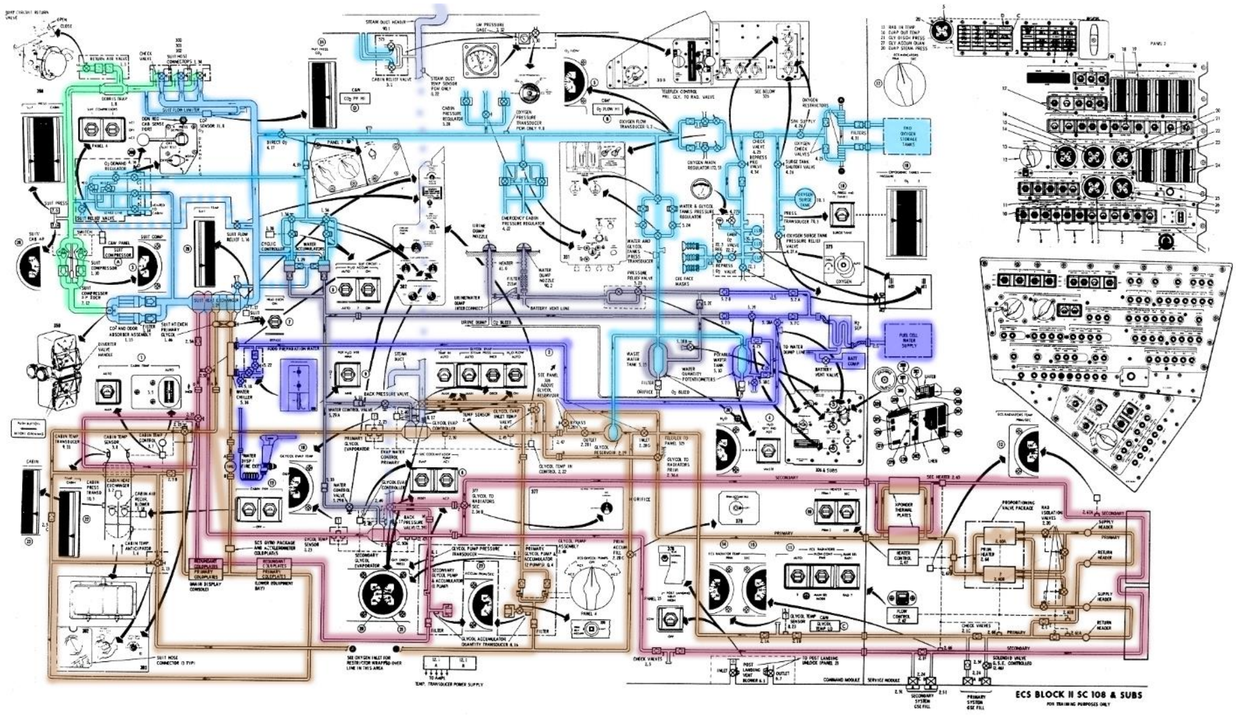
If the radiator outlet temperature falls below the desired minimum, the effective radiator surface temperaturte will be controlled passively by the selective stagnation method. The two primary circuits are identical, each consisting of five tubes in parallel and one downstream series tube. The two panels, as explaind in the flow-proprotioning control system, are in parallel with respect to each other. The five parallel tubes of each panel have manifolds sized precicly to provide specific flow-rate ratios in the tubes, numbered 1 through 5. Tube 5 has a lower rate than tube 4, and so on, through tube 1 which has the higher flow. It follows, that for equal fin areas the tube with the lower flow rate will have a lower coolant temperature. Therefore, during minimum CM heat loads, stagnation beings to occur in tube 5 as its temperature decreases; for as its temperature decreases, the fluid resistance increases, and the flow rate decrases, as the fin area around tube 5 gets colder, it draws heat from tube 4 and the same process occurs with tube 4. In a fully stagnated condition, there is essentially no flow in tubes 3, 4, and 5, and some flow in tubes 1 and 2, with most of it in tube 1.

When the CM heat load increases and the radiator inlet starts to increase, the temperature in tube 1 increases and more heat is transferred through the fin towards tube 2. At the same time, the PRIMARY GLYCOL EVAP INLET TEMP valve starts to close and force more coolant to the radiators, thus helping to thaw the stagnat portion of the panels. As tube 2 starts to get warmer and receives more flow, it in turn starts to thaw tube 3, etc. This combination of higher inlet temperatures and higher flow rates quickly thaws out the panel. The panels automatically provide a high effectiveness (completely thawed panels operating at a high-average fin temperature) at high-heat loads, and low effectiveness (stagnated panels operating at a low-average fin temperature) at low-heat loads.

The secondary radiator consists of four tubes which are an integral part of the ECS radiator panel structure. Each tube is purposely placed close to the hottest primary radiator tubes (i.e., the number 1 and the downstream series tube on each panel) to keep the water-glycol in the secondary tubes from freezing while the secondary circuit is inoperative. The "selective stagnation" principle is not utilized in the secondary radiator because of the "narrower" heat load range requirements. This is also the reason the secondary radiator is a series loop. Because of the lack of this passive control mechanism, the secondary ECS circuit is dependent on the heater control system at low-heat loads and the evaporator at high-heat loads for control of the water-glycol temperature.

The secondary heater control receives power though the ECS RADIATOR HEATER switch in the SEC position. The secondary heaters differ from the primary in that they can be operated simultaneously. When the secondary outlet temperature reaches 45 °F the No. 1 heater comes on, and at 42 °F the No. 2 heater comes on; at 44 °F No. 2 goes off, and at 45 °F No. 1 goes off.

This concludes the description of the ECS system. As a summary, this is the final colored ECS diagram encapsulating this chapter. The additional thing added is the waste water steam that goes through the steam duct from the primary and secondary evaporators.

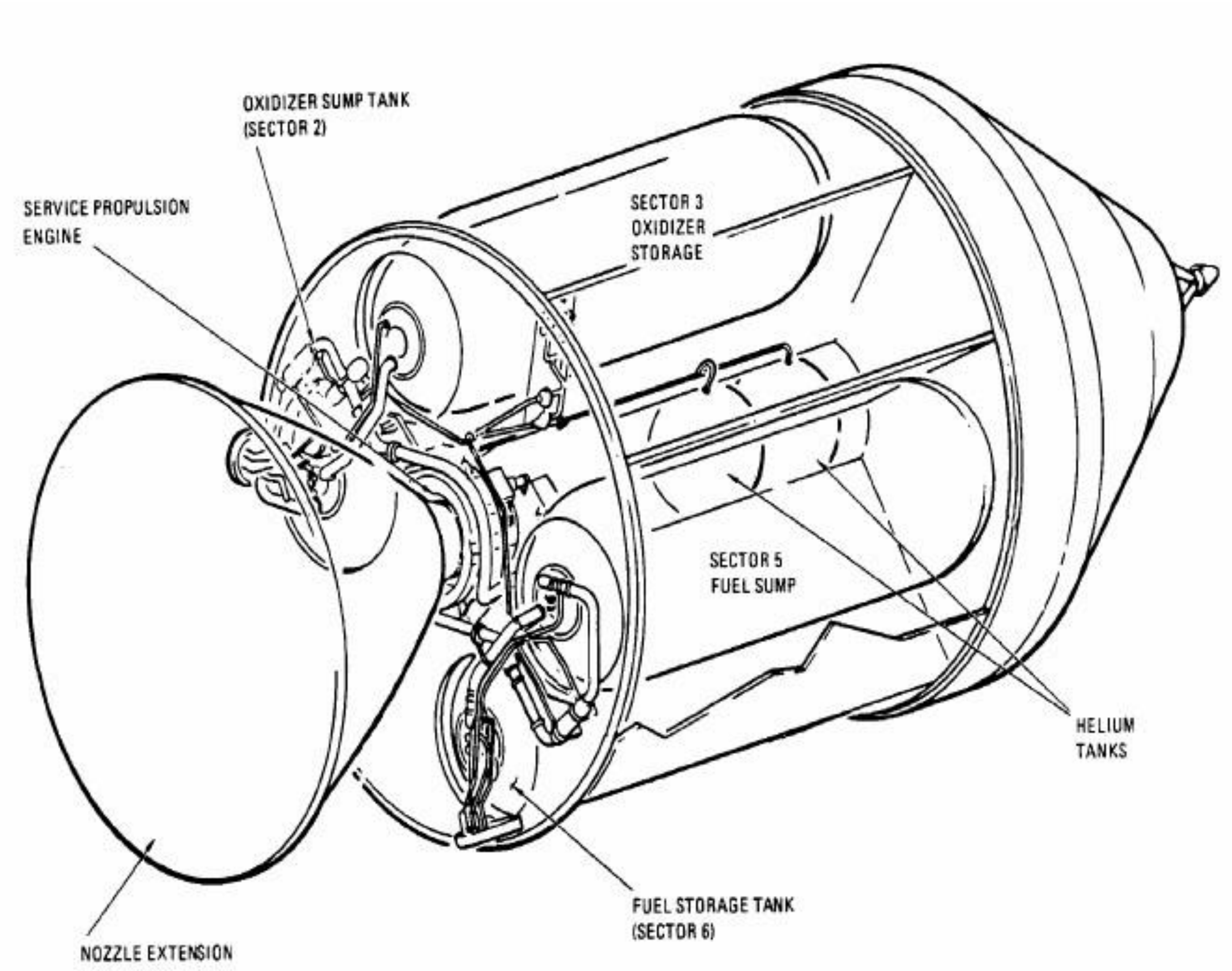

ECS BLOCK II SC 108 & SUBS

VII. SERVICE PROPULSION SYSTEM

VII. SERVICE PROPULSION SYSTEM

1. GENERAL

The service propulsion subsystem provides for all X-axis velocity changes (ΔVs) throughout a mission, and the SPS abort capability during ascent after the launch escape tower is jettisoned. The Service Propulsion System (SPS) consists of a helium pressurization system, a propellant feed system, a propellant gauging and utilization system, and a rocket engine.



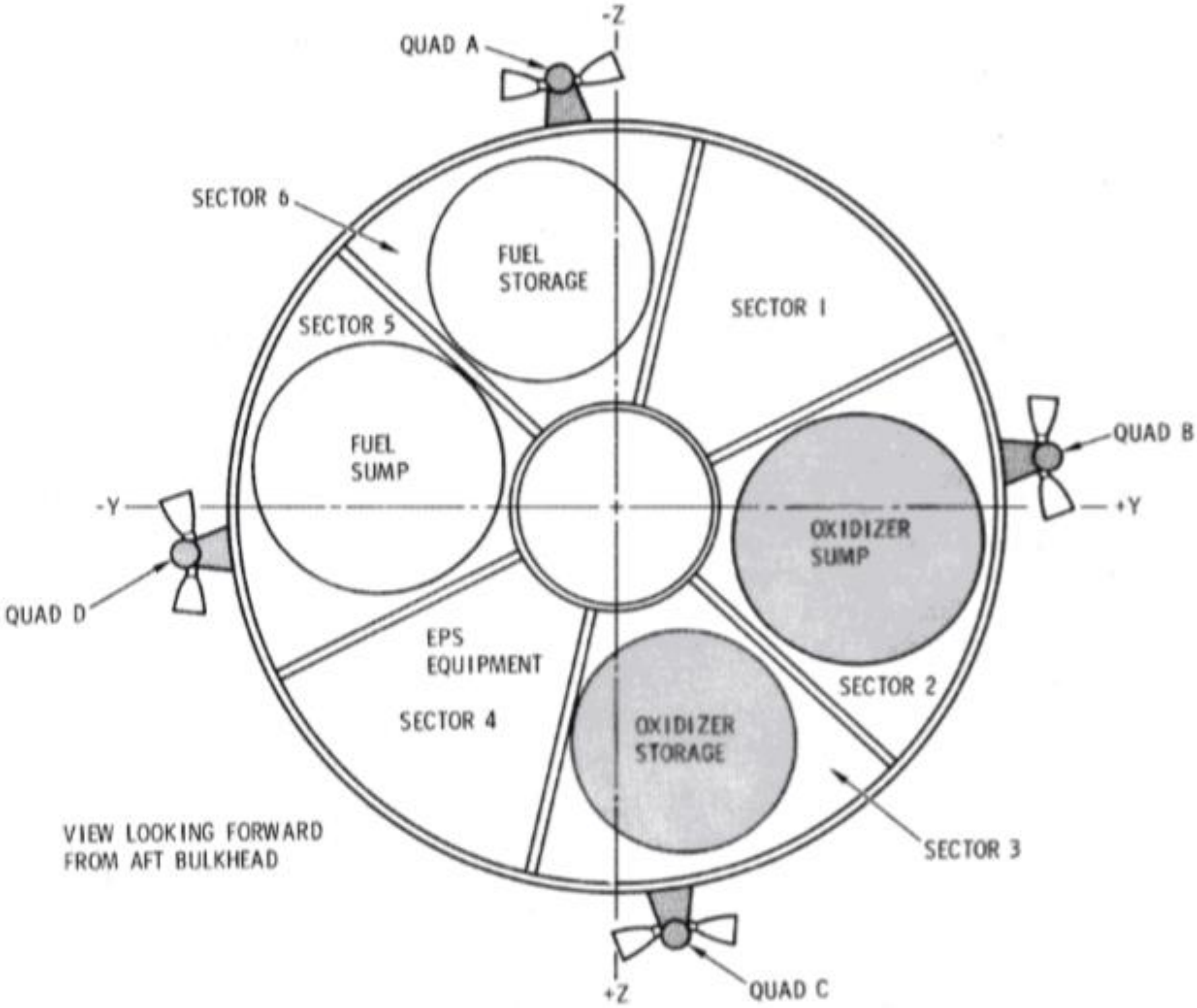
The oxidizer is inhibited nitrogen tetroxide and the fuel is a blend hydrazine. The pressurizing gas is helium. The restartable rocket engine has a nominal thrust of 20,500 lbs (91.2 kN) and can be gimbaled using the Thrust Vector controls.

The SPS is used during ΔV burns required to change the trajectory. This is usually during mid-course corrections while coasting towards the Moon, when breaking to reach Lunar orbit, or to get back to Earth after being in Lunar orbit.

2. PROPELLANT

The oxidizer and the fuel in the SPS is used to ignite and generate thrust in the SPS engine.

The total propellant supply is contained within four similar tanks; an oxidizer storage tank, oxidizer sump tank, fuel storage tank, and fuel sump tank. The substance is directed from the main tank to the sump tank, and then to the engine thrust chamber. A propellant utilization valve is installed in the oxidizer line and is only powered during thrusting or testing.



It is pressurized with Helium at 175 psi to push the substances into the engine thrust chamber. The Helium valves can be controlled using the SPS He VLV A/B switches on MDC-3.

The SPS He VLV talkback indicators show if the Helium valves are open (gray) or closed (barberpole).

The switches controls the valves (1 for A, 2 for B). It can be in AUTO, OFF or ON.
AUTO will control the valves automatically by the thrust on/off logic and is the normal position.
OFF will close the valve and ON will open it.

The SPS is designed to be very reliable, and is a critical instrument in the mission. It is the primary method of getting home from Lunar Orbit.

PROPELLANT UTILIZATION & GAUGING SUBSYSTEM

The PUGS is used to monitor the propellant. The SPS has a normal ratio of fuel:oxidizer at 1:1.6 initially. When both the fuel and the oxidizer levels are the same, the system is balanced.

PUGS indicates the remaining fuel and oxidizer quantities, and can control the fuel/oxidizer mix-ratio. The controls are located on MDC-3.

The OXID UNBAL gauge shows the balance of the system. If it reads 0, the system is balanced. This is the ratio between the OXID and FUEL percentage above.

It is important that these are balanced.

If it is umbalanced, the OXID UNBAL gauge will indicate a value on either the INCR or DECR side. Propellant utilization valves can be used to correct any unbalacing. It will change the mixture-ratio to balance the system.

The valves are only powered during a burn or a system test. A primary and secondary valve exists, and is controlled using the OXID FLOW VALVE PRIM/SEC valve (see image above). Primary is the normal position.

Looking at the OXID UNBAL gauge, if it shows anything on the INCR side, the OXID FLOW VALVE MODE switch is set to INCR. This will increase the flow of oxidizer, and the upper OXID FLOW VALVE talkback will indicate MAX. The Primary valve will increase the oxidizer ratio with 3% while the Secondary valve will increase it with 6%. It will take 3.5 seconds for this to take effect.

If the gauge shows DECR, the OXID FLOW VALVE MODE switch is set to DECR. The logic is the same as above, except that the fuel ratio will increase, and the ratio is either changed by 3.5% or 7%, and MIN will show in the lower talkback indicator.

PUGS TEST

The PUGS can be tested using the TEST switch. With PUGS MODE set to PRIM, TEST 1 the test signal is applied to the system after 4 seconds. The fuel and oxidizer readouts are driven to an increased reading at different rates, thus creating an unbalanced system on the INCR side. When the test switch is returned to center, the change is fixed at that setting. TEST 2 will send a test signal that after 4 seconds will drive the fuel and oxidizer readouts to a decreased reading. If TEST 1 was performed prior, it will be driven back to what the values were before TEST 1 was performed. If not, or it triggered again, TEST 2 will deacrease the umbalacing so it indicates a DECR on the OXID UNBAL gauge. If this is done, TEST 1 needs to be performed to drive it back to normal again.

With PUG MODE set to AUX, the above is the same except there are no time delays.

3. OPERATION

The SPS engine is a restartable engine and is the primary source of thrust after S-IVB separation. There are two pairs of engine injector valves named the bipropellant valve system A/B. The engine is ignited by opening one or both of these, and is shut down by closing the opened valve(s). When opened, the engine will throttle at max thrust for the duration of the burn.

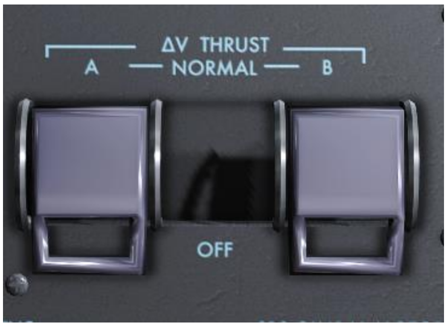
GETTING THE ENGINE READY

Each engine ignition requires nitrogen from the bipropellant valve system in use to start. At the launchpad, this is filled to 2500 psia for each system. This will need to be at least 400 psi for the system in use. In additoin, each ignition will require 50 psi of Nitrogen from the bipropellant valve system A and/or B.

The SPS instrumentaion gauges on the upper part of MDC-3 lets you see the status of the SPS systems. The He/N2 line can be selected using the SPS PRESS IND switch.
It can show the temperature, Helium and Nitrogen levels, and the Fuel/Oxidizer levels.
This is located on MDC-3.

The SPS PRESS IND lets you choose if the He/N2 gauge above will display the Helium or Nitrogen level of either System A or System B.
This is located on MDC-3.

Most of the controls to ignite the SPS engine is located on MDC-1.



ΔV THRUST A/B switch is used to ARM the control logic for the eninge injector valves A/B.

The LVα/SPS Pc gauge shows the chamber pressure if the LV/SPS IND switch below is in Pc.

During a burn this is normally 100 psi.

Controls the data displayed in the LVα/SPS Pc gauge.

If the SPS propellant is less than 50%, the fuel might be floating around in the tank due to free fall gravity. Therefore, before igniting the engine, the propellant needs to be settled down in the tanks. This is done using the DIRECT ULLAGE button or using the forward translation thrusters.

DIRECT ULLAGE is found on MDC-1 and is used to fire the rear thrusters to translate forward briefly. This is done just to separate some distance or to settle the SPS propellant in the tanks.

IGNITING THE ENGINE

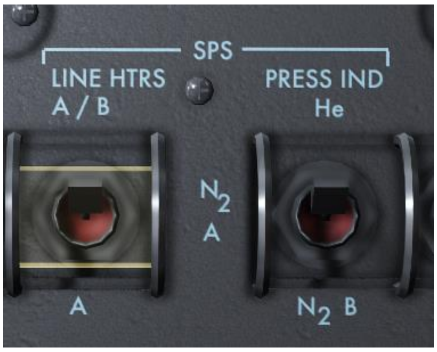
The engine is ignited in three different ways after being armed and ready:

- CMC ΔV mode is using the Command Module Computer to control the engine. The Apollo Guidance Computer chapter will go through how to do this using Program 30 and Program 40.
- SCS ΔV mode uses the SCS to control the SPS engine. The SC CONT switch needs to be in SCS, and the EMS needs to be in ΔV mode with the EMS ΔV/RANGE set to a number above 0 ft/s. When this is set, the THRUST ON button is pressed to ignite the engine.
  

- SPS thrust direct on mode is the easiest way to fire the engine and is used as a backup. The SPS THRUST switch is set to DIRECT ON to ignite the engine, and NORMAL to shut it down.
  

THERMAL CONTROL

The propellant feed lines normal operating temperature should be between 27 °F and 100 °F. The thermal control is controlled by heaters, and radiation to space. Two heaters are available, heater A and heater B.



If the temperature drops below 45 °F, the SPS LINE HTRS is set to A/B or A. It is set to OFF when the temperature is 75 °F or above.

The position of the spacecraft relative to the sun affects the temperature as well. The spacecraft can enter a Passive Thermal Control mode (PTC REFSMMAT) to roll at a slow and constant rate during coasting.

VIII. APOLLO GUIDANCE COMPUTER

VIII. APOLLO GUIDANCE COMPUTER

1. GENERAL

The Apollo Guidance Computer is a control computer located in the Command Module (a similar one exist in the Lunar Module), and is operated through two Display and Keyboard panels (DSKYs). One is located on MDC-2 while the other is located next to the optics system in the lower equipment bay. Both DSKYs control the same computer.

The Computer located in the Command Module is generally referenced to as the Command Module Computer (CMC). The CMC processes data and issues discrete control signals for both the PGNCS and other systems.

It aids in solving guidance problems, and monitors many of the the spacecraft systems.

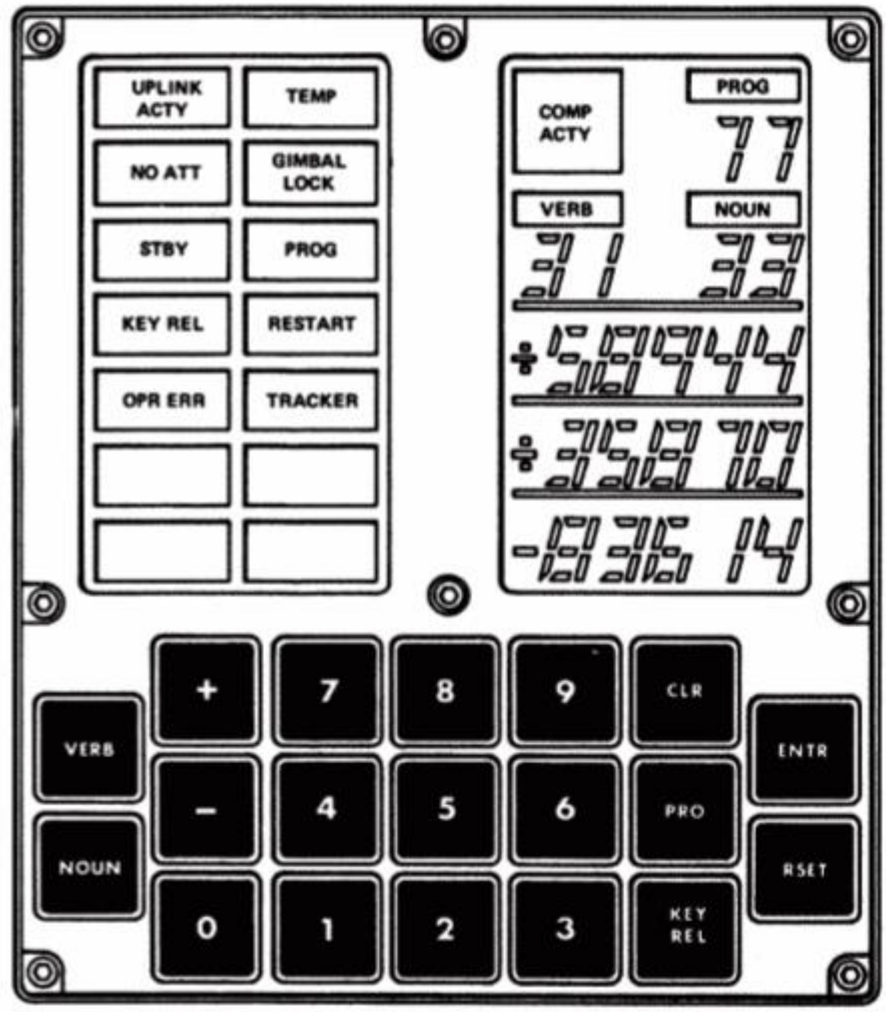
The CMC can control the Service Propulsion System by providing ignition commands (with input from the crew), can reorient the spacecraft to different attitudes, and display important information to the crew.

The CMC can run one major mode (mission program) at a time. It is controlled by using something called VERBs and NOUNs. A VERB is an action that is to be performed, like changing the mission program, monitor data, change data etc. A NOUN is the location or register the VERB (action) is being performed. For example, if the flight crew wish to run major mode 11, they enter VERB 37 that means ACTION: CHANGE PROGRAM (MAJOR MODE), and NOUN 11 that means TO PROGRAM 11. This will basically run program 11, which is the boost/ascent program used to monitor ascent velocity, acceleration etc.

It takes some time to understand this, but it will be easier once you know the basics and start using it.

2. DISPLAY AND KEYBOARD

The DSKYs facilitate intercommunication between the flight crew and the CMC.



The DSKYs have buttons for input, warning lights and a display. Below is a table with a short description of each component.

DISPLAY

COMP ACTY light	When illuminated, the CMC is occupied with an internal sequence.
PROG display	Shows the current major mode (mission program) running on the computer.
VERB display	Shows the current VERB being performed.
NOUN display	Shows the current NOUN where the action (VERB) is being performed.
REGISTER 1, 2 and 3	Three registers are used to display data from a register or memory location. Different VERBs and NOUNs are used to show content in the registers.

INDICATORS

UPLINK ACTY light	Shows when the CMC received data remotely from for example mission control.
NO ATT light	Illuminated when the CMC don't have an attitude from the IMU. This usually happens when the IMU is in a coarse align mode.
STBY light	On when the CMC is in standby mode
KEY REL light	Illuminates when the astronaut is using the DSKY. When pressing a key, the computer enters a mode where it won't interrupt the input. If the CMC desires to display data during this, they KEY REL light will illuminate/flash. This means the CMC has data to show, but is waiting for the crew to complete their input.
OPR ERR light	Illuminates when an input error has happened, like improper sequence of key depressions.
TEMP light	Illuminated when the IMU is outside its operational temperature range of 126.3 to 134.3°F
GIMBAL LOCK	Illuminated when the middle gimbal (yaw) exceed +/- 70 degrees from its zero position. This can require a realignment of the stable platform.
PROG light	Illuminated when the internal program detects computational difficulties.
RESTART light	Illuminates when the CMC detects a temporary hardware or software failure.
TRACKER light	Illuminated when the CMC receives a signal from the optics CDU indicating a failure.

KEYBOARD

Numeric keys	Ten numeric keys (0 – 9) is used to enter numbers.
+ and -	Sets the sign before entering a numeric value into any of the three registers.
NOUN	The next two numeric inputs will be for a NOUN.
VERB	The next two numeric inputs will be for a VERB.
CLR	Clears the current active input field. Used if a numeric input mistake was made. If NOUN is active, depressing this will clear the NOUN fields and position the input

	position to the beginning, same with a REGISTER etc.
ENTR	Used to ENTER data into the registers, NOUN or VERB fields. Will execute the requested function.
PRO	Proceed in a program, with or without data, and go to the next program step.
KEY REL	Will release the display from the flight crew to the computer when the computer wish to display data (KEY REL light)
RSET	Extinguishes the DSKY caution indicators 9OPR ERR, PROG, RESTART, STBY and UPLINK ACTY).

3. VERBS

Verbs and Nouns are used to talk with the computer, where each word is a digit. A verb code decides what action is to be taken.

A DESCRIPTION OF EACH VERB

VERB CODE	**DESCRIPTION**
01	Display Octal Component 1 in R1
04	Display Octal Components 1, 2 in R1, R2
05	Display Octal Components 1, 2, 3 in R1, R2, R3
06	Display decimal in R1 or R1, R2 or R1, R2, R3
16	Monitor decimal in R1 or R1, R2 or R1, R2, R3
21	Load Component 1 into R1 Allows the flight crew to enter data into register 1. The noun decides what memory location is bound th this register. ENTR will commit the data.
22	Load Component 2 into R2 Allows the flight crew to enter data into register 2. The noun decides what memory location is bound th this register. ENTR will commit the data.
23	Load Component 3 into R3 Allows the flight crew to enter data into register 3. The noun decides what memory location is bound th this register. ENTR will commit the data.
24	Load Component 1,2 into R1, R2 Allows the flight crew to enter data into register 1 and 2. The noun decides what memory location is bound th this register. ENTR will commit the data.
25	Load Component 1,2,3 into R1, R2, R3 Allows the flight crew to enter data into register 1, 2, and 3. The noun decides what memory location is bound th this register. ENTR will commit the data.
32	Recycle Program
34	Terminate function

35	Test lights
37	Change program (major mode)
41	Coarse align CDU's (specify N20 or N91)
45	Reset surface flag
46	Establish G & N autopilot control
47	Move LM state vector into CM state vector
48	Request DAP Data Load routine (R03)
49	Start automatic attitude maneuver
50	Please perform
51	Please mark
66	Vehicles are attached. Move this vehicle state vector to other vehicle.
75	Backup liftoff
78	Update prelaunch azimuth
83	Request Orbit Parameter display (R30)
96	Terminate integration and go to POO
99	Please enable Engine Ignition

4. NOUNS

A noun refers to locations, registers, devices or informations used/needed by the verb. Registers are used to display information related to the noun. A noun can be made up of up th three components. These are displayed in the three registers. A verb can be used to request an action to enter data into each or all of the registers.

A DESCRIPTION OF EACH NOUN

NOUN CODE	DESCRIPTION	FORMAT
00	Not in use	
05	Angular error/difference	XXX.XX deg
06	Option code ID Option code	Octal Octal
09	Alarm codes First Second Last	 Octal Octal Octal
14	Specified inertial velocity at TLI cutoff (VI C/O)	XXXXX. ft/s
17	Astronaut total attitude	R XXX.XX deg P XXX.XX deg Y XXX.XX deg
18	Desired automaneuver FDAI ball angles	R XXX.XX deg P XXX.XX deg Y XXX.XX deg

20	Present ICDU angles	R(OG) XXX.XX deg P(IG) XXX.XX deg Y(MG) XXX.XX deg
22	Desired ICDU angles	R(OG) XXX.XX deg P(IG) XXX.XX deg Y(MG) XXX.XX deg
25	CHECKLIST (used with N25)	XXXXX.
29	XSM launch azimuth	XXX.XX deg
32	Time from Perigee	00XXX. h 000XX. min 0XX.XX s
33	Time of ignition (GETI)	00XXX. h 000XX. min 0XX.XX s
34	Time of event	00XXX. h 000XX. min 0XX.XX s
35	Time from event	00XXX. h 000XX. min 0XX.XX s
36	Time of AGC clock	00XXX. h 000XX. min 0XX.XX s
40	Time from ignition/cutoff (TFI/TFC) VG Delta V (accumulated)	XXbXX min/s XXXX.X ft/s XXXX.X ft/s
42	Apocenter altitude Pericenter altitude Delta V (required)	XXXX.X nmi XXXX.X nmi XXXX.X ft/s
44	Apocenter altitude Pericenter altitude TFF	XXXX.X nmi XXXX.X nmi XXbXX min/s
45	Marks (VHF/optics) Time from ignition of next burn Middle gimbal angle	XXXXX. marks XXbXX min/s XXX.XX deg
46	DAP configuration	Octal Octal
47	CSM weight LM weight	XXXXX. lbs XXXXX. lbs
48	Gimbal pitch trim Gimbal yaw trim	XXX.XX deg XXX.XX deg
54	Range Range rate Theta	XXX.XX nmi XXXX.X ft/s XXX.XX deg
60	GMAX VPRED	XXX.XX g XXXXX. ft/s

	GAMMA EI	XXX.XX deg(+above)
61	Impact Latitude Longitude Heads up/down	 XXX.XX deg(+north) XXX.XX deg(+east) +/- 00001
62	Inertial velocity magnitude Altitude rate Altitude above pad radius	XXXXX. ft/s XXXXX. ft/s XXXX.X nmi
63	Range from EI altitude to splash Predicted Interial Velocity Time of EI altitude	XXXX.X nmi XXXXX. ft/s XXbXX min/s
64	Drag acceleration Inertial velocity Range to splash	XXX.XX g XXXXX. ft/s XXXX.X nmi (+ is overshoot)
65	Sampled AGC time (fetched in interrupt)	00XXX. h 000XX. min 0XX.XX s
66	Commanded bank angle Crossrange error Downrange error	XXX.XX deg XXXX.X nmi (+ south) XXXX.X nmi (+ overshoot)
67	Range to target Present latitude Present longitude	XXXX.X nmi (+ overshoot) XXX.XX (+ north) XXX.XX (+ east)
68	Commanded bank angle Inertial velocity Altitude rate	XXX.XX deg XXXXX. ft/s XXXXX. ft/s
69	Commanded bank angle Drag level Exit velocity	XXX.XX deg XXX.XX g XXXXX. ft/s
70	Celestial body code (before mark) Landmark data Horizon data	Octal Octal Octal
71	Celestial body code (after mark) Landmark data Horizon data	Octal Octal Octal
74	Commanded bank angle Inertial Velocity Drag acceleration	XXX.XX deg XXXXX. ft/s XXX.XX g
81	Delta VX (LV) Delta VY (LV) Delta VZ (LV)	XXXX.X ft/s XXXX.X ft/s XXXX.X ft/s
91	Present optics angles Shaft Trunnion	 XXX.XX deg XX.XXX deg
92	New optics angles Shaft	 XXX.XX deg

	Trunnion	XX.XXX deg
93	Delta gyro angles	X XX.XXX deg Y XX.XXX deg Z XX.XXX deg
94	Alternate LOS Shaft angle Trunnion angle	 XXX.XX deg XX.XXX deg

5. OPERATION

The VERB and NOUN combinations are used to operate the computer. Referring to the lists above, you can start talking with the computer using its language.

For example, if you wish to display a decimal in the register(s) from a noun, you use Verb 06. If you want to display the data from the current total attitude of the spacecraft using Verb 06, you use Noun 17.

To let the computer know your intention, you first depress the VERB button, then followed by two numerics, 0 and 6. Then you depress the NOUN button, followed by two numerics, 1 and 7. When you are ready to execute, you depress the ENTR button.

The input sequence above is then the following:
VERB 0 6 NOUN 1 7 ENTR

Once ENTR is pressed, register 1 will show the ROLL, register 2 will show the PITCH and register 3 will show the YAW. Each register is either positive or negative, and will always consit of five digits. You will always see the sign and the five digits, no matter what the format of the numer really is. In this case, the format is that each register is a decimal numer with two decimals: XXX.XX, so if register 1 (R1) reads +04510, the current roll of the spacecraft is +045.10 or 45.1 degrees.

Each noun controls the format of the register, and the format each register within a given noun can be different. The first register in a noun can for example be XXX.XX, the second XXXXX (whole number, integer), and the third can be XXXX.X. Time can some times be displayd using the following format: XX0XX where the first two XX is the minutes, and the last two XX is the seconds. So if for example a NOUN wants to display the time for a burn in register 1, R1 can look like this: 16045, meaning the burn is 16 minutes and 45 seconds away. Sometimes the excess zero in the middle is hidden, so that the register would read 16 45 (the zero in the middle is blank).

When you tell the computer you wish to enter data into the registers using Verb 21 to 25, or change the NOUN or VERB using the push buttons, the active input field will blank.

It is normal for checklists to use a shortened form to communicate with the computer. Looking at the above example:
VERB 0 6 NOUN 1 7 ENTR

This is normally shortened to V06N17E.

When a verb-noun combination or program wants you to input data, the verb and noun fields are usually flashing, meaning you can change the data using V21 to V25, or proceed without changes.

6. MAJOR MODES

There are many major modes that the computer can run. There are different major modes for the different phases of the mission, so it is also normally referred to as a mission program.

A major mode can for example be used to monitor the ascent, the TLI burn, set up an SPS burn, execute a burn, and much more.

The major modes each follow a program much like a normal executable on a PC. A major mode can request the astronaut to validate/change data, and use this as input to calculation and routines. A major mode is using verb-noun combinations to go through its intended flow, as well as internal routines (functions) for calculations.

Another example of a major mode is to prepare for reentry. Reentry is a complex process and requires a lot of setup and calculations. The entire entry sequence consits of many major modes, usually referred to as the 60's. Major Mode 61 (Program 61 or simply P61) will ask for entry parameters used for calculations, 62 will account for CM/SM separation and maneuvering, 63 will initialize the CM entry and wait for 0.05g deceleration, and 64 will use the velocity to select what other P60's to execute before the final descent using P67.

PHASE	PROGRAM	TITLE
Pre-launch & service	00	Idle program
	01	Prelaunch or Service-Initialization
	02	Prelaunch or Service-Gyrocompassing
	06	AGC Power Down
Boost	11	Earth Orbit Insertion Monitor
	15	TLI Initiate/Cutoff
Pre-Thrusting	30	External Delta V
Thrusting	40	SPC
Alignment	51	IMU Orientation Determination
	52	IMU Realign
Entry	61	Entry-Preparation
	62	Entry-CM/SM Separation and Preentry Maneuver
	63	Entry-Initialization
	64	Entry-Post 0.05G
	65	Entry-Upcontrol
	66	Entry-Ballistic

	67	Entry-Final Phase
	79	Rendezvous Final Phase

7. CHECKLIST REFERENCE (V50N25)

Verb 50 means Please Perform: and V 25 means Checklist. V50N25 will show the checklist that needs to be perfomed in R1. The following is a table contains all the checklists:

CODE	CHECKLIST
00013	Perform coarse alignment
00014	Key in fine alignment option
00015	Perform celestial body acquisition
00016	Key in Terminate Mark sequence
00017	Perform MIN KEY rendezvous sequence
00020	Perform MINKEY PC pulse torquing
00041	Switch CM/SM separation to UP
00062	Key in AGC power down
00202	Perform GNCS automatic maneuver
00204	Perform SPS gimbal trim

NOTES:
Switch-denotes change position of a console switch.
Perform-denotes start or end of a task.
Key In-denotes key-in of data through the DSKY.

8. ALARM CODES (V05 N09)

If an alarm code is present, relevant alarm code is visible in V05 N09. Below is a list of what they mean.

CODE	PURPOSE	SET BY
00213	IMU not operating with turn-on request	T4RUPT
00405	Two stars not visible	P52
00210	IMU not operating	IMU mode sw, P51, R02
00220	IMU not aligned	R02, P51

9. PROGRAMS

The following section will go into each program in detail. This includes the purpose and assumptions of the program, as well as the sequence of events.

P00 – CMC IDLING PROGRAM

Purpose:

1. To maintain the CMC in a condition of readiness for entry into other programs.
2. To update the CSM and LM state vectors every four time steps.

Assumptions:

1. This program is automatically selected by V96E, which may be done during any program. State vector integration is permanently inhibited following V96E. Normal integration functions will resume after selection of any program or extended verb. P00 integration will resume when P00 is reselected. Usage of V96 can cause incorrect W-matrix and state vector synchronization.

2. Program changes are inhibited during integration periods and program alarm 15208 will occur if a change is attempted when inhibited.

Sequence of Events:

V37E00E

V06N38E

Optional Display

V06N38	Time of State Vector Being Integrated	00XXX h 000XX min 0XX.XX s

P01 – PRELAUNCH OR SERVICE-INITIALIZATION PROGRAM

Purpose:

1. To initialize the platform for the prelaunch programs.
2. To provide an initial stable member orientation for Gyrocompas.sing (P02).

Assumptions:

1. Erasable locations have been properly initialized. (Azimuth, +1; Latitude, +1; LAUNCHAZ, +1; IMU compensation parameters).

Sequence of Events:

V37E01E

No Att Light - ON, then OFF. Initializes the system and coarse aligns the platform to the desired orientation.

AGC advances to P02.

P02 – PRELAUNCH OR SERVICE-GYROCOMPASSING PROGRAM

Purpose:

1. To provide the proper stable member orientation for launch.

Assumptions:

1. This program may be interrupted to perform the Prelaunch or Service-Optical Verification of Gyrocompassing program (P03).
2. V75 will be keyed in and displayed during this program to permit crew backup of the liftoff discrete.
3. The program is automatically selected by the Initialization program (P01).
4. This program has the capability (via V78E) to change the launch azimuth of the stable member while gyrocompassing.

Sequence of Events:

P02 entered automatically from P01.
Vertical erect for 640 seconds (90 in the Reentry), then gyrocompass.

V78E Optional entry if launch azimuth change is desired.

Flashing V06N29	XSM Launch Azimuth	XXX.XX deg

V21E Enter new launch azimuth.
Vertical erect for 320 seconds, then gyrocompass.

V75E Optional at Liftoff if automatic Liftoff discrete is not received.

AGC advances to P11 at liftoff.

P06 – CMC POWER DOWN PROGRAM

Purpose:

1. To transfer the CMC from the operate to the standby condition

Assumptions:

1. If the computer power is switched off, the AGC Update program (P27) would have to be done to update the state vector and computer clock time.
2. The AGC is capable of maintaining an accurate value of ground elapsed time (GET) for only 23 hours when in the Standby mode. If the AGC is not brought out of the standby condition to the running condition at least once within 23 hours, the AGC value of GET must be updated.
3. Once the program has been selected, the AGC must be put in Standby. When P06 appears, the AGC will not honor a new program request (V37E XXE), a terminate (V34E), or an ENTER in response to the request for standby.

Sequence of Events:

V37E06E

Flashing V50N25	Checklist Code	00062

Power down AGC.
If IMU power off desired – cb IMU Operate - OPEN

PRO Until Standby light on.

TURN-ON

Standby light on.

PRO Until Standby light off.

Flashing V37

00E Select P00
If IMU power up desired – cb IMU Operate – CLOSE
No Att light for 90 seconds

P11 – EARTH ORBIT INSERTION MONITOR PROGRAM

Purpose:

1. To indicate to the astronaut that the AGC has received the liftoff discrete.
2. To generate an attitude error indication on the FDAI error needles, scaled for the 50/15 setting; from liftoff to the beginning of pitchover/rollout the attitude error is equal to the difference between the current vehicle attitude and the attitude stored at liftoff. During pitchover/rollout the attitude error is equal to the difference between the current vehicle attitude and the AGC nominal computation of vehicle attitude based on the stored polynomials in pitch and roll.
3. To display AGC computed trajectory parameters.
4. AGC takeover of Saturn during Boost.
   a. Automatic Control-of-First Stage Only: should the saturn platform fail the astronaut may set the LV Guidance Switch to the CMC position. This stores the current attitude errors as a bias. The Attitude Error routine for each cycle thereafter will compute the attitude error, subtract the bias, and transmit the difference information to the Saturn Instrumentation Unit (IU) for steering.

   b. Manual Control-The astronaut may select the Saturn stick function via V46E (DAP configuration == 3). This will terminate the Attitude Error routine.

Assumptions:

1. The program is normally automatically selected by the Gyrocompassing program (P02) when the AGC receives the liftoff discrete from the SI VB. In the backup case it would have been selected by keying in V75 ENTER.
2. The orbit parameter display routine is available by keying in V82E.

Sequence of Events:

V75 Enter is not keyed unless the liftoff discrete fails and P11 does not start automatically.

P11 displayed - Average G on.

V06N62	Inertial Velocity Magnitude	XXXXX. ft/s
	Altitude Rate	XXXXX. ft/s
	Altitude	XXXX.X nmi

Pitch/roll polynomial start at liftoff +11.85 seconds.

Terminate polynomial at liftoff +161.35 seconds.

V82E Orbital parameter display.

Flashing	Apogee Altitude	XXXX.X nmi
V16N44	Perigee Altitude	XXXX.X nmi
	TFF	XXbXX min/s

PRO

V37E00E
Average G off. P00 is selected.

V46E While in P11 will terminate polynomial computations and enable the RHC to steer the Saturn vehicle through the AGC interface .

P15 – TLI INITIATE/CUTOFF

Purpose:

1. Provide backup for initiation of Saturn Time Base 6 (TB6), S-IVB, injection sequence start.
2. Provide TLI burn monitor capability during a Saturn IU controlled TLI maneuver (Saturn DAP in IU/Display Operational Mode).
3. Provide automatic TLI shutdown capability during a CMC controlled TLI maneuver (Saturn DAP in CMC/Steer Operational Mode).

Assumptions:

1. The TLI target parameters VI C/O (velocity magnitude at cutoff), TB6 (GET of TB6 initiation), and DTF (a bias to compensate for tail off Delta V and actuator delays) are all available.

Sequence of Events:

V37E15E

Flashing		00XXX h
V06N33	GET of TB6 Initiation	000XX m
		0XX.XX s

V25E to Load desired TB6 time.

PRO

Flashing		
V06N14	Velocity magnitude at S-IVB Cutoff	XXXXX. ft/s

V21E to Load desired velocity magnitude

PRO

V06N95	Time From TLI Ignition (TFI)	XXbXX min/s
	Velocity to be Gained (Vg)	XXXXX. ft/s
	Velocity Magnitude (VMAGI)	XXXXX. ft/s

UPLINK activity Light and S-IVB injection sequence start discrete ON for 10 seconds at TB6 start time (TIG minus 9 minutes 38 seconds).
DSKY blanks for 5 seconds at TIG minus 105 seconds.
Average G on at TIG minus 100 seconds.
V06N95 returns.
At ignition plus 10 seconds, R1 equals time from cutoff (TFC). XXbXX min/s
S-IVB cutoff discrete issued when V1 C/O attained.

	Flashing	
	V16N95	Same as N95 above but TFC display frozen.

PRO

V37E00	Enter Idling program

P30 – EXTERNAL DELTA V PROGRAM

Purpose:

1. To accept targeting parameters obtained from a source(s) external to the AGC and compute therefrom the required velocity and other initial conditions required by the AGC for execution of the desired maneuver. The targeting parameters inserted into the AGC are the time of ignition (TIG) and the impulsive dV along CSM local vertical axes at TIG.

Assumptions:

1. Target parameters (TIG and dV(LV)) may have been loaded from the ground during a prior execution of P27
2. External Delta V flag is set during the program to designate to the thrusting program that external Delta V steering is to be used.

Sequence of Events:

V37E30E

Flashing V06N33	Ground Elapsed Time of Ignition (TIG)	00XXX. h 000XX. min 0XX.XX s

V25E to load desired TIG.

PRO

Flashing V06N81	Impulsive Delta V at TIG in Local Vertical Coordinates	X XXXX.X ft/s Y XXXX.X ft/s Z XXXX.X ft/s

V25E to load desired Delta V.

PRO

Flashing V06N42	Apogee/Apolune Altitude	XXXX.X nmi
	Perigee/Perilune Altitude	XXXX.X nmi
	Magnitude of Delta V at TIG	XXXX.X ft/s

PRO

Flashing V16N45	Mark Counter (VHF-Optics)	XXXXX marks
	Time from Ignition (TFI)	XXbXX min/s
	Middle Gimbal Angle at TIG with Vehicle +X Axis in Direction of Thrust	XXX.XX deg

If the REFSMMAT flag is reset (that is, the IMU is not aligned) MGA will equal -00002.

PRO

V37E00 Enter Idling program

P40 – SPS PROGRAM

Purpose:

1. To compute a preferred IMU orientation and a preferred vehicle attitude for an SPS thrusting maneuver and to maneuver the vehicle to the thrusting attitude.
2. To calculate and display the gimbal angles which would result from the present IMU orientation if the vehicle were maneuvered to the preferred vehicle attitude for an SPS thrusting maneuver. The crew is thereby given an opportunity to perform the maneuver with:
    a) The present IMU orientation (not recommended if middle gimbal angle is greater than 45 degrees). If the IMU has not been aligned within the last 3 hours, realignment is desirable.
    b) A new orientation achieved by selection of P52.
3. To control the GNCS during countdown, ignition, thrusting, and thrust termination of a GNCS controlled SPS maneuver.

Assumptions:

1. The target parameters have been calculated and stored in the AGC by execution of a pre-thrusting program.
2. The required steering equations are identified by the prior pre-thrust program, which either set or reset the external Delta V steering flag. For external Delta V steering, VG is calculated once for the specified time of ignition. Thereafter, both during thrusting and until the crew notifies the AGC trim thrusting has been completed, the AGC updates VG only as a result of compensated accelerometer inputs.
   For Lambert steering, VG is calculated and updated similarly; however, it is also updated periodically by Lambert solutions to correct for changes in the CSM state vector.
3. The TTE clock is set to count to zero at TIG.
4. Engine ignition may be slipped beyond the established TIG if desired by the crew or if integration can not be completed on time.
5. The SPS thrusting program does not monitor the SC control discrete (Channel 31, Bit 15) during thrusting. This means that the AGC will continue to generate engine actuator commands, SPS Engine On discrete, and FDAI attitude error needle commands until the AGC solution indicates Engine Off at which time these commands and the Engine On discrete are terminated. However. this program is not written to take into account the situation where control may be taken away from the GNCS and then given back, and it is not recommended. In event control is taken away from the GNCS, the AGC will only be responsible for computation of position and velocity.
6. The value of Delta V required will be stored in the local vertical coordinate system and is available during this program until average g turn-on by keying in V06 N81E.

7. The Orbit Parameter Display routine (R30) may be called during this program by keying in V82E.
8. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller, go to Flashing V50 N18.

Maneuver to pad burn attitude and check SXT and boresight stars using optics angles on pad.

V37E40E

Flashing V50N18	Desired FDAI Angles for Automaneuver	OG(R) XXX.XX deg IG(P) XXX.XX deg MG(P) XXX.XX deg

Request maneuver to completed burn attitude.

PRO

V06N18	Same as N18 above.

Maneuver is in process; final FDAI angles displayed.

Flashing V50N18	Same as N18 above. Automaneuver is completed.

SCS GDC aligned to IMU for backup attitude reference.
SPS gimbal driver motors energized
S/C Control to SCS; SPS servo check and manual drive check performed.
S/C Control to CMC.
PRO

Flashing V50N18	Same as N18 above. Vehicle is trimmed to burn attitude.

ENTER

Flashing V50N25	Gimbal Slew Test Option. Checklist Code	 00204

PRO Slews SPS gimbal +/-2 degrees; ENTER – Bypasses gimbal slew test.
SPS gimbals commanded to trim angles (P, Y)

V06N40	Time from Ignition/Cutoff (TFI)	XXbXX min/s
	Velocity to be Gained (Vg)	XXXX.X ft/s
	Accumulated Velocity (dV)	XXXX.X ft/s

DSKY blanks at TIG - 35 seconds, and V06N40 resumes at TIG -30 seconds.
Average G on.

Ullage initiated with THC if required.

Flashing V99N40	Same as N40 above at TIG -5 seconds. Astronaut approval of ignition requested.	

PRO Ignition approved

V06N40	Same as N40 above.	

Ignition at TIG.
TVC DAP activated.
SPS engine cutoff; burn complete.
TVC DAP off.

Flashing V16N40	Same as N40 above.	

PRO

Flashing V16N85	Vg Residuals in Control System (body) Coordinates	X XXXX.X ft/s Y XXXX.X ft/s Z XXXX.X ft/s

Trim Vg residuals with THC if required.

PRO

V82E Request orbital parameter display.

Flashing	Apocenter Altitude, Ha	XXXX.X nmi
V16N44	Pericenter Altitude, Hp	XXXX.X nmi
TFF		XXbXX min/s

PRO

Average G off.

V37E00 Enter Idling program

P52 – IMU REALIGN PROGRAM

Purpose:

1. To align the IMU from a "known" orientation to one of four orientations selected by the astronaut using sightings on two celestial bodies with the scanning telescope or the sextant:
   a. Preferred Orientation (00001)
      An optimum orientation for a previously calculated maneuver. This orientation must be calculated and stored by a previously selected program (P30) or previously uplinked via P27.

   b. Landing Site Orientation (00004)
      The landing site option is used for aligning the CSM and LM stable members to the same orientation prior to LM/CSM separation and prior to LM ascent from the lunar surface.

   c. Nominal Orientation (00002)
      Aligns with local vertical at a selected mission time.

   d. REFSMMAT (00003)
      The present IMU orientation differs from that to which it was last aligned due to gyro drift. This option realigns the IMU to its previous alignment orientation (REFSMMAT).

Assumptions:

1. If the CMC Mode switch is in CMC-Attitude Hold during the Gyro Torquing routine, the DAP will maneuver the vehicle to follow the platform.
2. An option is provided to point the sextant LOS at astronaut or AGC selected stars either manually by crew input or automatically under AGC control.

Sequence of Events:

If entered automatically by MINKEY controller, go to PC REALIGN.

V37E52

Flashing V04N06	Option ID Code Alignment Option 1–preferred, 2–nominal 3–REFSMMAT, 4–landing site	00001 0000X

V22E to key in desired alignment option.

PRO To appropriate option.

PC REALIGN

Flashing V06N22	Gimbal angles which will result from pulse torque to PC orientation	OG IG MG	XXX.XX deg XXX.XX deg XXX.XX deg

If MGA is not satisfactory, maneuver vehicle and V32E to recompute N22 angles.

PRO If N22 angles are satisfactory.

Flashing V50N25	MINKEY Pulse Torque Option Checklist Code	 00020

ENTER If this is first reorientation maneuver, the pulse torque to PC orientation is bypassed and MINKEY enters the RCS Burn program (P41). If this is the second reorientation maneuver, alarm 00402 is displayed. The platform must be torqued to its original orientation.

PRO Commence with pulse torquing.

V16N20	Present ICDU Angles	OG IG MG	XXX.XX deg XXX.XX deg XXX.XX deg

Upon completion of pulse torquing to new orientation, the MINKEY controller will initiate:

1. P41 if pre-plane change burn and if Delta V $<$ 7 ft/s
2. P40 if pre-plane change burn and if Delta V $\geqslant$ 7 ft/s
3. P33 if plane-change maneuver completed (second pulse torque)

LANDING SITE OPTION (00004)

Flashing V06N34	GET of Landing Site Coordinate System T(Align)	00XXX h 000XX min 0XX.XX s

V25E to load desired T(Align).

PRO

Flashing V06N89	Latitude of Landing Site Longitude/2 Altitude	XX.XXX deg (+ north) XX.XXX deg (+ east) XXX.XX nmi

V25E to load landing site coordinates.

PRO To Preferred Option

NOMINAL OPTION (00002)

Flashing V06N34	Same as N34 above, except GET of position and velocity vectors defining nominal coordinate system.

PRO To Preferred Option

PREFERRED OPTION (00001)

Flashing V06N22	Desired Gimbal Angles for New Orientation at Present Vehicle Attitude	OG IG MG	XXX.XX deg XXX.XX deg XXX.XX deg

If the new orientation yields gimbal lock, maneuver vehicle and V32E to recompute (N22) desired gimbal angles.

PRO

Flashing V50N25	Coarse Align Option Checklist Code	00013

CMC Mode Switch – FREE
(Avoids maneuvering vehicle) – Key in ENTER or PRO.

Gyro Torque Only

ENTER
Torques gyros to achieve new orientation (maintains attitude reference).

V16N20	Monitor Gimbal Angles	OG	XXX.XX deg
		IG	XXX.XX deg
		MG	XXX.XX deg

Go to RECHECK when torquing is complete.

Coarse Align Only

PRO Coarse aligns gimbals to achieve new orientation (lose attitude reference).
No Att light ON until coarse align complete.
Go to REFSMMAT option when No Att light out.

REFSMMAT OPTION (00003)

Flashing V50N25	Checklist Code	00015

Request Celestial Body acquisition.

PRO AGC will select two available stars. Use ENTER to specify crew selection of stars.

MARK SEQUENCE

Flashing V01N70	Star ID Code	000XX

V21E to key in star code.

ZERO OPTICS for 15 seconds.

OPTICS Mode – CMC

PRO For Planet XX = 00; if XX ≠ 00, go to V06N92 display.

Flashing	Unit Vector Specifies	X	.XXXXX
V06N88	Planet Position	Y	.XXXXX
		Z	.XXXXX

V22E to specify desired planet vector.

PRO

V06N92	Desired Optics Angles	Shaft	XXX.XX deg
		Trunnion	XX.XXX deg

CMC drives optics LOS to target.

OPTICS Mode – Manual

Flashing V51	Request Mark.

Mark on Target

Flashing V50N25	Checklist Code	00016

Terminate Mark Sequence option.

PRO Marking was okay, if not MARK REJECT.

Flashing V01N71	Star ID Code of Body Marked On	000XX

V21EXXE if not correct.

PRO If Star Code ≠ 0 and first MARK, recycle to Mark sequence.
If Star Code ≠ 0 and second MARK, go to Flashing V06N05.

Flashing V06N88	Same as N88 above.

V25E to correct planet vector.

PRO If first MARK recycle to MARK sequence.

Flashing V06N05	Star Angle Difference*	XXX.XX deg

If N05 not satisfactory, V32E, and go to RECHECK.

PRO

Flashing V06N93	Gyro Torque Angles to Fine Align	X	XX.XXX deg
		Y	XX.XXX deg
		Z	XX.XXX deg

CMC Mode Switch – Free (Avoids maneuvering vehicle when torquing gyros).

PRO Torque gyros. V32E to bypass gyro torquing.

RECHECK

Flashing V50N25	Checklist Code Fine Alignment Option	00014

PRO Recycles to REFSMMAT option for check on alignment.

ENTER

Flashing V37	Select New Program.

*Acceptable N05 Limits

STAR/STAR	SXT	0.03°
	SCT	0.11°
STAR/PLANET	SXT	0.18°
	SCT	0.21°

P61 – ENTRY-PREPARATION PROGRAM

Purpose:

1. To start navigation, check IMU alignment, and provide entry monitor system initialization data.

Assumptions:

1. The program is entered with adequate freefall time to complete the maneuvers from a worst-case starting attitude.
2. The ISS is on and precisely aligned to a satisfactory orientation.

Sequence of Events:

V37E61E

Average G On

Flashing	Impact Latitude	XXX.XX deg
V06N61	Impact Longitude	XXX.XX deg
	Roll Attitude Code	±0000X

X = +1 - heads up/lift vector down
X = -1 - heads down/lift vector up (normal)

V25E to load entry data.

PRO

Flashing	G Max	XXX.XX g
V06N60	VPRED	XXXXX. ft/
	GAMMA EI	XXX.XX deg

GMAX is the maximum predicted acceleration for ENTRY at nominal bank angle (L/D ratio = 0.18). VPRED is the predicted inertial velocity at Entry Interface (E I) altitude of 400 k ft. GAMMA EI is the flight path angle between the inertial velocity vector and the local horizontal at E I altitude of 400 k ft.

PRO

Flashing	RTOGO	XXXX.X nmi
V16N63	VIO	XXXXX. ft/s
	TFE	XXbXX min/s

RTOGO is the range to go from a pre-loaded altitude of 297,432 feet to splash. This is approximately 0.05 g altitude. VIO is the predicted velocity at 297,431 feet. TFE is the time until 297,431-foot altitude is reached.

RTOGO and VIO may be used for EMS initialization if pad values not available.

PRO

AGC advances to P62.

P62 – ENTRY-CM/SM SEPARATION AND PREENTRY MANEUVER PROGRAM

Purpose:

1. To notify crew when the GNCS is prepared for CM/SM separation.
2. To orient the CM to the correct attitude for atmospheric entry.

Assumptions:

1. The program is entered with adequate freefall time to accomplish CM/SM separation and complete the maneuver from a worst-case starting attitude.
2. The IMU is satisfactorily aligned for entry.
3. The program is automatically selected by the Entry-Preparation program (P61) or it may be selected manually.
4. The astronaut may monitor N63 (RTOGO, VIO, TFE) by keying in V16 N63 E.

Sequence of Events:

V37E62E

If entered manually; normally entered automatically from P61.

Average G on. Normally on from P61.

Flashing V50N25	Checklist Code	00041

Perform CM/SM separation.

Maneuver to Separation Attitude.
SC Control to SCS.
CM/SM Separation - On.
Maneuver to Horizon Track Attitude.

PRO

Entry DAP Activated

Flashing	Impact Latitude	XXX.XX deg
V06N61	Impact Longitude	XXX.XX deg
	Roll Attitude Code	±0000X

X = +1 - heads up/lift vector down
X = -1 - heads down/lift vector up (normal)

V25E to load desired data.

PRO If angle of attack of CM is within 45 degrees of desired, go to P63.

V06N22	Desired Gimbal Angles	OG(R) XXX.XX deg IG(P) XXX.XX deg MG(P) XXX.XX deg

Roll angle depends on heads up/down option. Pitch depends on the desired angle of attack into the atmosphere. When CM is within 45 degrees of desired advance to P63.

AGC Advances to P63.

P63 – ENTRY-INITIALIZATION PROGRAM

Purpose:

1. To initialize the entry equations.
2. To continue to hold the CM to the correct attitude with respect to the atmosphere for the onset of entry deceleration.
3. To establish entry DSKY displays.
4. To sense 0.05 g and display this event to the crew by selecting the Entry-Post 0.05 g program (P64).

Assumptions:

1. The program is automatically selected by the Entry-CM/SM Separation and Preentry Maneuver program (P62).

Sequence of Events:

P63 entered automatically from P62.

V06N64	Drag Acceleration	XXX.XX g
	Inertial Velocity	XXXXX. ft/s
	Range to Splash	XXXX.X nmi

This display may be monitored continuously by keying V16N64E.

OPTIONAL DISPLAYS

V16N68E

V16N68	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Altitude Rate (HOOT)	XXXXX. ft/s

V16N63

V16N63	Range from EMS Altitude (RTOGO)	XXXX.X nmi
	Inertial Velocity at EMS Altitude	XXXXX. ft/s
	Time to go Until EMS Altitude	XXbXX min/s

V06N74

V06N74	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Drag Acceleration (G)	XXX.XX g

Manual track of horizon reduces pitch error needle as pitch attitude approaches the desired angle of attack.

SC Control Switch - CMC/Auto.
Entry DAP now controlling vehicle attitude.

IMPORTANT: Manual entry is required in Reentry – An Orbital Simulator, set SC Control Switch to FREE or use SCS.

G&N system senses 0.05g drag acceleration.

AGC advances to P64.

P64 – ENTRY-POST 0.05 G PROGRAM

Purpose:

1. To start entry guidance at 0.05 g selecting roll attitude, constant drag level, and drag threshold, KA, which are keyed to the 0.05 g point.
2. Select final phase (P67) when 0.2 g occurs if V < 27,000 ft/s at 0.05 g.
3. Iterate for upcontrol solution (P65) if V > 27,000 ft/s and if altitude rate and drag level conditions are satisfied.
4. Select final phase (P67) if no upcontrol solution exists with VL > 18,000 ft/s.
5. To establish the 0.05 g mode in SCS.
6. To continue entry DSKY displays.

Assumptions:

1. The program is automatically selected by the Entry-Initialization program (P63).

Sequence of Events:

P64 entered automatically from P63 at 0.05 g.

V06N74	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Drag Acceleration (G)	XXX.XX g

OPTIONAL DISPLAYS
V16N64E

V16N64	Drag Acceleration (G)	XXX.XX g
	Inertial Velocity (VI)	XXXXX. ft/s
	Range to Splash (RTOTARG)	XXXX.X nmi

V16N68E

V16N68	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Altitude Rate (HOOT)	XXXXX. ft/s

AGC advances to P65 or P67.

If VI < 27 k ft/s at 0.05 g, go to P67 when 0.2 g drag is sensed.
If VI >= 27 k ft/s, a constant drag trajectory is flown until HDOT becomes more positive than -700 ft/s. A range-to-go check will determine if a controlled skip (P65) phase should be entered. The entry is targeted nominally for a RTOGO at EI which will be too small to satisfy P65 requirement and P67 is entered at this point.

P65 – ENTRY-UPCONTROL PROGRAM

Purpose:

1. To execute Entry-Upcontrol guidance which steers the CM to a controlled exit (skip out) condition.
2. To establish Entry-Upcontrol displays which are used in conjunction with the EMS to determine for the astronaut if the backup procedures should be implemented.
3. To sense exit (drag acceleration less than Q7 ft/s2) and thereupon to select the Entry-Ballistic Phase program (P66).
4. Where HDOT is negative and the V is sufficiently low, the program will exit directly to P67 (Final Phase).

Assumptions:

1. This program is automatically selected by the Entry-Post 0.05 g program (P64) when constant drag control has brought range prediction to within 25 nmi of the desired range. It is skipped in earth orbit missions.

Sequence of Events:

P65 entered automatically from P64.

Flashing	Commanded Bank Angle (Beta)	XXX.XX deg
V16N69	Drag Level at Skipout (OL)	XXX.XX g
	Skipout Velocity (VL)	XXXXX. ft/s

PRO Manual response to N69 is not necessary to terminate P65. Selection of P66 or P67 by entry guidance provides automatic termination.

V06N74	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Drag Acceleration (G)	XXX.XX g

OPTIONAL DISPLAYS
V16N64E

V16N64	Drag Acceleration (G)	XXX.XX g
	Inertial Velocity (VI)	XXXXX. ft/s
	Range to Splash (RTOTARG)	XXXX.X nmi

V16N68E

V16N68	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Altitude Rate (HOOT)	XXXXX. ft/s

AGC advances to P66 or P67.

P67 will be entered when HDOT is negative, and the velocity is sufficiently low. P66 will be entered when exit is sensed.

P66 – ENTRY-BALLISTIC PROGRAM

Purpose:

1. To maintain CM attitude during ballistic (skip out) phase for atmospheric reentry.
2. To sense reentry (drag acceleration builds up to Q7 + 0.5 ft/s2 or approximately 0.2 g) and thereupon to select the Entry-Final Phase program (P67).

Assumptions:

1. This program is automatically selected by the Entry-Upcontrol program (P65) when drag acceleration becomes less than Q7 ft/s2.

Sequence of Events:

P66 is entered automatically from P65.

V06N22	Desired Gimbal Angles	OG	XXX.XX deg
	to Orient the Vehicle to	IG	XXX.XX deg
	Correct Angle of Attack	MG	XXX.XX deg

Three-axis control of S/C is regained when acceleration falls below 0.05 g and is relinquished when the drag increases above this value.

OPTIONAL DISPLAYS

V16N64E

V16N64	Drag Acceleration (G)	XXX.XX g
	Inertial Velocity (VI)	XXXXX. ft/s
	Range to Splash (RTOTARG)	XXXX.X nmi

V16N68E

V16N68	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Altitude Rate (HOOT)	XXXXX. ft/s

V16N74E

V06N74	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Drag Acceleration (G)	XXX.XX g

AGC advances to P67.

P67 is entered at reentry or when approximately 0.2 g is sensed.

P67 – ENTRY-FINAL PHASE PROGRAM

Purpose:

1. To continue entry guidance after Q7F + 0.5 ft/s2 (or approximately 0.2 g) until termination of steering when the CM velocity WRT earth = 1,000 ft/s (altitude is approximately 65,000 ft).
2. To continue entry DSKY displays.

Assumptions:

1. The program is automatically selected by:
   a. P65 when HOOT is negative and the V is sufficiently low (V-VL-C18 neg).
   b. P66 when drag acceleration builds up to Q7F + 0.5 ft/s2 (or approximately 0.2 g).
   c. P64 if no upcontrol solution exists with VL > 18,000 ft/s.

Sequence of Events:

P67 is entered automatically from P64, P65, or P66.

V06N66	Commanded Bank Angle (Beta)	XXX.XX deg
	Crossrange Error	XXXX.X nmi (+ south)
	Downrange Error	XXXX.X nmi (+ overshoot)

OPTIONAL DISPLAYS

V16N64E

V16N64	Drag Acceleration (G)	XXX.XX g
	Inertial Velocity (VI)	XXXXX. ft/s
	Range to Splash (RTOTARG)	XXXX.X nmi

V16N68E

V16N68	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Altitude Rate (HOOT)	XXXXX. ft/s

V16N74E

V06N74	Commanded Bank Angle (Beta)	XXX.XX deg
	Inertial Velocity (VI)	XXXXX. ft/s
	Drag Acceleration (G)	XXX.XX g

Relative velocity reaches 1,000 ft/s

Flashing	Range-to-Splash (RTOTARG)	XXXX.X nmi (+ overshoot)
V16N67	Present Latitude	XXX.XX deg (+ north)
	Present Longitude	XXX.XX deg (+ east)

SC Control – SCS

Prevent jet firings when Drogue chutes deploy.

PRO

V37E00	Enter Idling program

Average G off.

P79 – FINAL RENDEZVOUS PROGRAM

Purpose:

1. To establish X-axis tracking by P20.
2. To select the rendezvous parameter display (R31) internally to provide range and range rate information prior to the braking phase of rendezvous.

Assumptions:

1. This program may be selected manually or internally by the MINKEY controller.

Sequence of Events:

If entered automatically by MINKEY controller. go to MANEUVER.

V37E79E

Note: If P20 rendezvous options is not running, P20 Option 0 is activated now.

MANEUVER

If the tracking attitude error between the vehicle X-axis and the LOS to the LM is less than 10 (computed by P20/R61), go to DISPLAY.

Flashing V50N18	Desired FDAI angles for automaneuver	OG(R)	XXX.XX deg
		IG(P)	XXX.XX deg
		MG(Y)	XXX.XX deg

PRO

V06N18 Maneuver in Progress

When maneuver is complete, go to DISPLAY

Note: P20(R61) will maintain tracking attitude computations. If the attitude error becomes greater than 10, the astronaut will be alerted by: UPLINK ACTY light on.

V58E

Request automaneuver execution. Go to MANEUVER

DISPLAY

Flashing	Range	XXX.XX nmi
V16N54	Range Rate	XXXX.X ft/s
	THETA	XXX.XX deg

PRO

V37E00 Enter Idling program

10. ROUTINES

This section will describe the routines needed to set up the Digital AutoPilot (DAP) and automaneuvering.

R03 – (V48) DAP DATA LOAD PROCEDURE

Key V48E to load Routine 03, the DAP Data Load Routine.

The table below describes the DAP parameters:

NOUN 46 -- Registers 1 and 2 each display five octal digits (Register 3 is blank):

Register 1

Config.	XTAC	XTBD	DB	RATE

Configuration:
- 0 -- no DAP is requested
- 1 -- CSM alone
- 2 -- CSM and LM
- 3 -- SIVB, CSM and LM (SIVB control)
- 6 -- CSM and LM (ascent stage only)

XTAC: X-translations using Quads AC
- 0 -- Do not use AC
- 1 -- Use AC

XTBD: X-translations using Quads BD
- 0 -- Do not use BD
- 1 -- Use BD

DB: Angular Deadband for Attitude Hold and Automatic Maneuvers
- 0 -- ± 0.5 deg
- 1 -- ± 5.0 deg

RATE: Rate Specification for RHC in HOLD or AUTO Mode and for KALCMANU-supervised Automatic Maneuvers
- 0 -- 0.05 deg/sec
- 1 -- 0.2 deg/sec
- 2 -- 0.5 deg/sec
- 3 -- 4.0 deg/sec

Register 2

AC Roll	Quad A	Quad B	Quad C	Quad D

AC Roll: Roll-Jet Selection
- 1 -- Use AC Roll
- 0 -- Use BD Roll

A, B, C, D: Quad Fails
- 1 -- Quad operational
- 0 -- Quad has failed

PROCEDURE

1. Key V48E

2. FL V04 N46

R1: A B C D E

R2: A B C D E

Register 1

A: What is the configuration:

A = 1 - CSM

A = 2 - CSM & LM

A = 3 - CSM & SIVB

A = 6 - CSM & LM Ascent Stage Only

B: QUAD A/C FOR X

B = 0 - Fail A/C

B = 1 - Use A/C

C: QUAD B/D FOR X

C = 0 - Fail B/D

C = 1 - Use B/D

D: ERR DEADBAND

D = 0 - Attitude deadband 0.5 degrees

D = 1 - Attitude deadband 5.0 degrees

E: RATE SELECT

E = 0 - 0.05 deg/sec

E = 1 - 0.2 deg/sec

E = 2 - 0.5 deg/sec

E = 3 - 2.0 deg/sec

Register 2

A = ROLL QUAD SELECT

A = 0 - USE B/C

A = 1 - USE A/C

B: QUAD A

B = 0 - Fail

B = 1 - Use

C: QUAD B

C = 0 - Fail

C = 1 - Use

D: QUAD C

D = 0 - Fail

D = 1 - Use

E: QUAD D

E = 0 - Fail

E = 1 - Use

Accept: Key PRO

Reject: Key V21, V22, or V24 - Load desired DAP data code and/or channel 30 back-up code

3. FL V06 N47

R1: CSM weight	XXXXX lb
R2: LM weight	XXXXX lb

Accept: Key PRO - If DPS has been staged, exit RO3

Reject: Key V21E, V22E, or V24E

Load Correct Data

4. FL V06 N48

R1: P Trim	XXX.XX deg
R2: Y Trim	XXX.XX deg

Accept: PRO - Return to prog

Reject: Key V21E, V22E, or V24E

Load Correct Data

5. To activate DAP

Panel 1:

CMC MODE - FREE

Key V49E

R62 – (V49) CREW DEFINED MANEUVER

Key V49E to load Routine 62, the Crew Defined Maneuver.

This maneuver is used to orient the spacecraft towards a crew defined attitude, where the digital autopilot automatically will maneuver towards the target attitude.

PROCEDURE

(V49) CSM Crew Defined Maneuver (R62)

CMC - on (req)

ISS - on & orient known (req)

SCS - on (req)

Panel 2, 140:

1 Key V37E 00E

2 Sel Tot Att (ISS) Disp

3 Key V49E

Poss OPR ERR

4 FL V06 N22 (fnl gmbl angles)

R, P, Y XXX.XX°

Accept PRO

Reject V25E load desired gmbl angles

(R60 - Attitude Maneuver Routine)

5 FL V50 N18 (auto mnvr request)

R, P, Y XXX.XX DEG

Panel 1:

Accept BMAG MODE (3) - RATE 2

Sel CMC Att Cont Auto

Panel 2, 140:

PRO

V06 N18

R, P, Y XXX.XX DEG

Mon auto mnvr on FDAI

Reject Key V62E

RHC - Null FDAI needles

When att satisfactory

ENTR

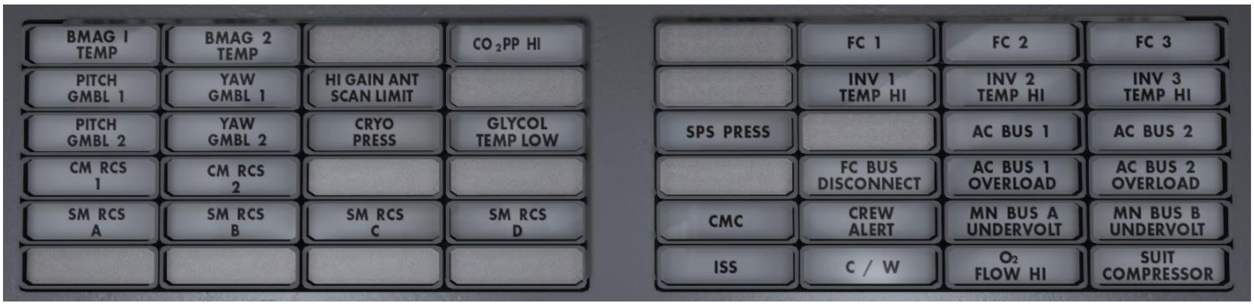
IX. CAUTION & WARNING SYSTEM

IX. CAUTION & WARNING SYSTEM

1. GENERAL

The Caution and Warning System (C&WS) is the christmas tree warning light panel in MDC-2 and should be monitored frequently. It monitors critical parameters of most of the sysmtes on the CM and SM.

The C&WS uses warning lights with a labeled text used to identify what system the warning comes from. Each light is illuminated due to a failure or an unusual condition. Each warning light is different, and has to be turned off either using a reset switch, or to correct the contition. A MASTER ALARM is usually also triggerd with a warning light to drive the attention to the C&WS panel.



Two power systems (1/2) power the C&WS.

2. OPERATION

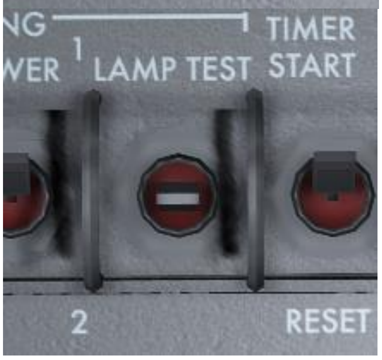
The C&WS can be controlled using the switches on MDC-2.

Below is a description of each control:

NORMAL will trigger all the MASTER ALARM indicators when an error occurs. BOOST will disable the left-hand MASTER ALARM to not disturb the commander and confuse it with an abort. In ACK, the C&WS lights are only visible while pressing the MASTER ALARM button.

The CSM mode enables monitoring of the Service Module and the Command Module. CM monitors the Command Module only. This switch needs to be set to CM before CSM separation.

The POWER switch lets you choose what power supply you wish to use for the C&WS.



The lamp test is used to test the C&WS lights. 1 tests the left side and 2 tests the right side and center disables the test.

The following procedure can be used to test the lights:

STA/T STEP	PROCEDURE	PANEL	REMARKS
	5.5.1 <u>C&WS Operational Check</u>		
CP	C/W LAMP TEST - 1 (hold)	2	Position 1 is momentary. Lamp test of MASTER ALARM light on panel 122 is accomplished with the G&N COND LAMP - TEST switch on panel 122. Master alarm tone not activated by this test.
AC	MASTER ALARM pb/lt - on	1	Panel 1 master alarm is disabled when C/W NORM switch is in BOOST mode and cannot be tested.
CP	lh C/W lts (18) - on	2	
	C/W LAMP TEST - 2 (hold)		Position 2 is momentary.
AC	MASTER ALARM pb/lt - out	1	
CP	lh C/W lts (18) - out	2	All lights may not be out following release of lamp test switch due to pre-existing malfunctions or conditions.
DP	MASTER ALARM pb/lt - on	3	
CP	rh C/W lts (18) - on	2	
	C/W LAMP TEST - rel		
DP	MASTER ALARM pb/lt - out	3	
CP	rh C/W lts (18) - out	2	All lights will not extinguish following release of lamp test switch if there are pre-existing malfunc- tions or conditions.
	C/W CSM - CM CM RCS lt (both) - on		MASTER alarm tone activated by this test. Systems 1 and 2 status lights.
ALL	MASTER ALARM lb/lt (3) & tone - on MASTER ALARM pb/lt - push MASTER ALARM lb/lt (3) & tone - out	1,3,122	MASTER ALARM light on panel 1 will not come on if C/W NORM switch is in BOOST position and cannot be used for reset under this condition.
CP	C/W CSM - CSM CM RCS lt (both) - out	2	

C&WS OPERATIONAL CHECK

3. WARNINGS & CRITICAL PARAMETERS

The following section contains a description of each warning light.

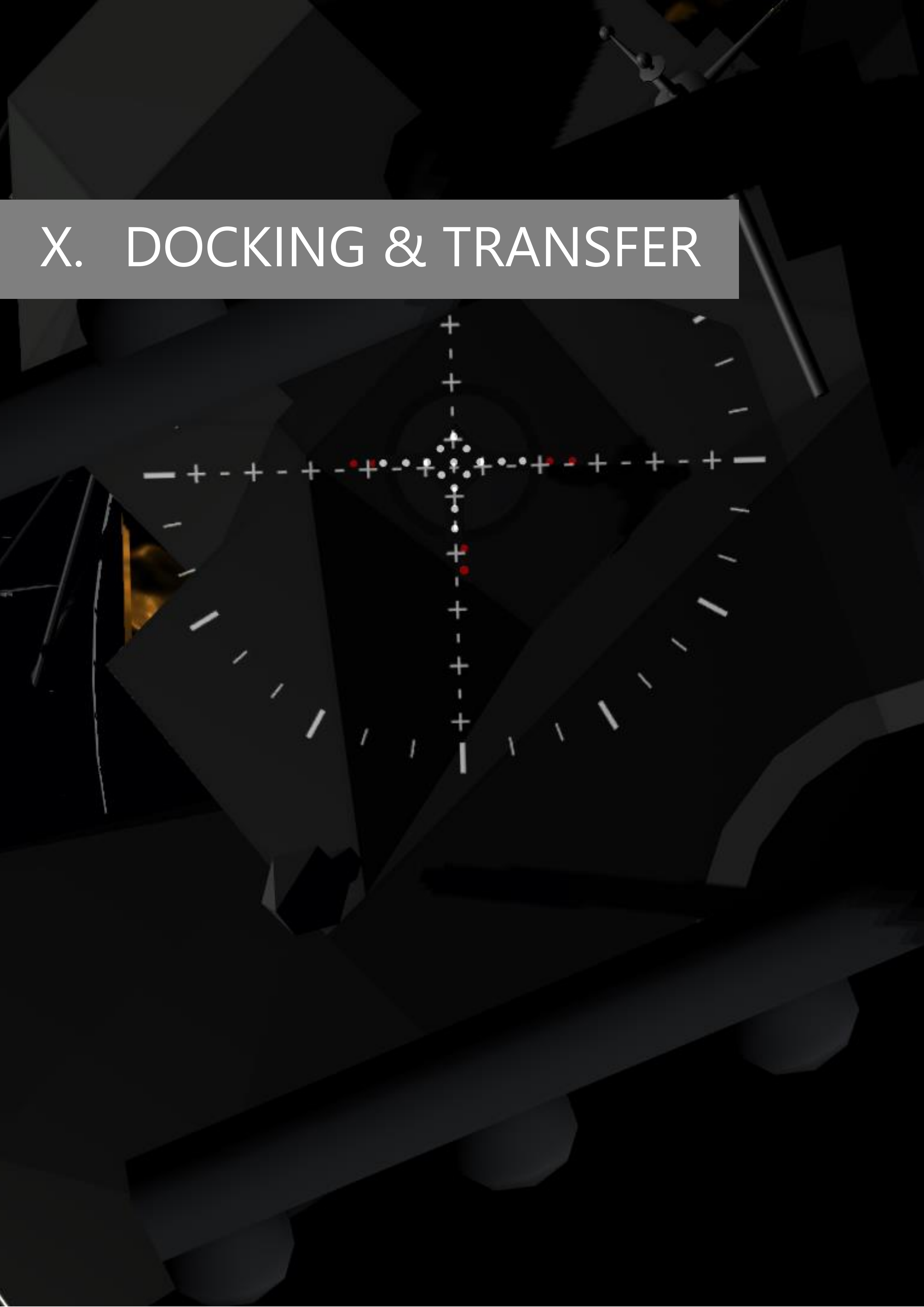
System Status Lights	Trigger Values	Other Indications (Lights, Gauges, Meters, etc.)	CM or SM	Remarks
BMAG 1	1. Any BMAG <168°F	None	CM	If activated, the BMAG POWER switch should be left in WARM UP until light is extinguished.
	2. Any BMAG >172°F			
BMAG 2	Same as BMAG 1			
CO_2 PP HI	At 7.6 mm Hg	PART PRESS CO_2 meter (MDC-2)	CM	
PITCH GMBL 1	Overcurrent conditions dependent on time and temperature.	None	SM	
YAW GMBL 1	Same as PITCH GMBL 1	None		
PITCH GMBL 2	Overcurrent conditions dependent on time and temperature.	None	SM	
YAW GMBL 2	Same as PITCH GMBL 2	None		
CRYO PRESS	1. Tank 1 O_2 <800 psia	CRYOGENIC TANKS - PRESSURE-O_2-1 meter (MDC-2)	SM	
	2. Tank 1 O_2 >950 psia			
	3. Tank 2 O_2 - Same as tank 1 O_2	CRYOGENIC TANKS - PRESSURE-O_2-2 meter (MDC-2)		
	4. Tank 1 H_2 <220 psia	CRYOGENIC TANKS - PRESSURE-H_2-1 meter (MDC-2)		
	5. Tank 1 H_2 >270 psia			
	6. Tank 2 H_2 - Same as tank 1 H_2	CRYOGENIC TANKS - PRESSURE-H_2-2 meter (MDC-2)		
GLYCO TEMP LOW	At -30°F	ECS RADIATOR TEMP - PRIM-OUTLET meter (MDC-2)	CM	Indication is for primary water glycol system only.
CM RCS 1	1. He manf press <260 psia	CM RCS - PRESS-MANF meters (MDC-2)	CM	Light functional only when CAUTION/WARNING - CSM-CM switch is in CM position
	2. He manf press >330 psia			
CM RCS 2	Same as CM RCS 1			
SM RCS A	1. Pkg temp <75°F	SM RCS - TEMP PKG meter (MDC-2)	SM	
	2. Pkg temp >205°F			
	3. Sec fuel press <145 psia	SM RCS - PRESS-SEC-FUEL meter (MDC-2)		
	4. Sec fuel press >215 psia			
SM RCS B	Same as SM RCS A			
SM RCS C	Same as SM RCS A			

System Status Lights	Trigger Values	Other Indications (Lights, Gauges, Meters, etc.)	CM or SM	Remarks
SM RCS D	Same as SM RCS A			
FC 1	1. H_2 flow >0.16 lb/hr	FUEL CELL - FLOW-H_2-O_2 indicator (MDC-3)	SM	Event indicators (elec/mech) pH HI, and FC RAD TEMP LOW are activated at lamp trigger values.
	2. O_2 flow >1.27 lb/hr			
	3. Skin temp <360°F	FUEL CELL - MODULE TEMP-SKIN indicator (MDC-3)		
	4. Skin temp >475°F			
	5. Cond exh <155°F	FUEL CELL - MODULE TEMP-COND EXH indicator (MDC-3)		
	6. Cond exh >175°F			
	7. At pH factor of 9	pH HI event indicator (MDC-3)		
	8. Rad out temp below -30°F	FC RAD TEMP LOW event indicator (MDC-3)		
FC 2	Same as FC 1			
FC 3	Same as FC 1			
INV 1 TEMP HI	At >190°F	None	CM	
INV 2 TEMP HI	Same as INV 1 TEMP HI			
INV 3 TEMP HI	Same as INV 1 TEMP HI			
SPS PRESS	1. Fuel tk He press <157 psia	SPS PRPLNT TANKS - PRESS-FUEL meter (MDC-3)	SM	
	2. Fuel tk He press >200 psia			
	3. Ox tk He press - Same as fuel tank He press	SPS PRPLNT TANKS - PRESS-OXID meter (MDC-3)		
AC BUS 1	1. At 95±3 vac <	AC VOLTS meter (MDC-3)	CM	
	2. At 130±2 vac >			Overvoltage disconnects inverter from bus.
AC BUS 2	Same as AC BUS 1			
FC BUS DISCONNECT	1. Forward current >75 amps	DC INDICATORS - FC 1, 2 & 3 (MDC-3)	SM	DC AMPS meter (MDC-3)
	2. Reverse current >4 amps for 1 to 10 seconds			

System Status Lights	Trigger Values	Other Indications (Lights, Gauges, Meters, etc.)	CM or SM	Remarks
AC BUS 1 OVERLOAD	1. 3Ø at 27 amps for 15±5 seconds 2. 1Ø at 11 amps for 5±1 seconds	AC VOLTS meter (MDC-3)	CM	
AC BUS 2 OVERLOAD	Same as AC BUS 1 OVERLOAD			
CMC	1. Loss of prime power	CMC light illuminated (LEB-122)	CM	Items 5 through 11 will cause restart in the CMC.
	2. Scaler fail - if scaler stage 17 fails to produce pulses	RESTART & PGNS lights illuminated if restart and standby exist in CMC		
	3. Counter fail - continuous requests or fails to happen following increment request			
	4. SCADBL - 100 pps scaler stage >200 pps			
	5. Parity fail - accessed word, whose address is octal 10 or greater, contains even number of ones			
	6. Interrupt too long or infrequent - 140 to 300 ms			
	7. TC trap - too many TC or TCF instructions, or TCF instructions too infrequent			
	8. Night watchman - computer fails to access address 67 within 64 to 1.92 seconds			
	9. V fail - 4v supply >4.4v 4v supply <3.6v 14v supply >16.0v 14v supply <12.5v 28v supply <22.6v			
	10. If oscillator stops			
	11. Stand by			
CREW ALERT	Activated by real-time command from ground stations through the UDL	None	N/A	System status light must be extinguished by ground command
MN BUS A UNDERVOLT	At 26.25±0.1 vdc	DC VOLTS meter (MDC-3)	CM	
MN BUS B UNDERVOLT	Same as MN BUS A UNDERVOLT			

System Status Lights	Trigger Values	Other Indications (Lights, Gauges, Meters, etc.)	CM or SM	Remarks
ISS	1. IMU fail a. IG servo error >2.9 mr for 2 seconds b. MG servo error >2.9 mr for 2 seconds c. OG servo error >2.9 mr for 2 seconds d. 3200 cps <50% e. 800 wheel supply <50%	ISS light illuminated (LEB-122)	CM	IMU fail signal inhibited by CMC when in coarse align mode.
	2. PIPA fail a. No pulse during 312.5-ms period b. If both + and - pulses occur during 312.5-ms period c. If no + and - pulses occur between 1.28 to 3.84 seconds	PIPA fail will also illuminate PGNC lights and PROGRAM light on DSKY		PIPA fail signal inhibited by CMC except during CMC controlled translation or thrusting.
	3. CDU fail a. CDU fine error >1.0v rms b. CDU coarse error >2.5v rms c. Read counter limit >160 cps d. Cos (θ - ψ) <2.0v e. +14 dc supply <50%			CDU fail signal by CMC during CDU zero mode.
C/W	1. At +11.7 or -11.7 vdc 2. At +13.9 or -13.9 vdc	None	CM	Alarm tone inoperative.
O_2 FLOW HI	1.0 lb/hr for 16 sec	O_2 FLOW meter (MDC-2)	CM	
SUIT COMPRESSOR	ΔP across inlet and outlet <0.22 psia	SUIT COMPR ΔP meter (MDC-2)	CM	

X. DOCKING & TRANSFER



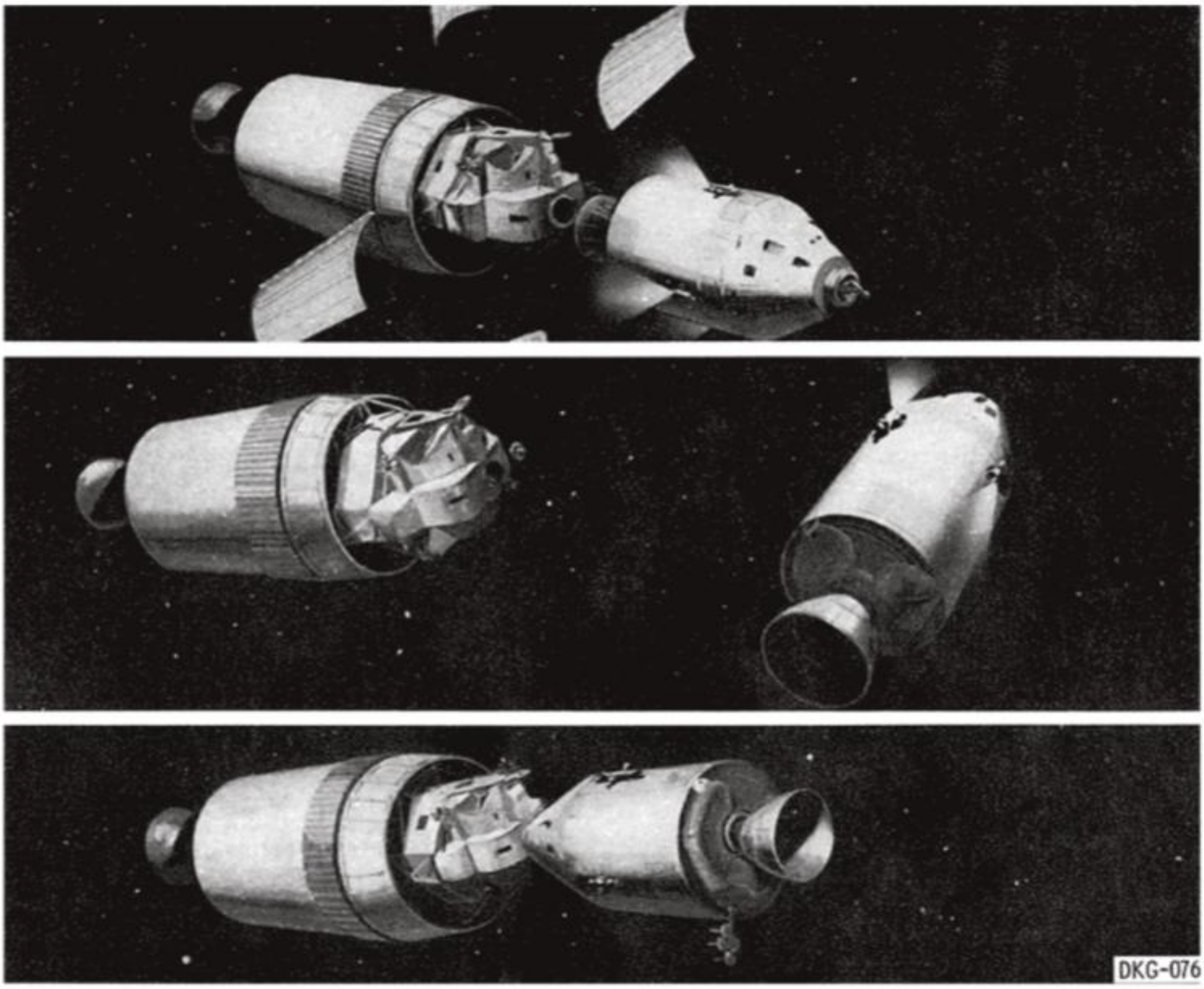
X. DOCKING & TRANSFER

1. GENERAL

Docking is needed to extract the Lunar Module from the S-IVB after TLI and when rendezvoising with the Lunar Module after Lunar Ascent. A docking probe is used to attach the Command Module to the Lunar Module.

TRANSPOSITION AND DOCKING

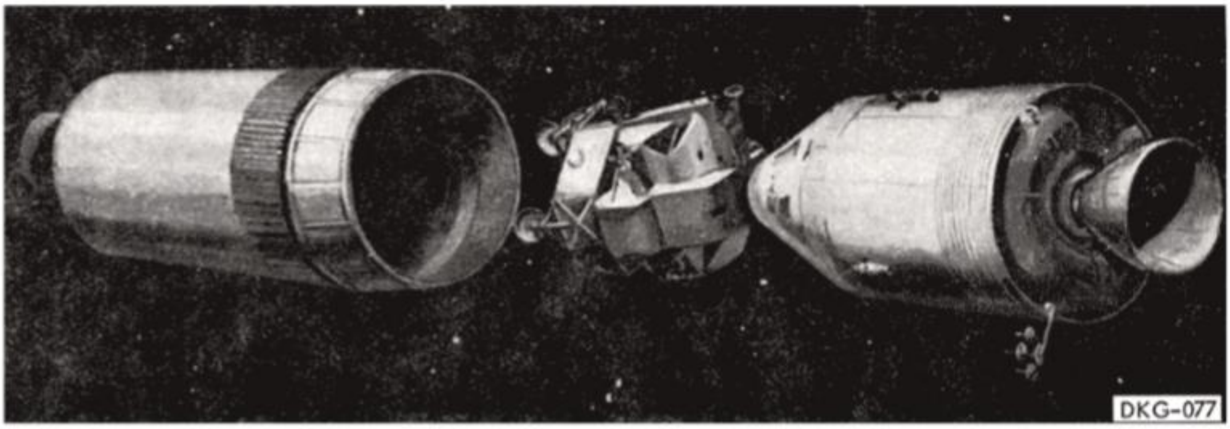
The T&D starts after TLI. The the CSM is separated from the S-IVB, docking is achieved by maneuvering the CSM close enough so that the extended probe engages with the drogue in the LM. When the probe engages the drouge with the use of the capture latches, the probe retract system is activated to pull the LM and CSM together.



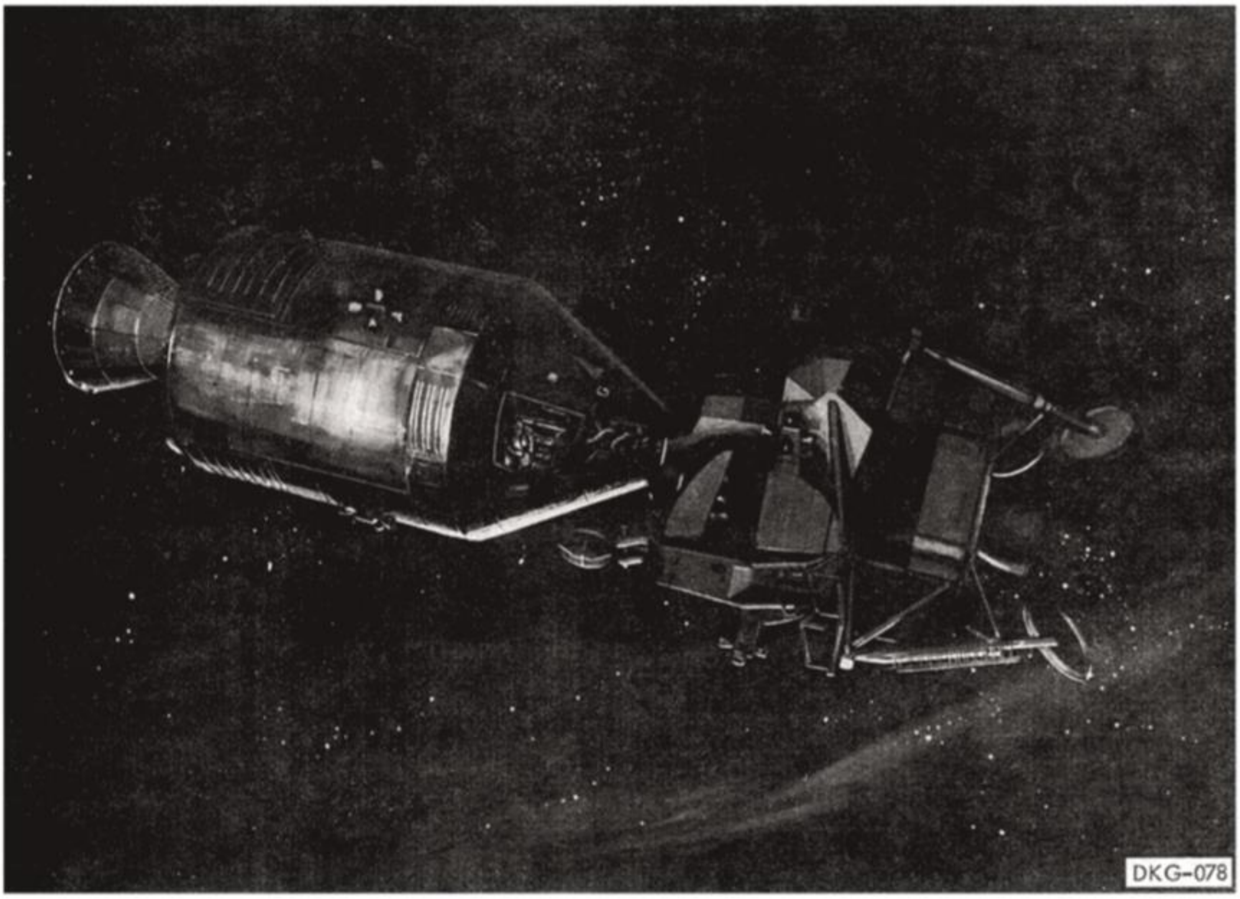
Upon retraction, the LM tunnel ring will activate the 12 automatic docking ring latches on the CM and effect a pressure seal between the modules through the two seals in the CM docking ring face. After the two vehicles are docked, the pressure in the tunnel is equalized from the CM through a pressure equalization valve. The CM forward hatch is removed and the actuation of all 12 latches is verified. The vehicle umbilicals supply power to release the LM from the SLA.

The SIVB/LM SEP switch will trigger the extraction of the LM. Using springs, the LM and CSM will be pushed away from the S-IVB (and vice versa). This switch is located on MDC-2.

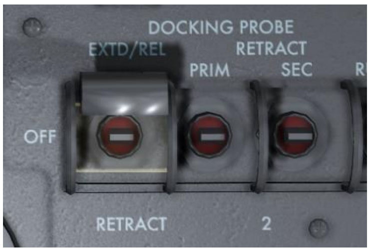
The CSM/LM will then continue onwards.



Once in Lunar Orbit, the tunnel is repressurized and a passageway between the two is available. If the pressure between them is equal, the tunnel can be opened and the crew can enter the LM cokcpit. Using the UI next to the LM entrance, you can open the passage and enter the Lunar Module. Doing this will change the activa spacecraft from the CM to the LM. Controls to quickly switch between the two is available if both spacecrafts are active.

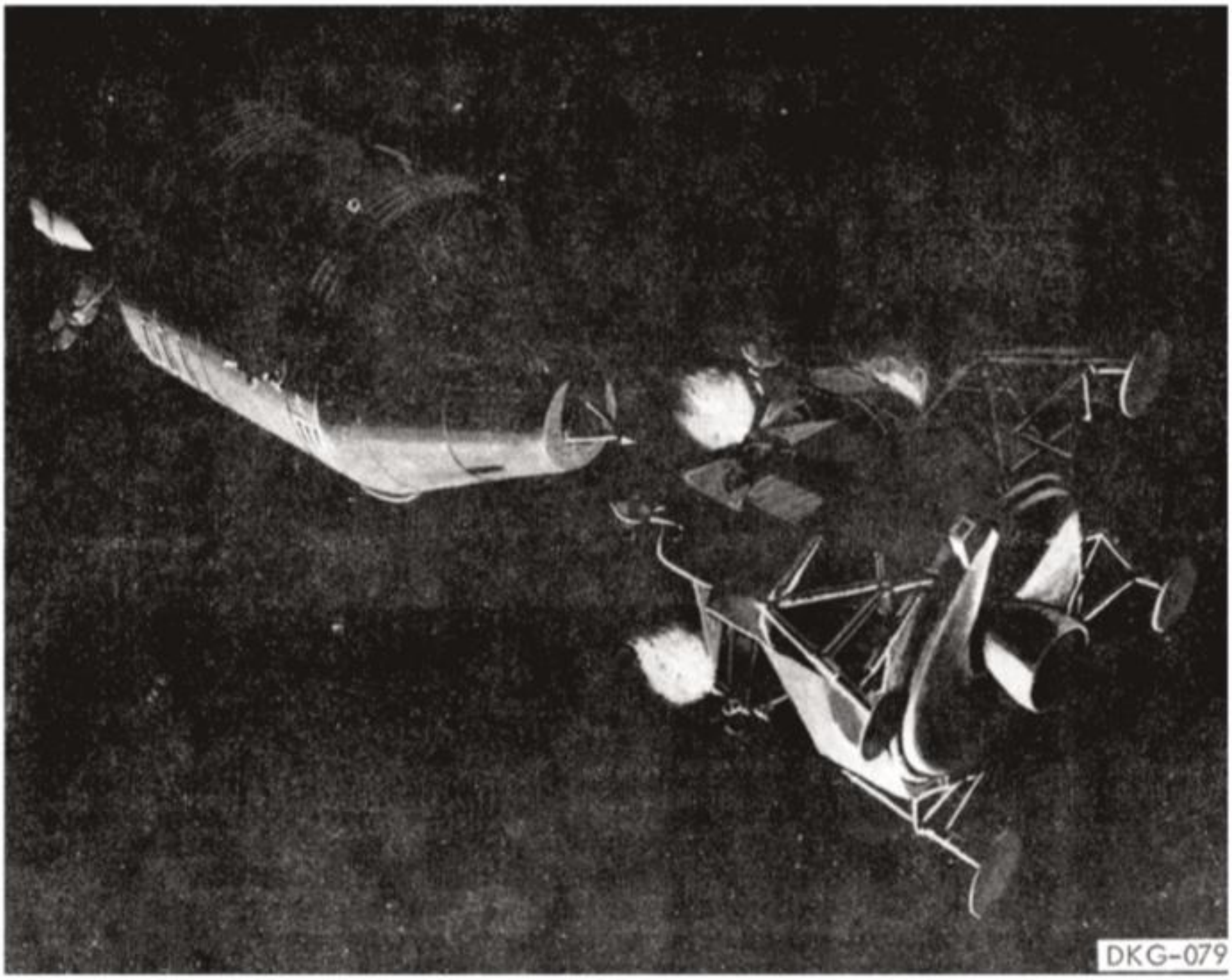


When ready to separate the LM, two crewmen will enter the LM and prepare it before sealing the entrance and separating them.



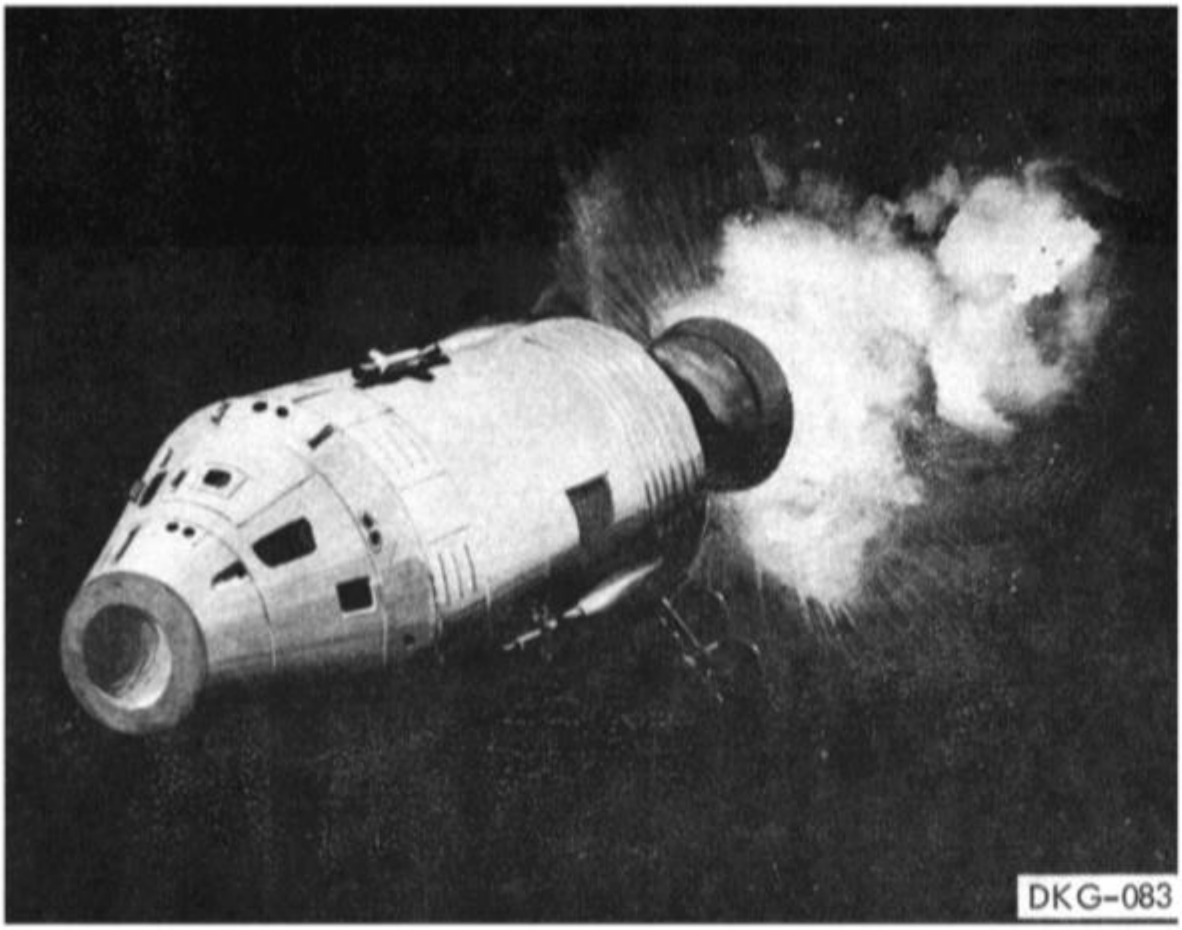
The separation is initiated using the EXTEND RELEASE/RETRACT switch on MDC-2. If placed into EXTEND/RELEASE position, the probe is extended and the LM is released from the CSM.

The LM continues on in its own orbit, and by controlling the Lunar Module, it can land on the Moon.



After performing some EVAs on the Moon, the ascent stage is launched back into orbit around the Moon to rendezvous with the CSM.

Once docked, the LM ascent stage is released and the SPS is used to return to Earth after the Transearth Injection.



2. OPERATION

Docking is achieved using the docking probe. The docking probe is the system that connects the Lunar Module with the CSM. When docking is detecting, it will retract and seal the connection.

The docking probe is controlled using the following panel on MDC-2.

The A and B talkback indicators indicates if the probe is ready for capture. When gray, it is extended and ready to capture, or if it is retracted. Barberpoled means it is in transition between the two states. It usually takes 30 seconds. Two systems can retract and extend the probe, named A and B.

The retraction switch is used to either EXTEND or RETRACT the system before a docking.

Two systems can retract or extend each of the A or B systems, PRIM and SEC.

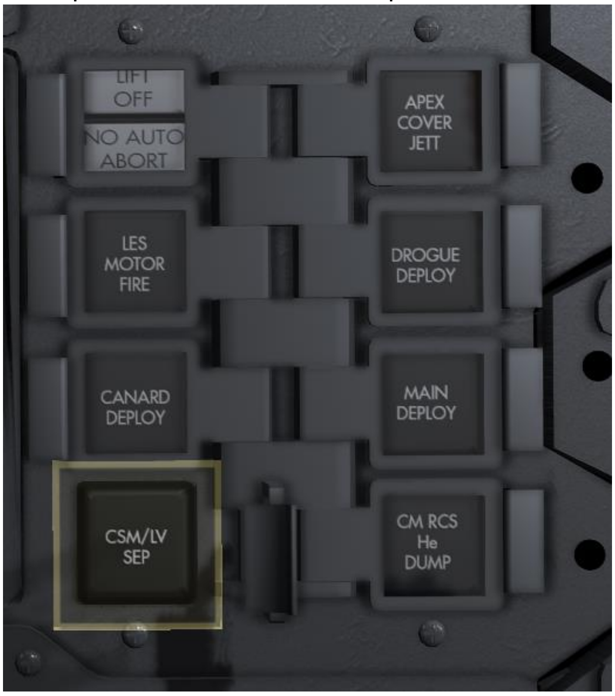
3. DOCKING PROCEDURES

The following section will contain the basic procedures needed to perform transposition and docking. You can also use the EMS to montor relative velocity, as well as the ASCP to set the attitude so the SCS can provide point-to directions.

CSM SEPARATION FROM SIVB

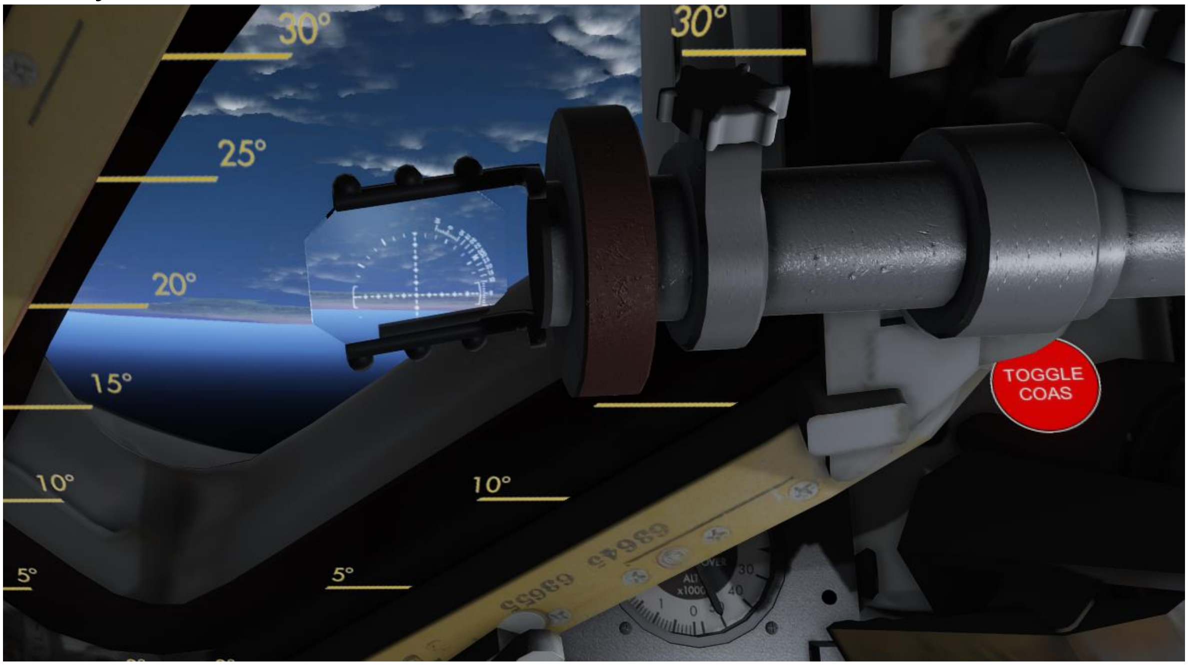
1) Set DOCK PROBE to EXTEND
2) Verify that the SM RCS logic is enabled and working.
3) Ensure the sequencer logic (SECS LOGIC) is enabled and set to ARM.

4) To separate from the SIVB, depress the CSM/LB pushbutton



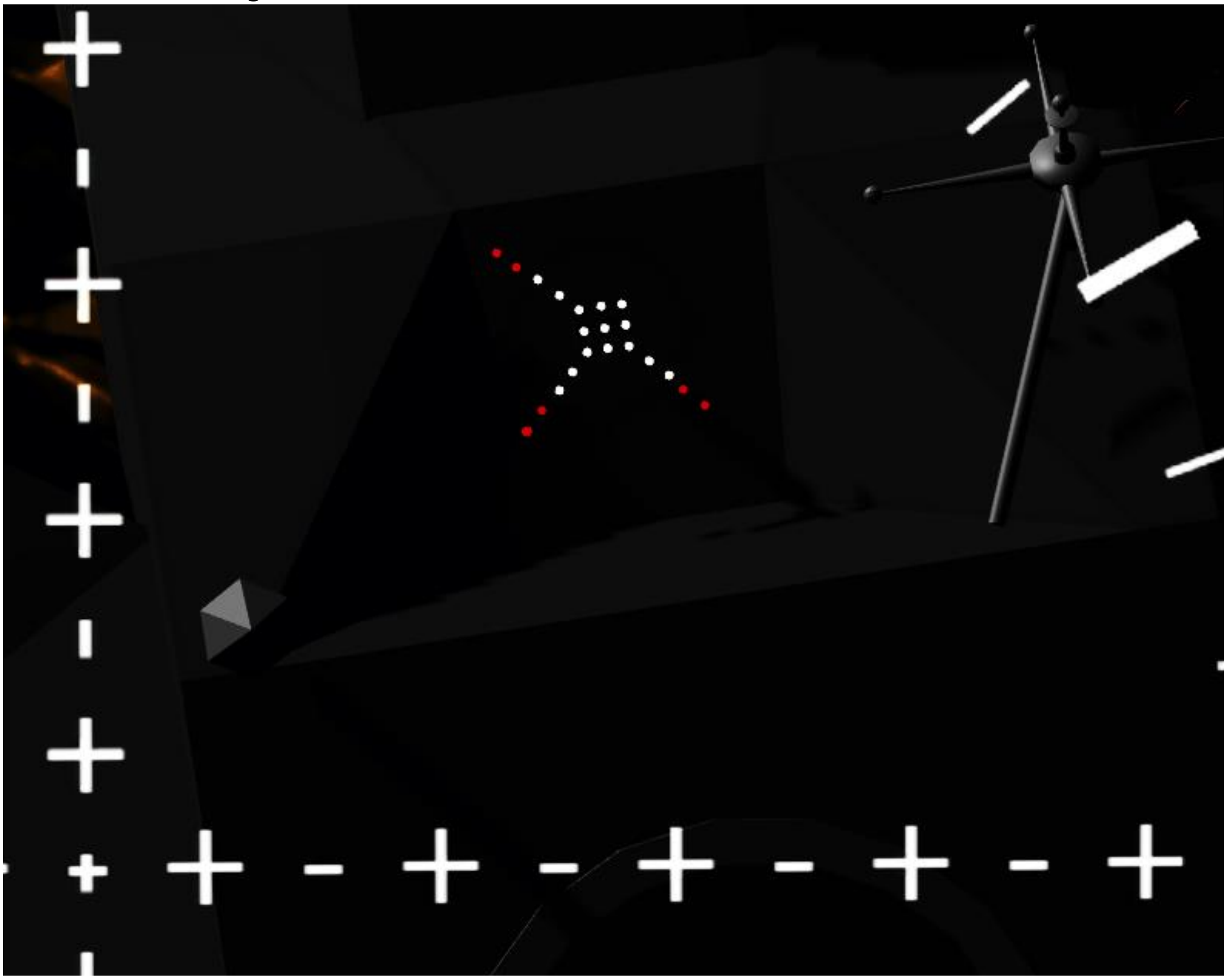
TRANSPOSITION

1) Once the CSM is separated from the SIVB, it is floating in-front of it. Use the RCS SM thrusters in the forward direction to move away from it (slowly).
2) After clearing the SIVB, perform a 180 degree turnaround to face the SIVB.
3) Use the COAS on the left window to target the LM. It can be put in position by using the COMMUNICATION/TOOLS by pressing [C] on the Keybaord, then press the COAS button just below the COAS on the window.



4) Using the COAS, you can now align the Lunar Module in-front of you using the target.

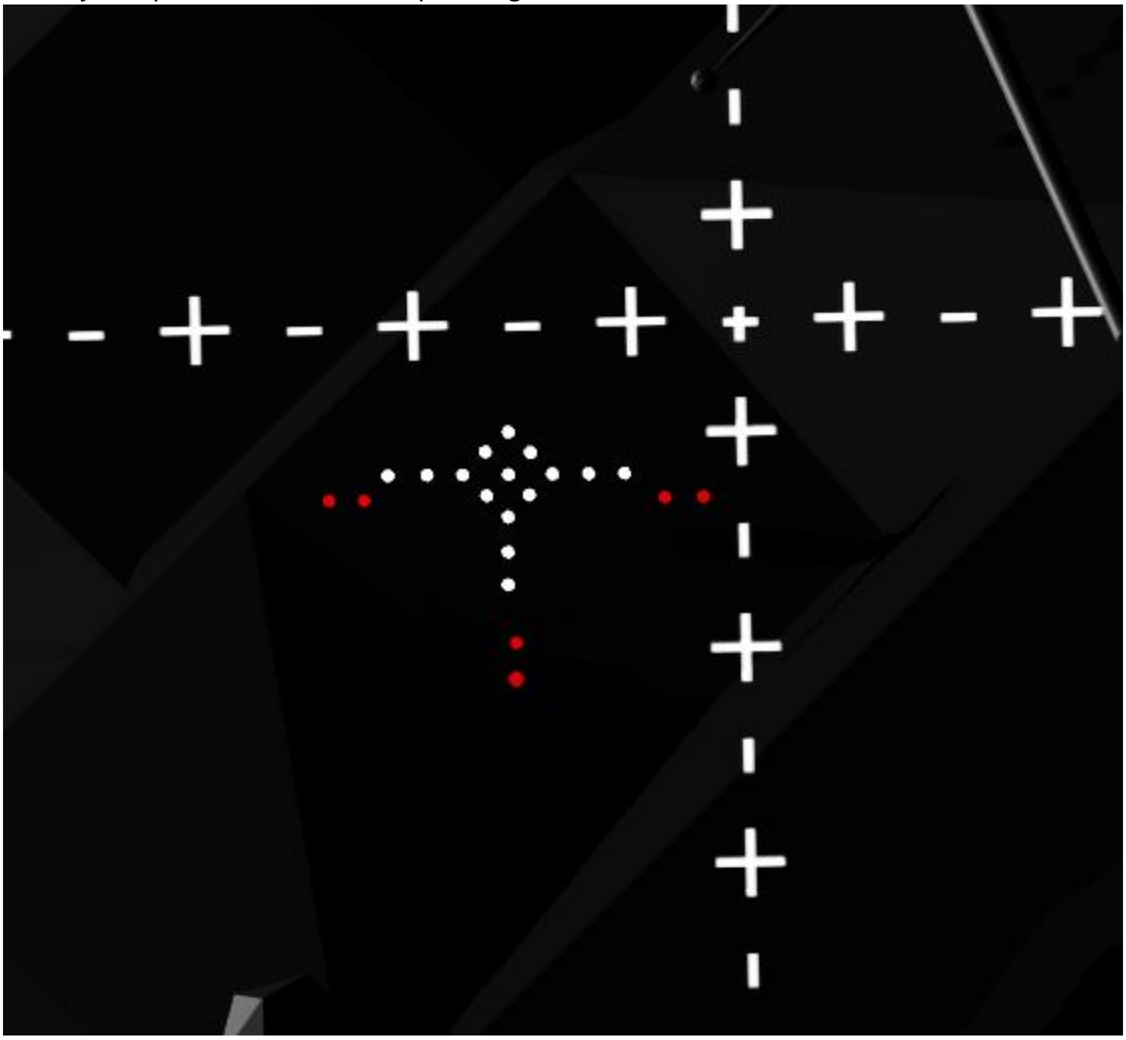
5) Look for a small target on the Lunar Module.



6) This target needs to be aligned with the COAS sight.

7) The target on the Lunar Module consists of two parts, one white and one red. The white line needs to be aligned with the red lines in both axes. This means the spacecraft is aligned in terms of attitude/direction as well.
8) If the alignment looks like below, it is out of alignment. Notice the white dots does not align with the red dots on the Y-axis/UP-axis. This means you are pitched wrong.

Modify the pitch and translate up to align the error below.



9) When target is aligned, and centered in the COAS, keep translating forward until the docking is complete.

DOCKING

1) Once you are docked with the Lunar Module, you are once again part of the SIVB stage.
2) RETRACT the DOCK PROBE

EXTRACTING THE LUNAR MODULE

1) The Lunar Module is still stuck in the SIVB.
2) Set the SIVB/LM SEP switch to the UP position to free the Lunar Module from the SIVB.
3) Immeadiately when released, fire the SM RCS thrusters so you back away from the SIVB, extracting the Lunar Module from the SIVB.

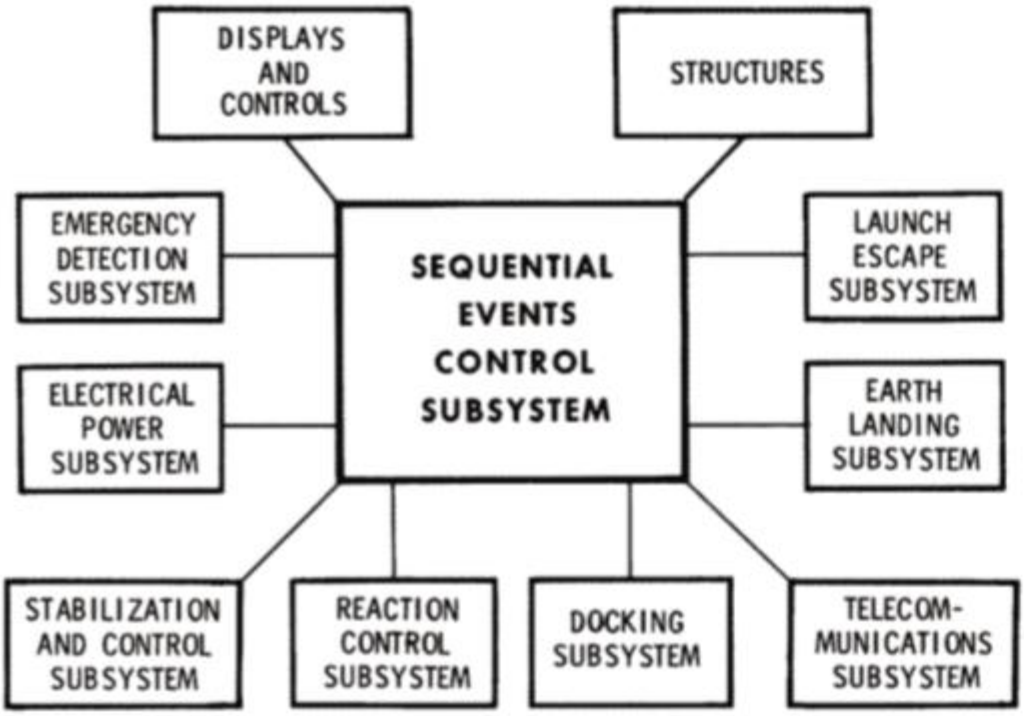
4) You are now free from the SIVB, and the SIVB will take it's own path to crash into the surface of the Moon.

XI. SEQUENTIAL SYSTEMS

XI. SEQUENTIAL SYSTEMS

1. GENERAL

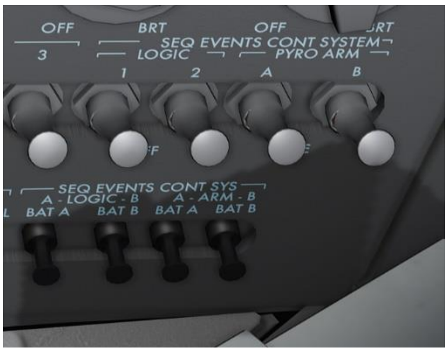
The Sequential Events Control Subsystem (SECS) controls many of the sequential requiremnets of the CSM and the LV. They are utilized during launch preparations, ascent, and entry portions of a mission, preorbital aborts, early mission terminations, docking maneuvers, and SC separation sequences.



Many of the events are initiated manually, while some automatically with manual backup.

2. OPERATION

The SECS is operated from MDC-8:

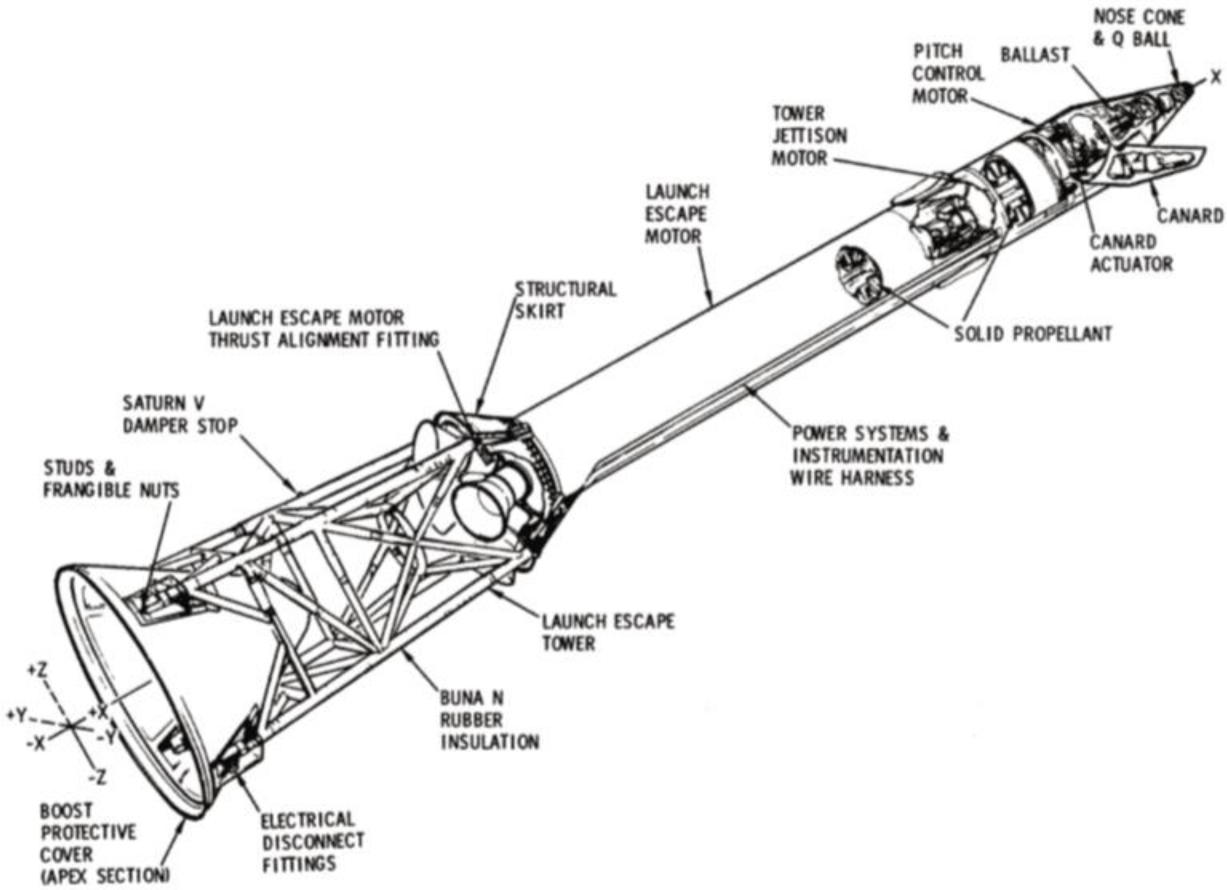


The logic controls are enabled by moving SECS LOGIC 1 and 2 to the UP position, while main power is enabled suing the SECS LOGIC A and B cbs.

3. LAUNCH ESCAPE SYSTEM

The Launch Escape System (LES) is attached to the top of the Command Module during ascent, and is jettisoned when no longer needed.

A boost protective cover (BPC) protects the Command Module from the boosters of the LES and the ascent itself. The Launch Escape Tower (LET) stands on the BPC.

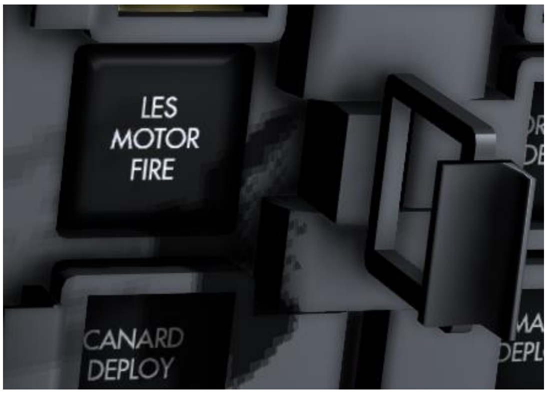


The Launch Escape Motor is used to separate the entire Command Module en the event of an Abort in the early stage of the boost ascent phase. The Tower Jettison Motor is used to separate the LET from the CM during ascent when it's no longer needed.

3.1. OPERATING THE LES

The LES is an automatic system, but provides manual control too.

The TWR JETT switches controls the two redundant systems on tower jettison. AUTO is fully automatic, while OFF will disable the jettison system so the crew can manually jettison it. UP will trigger the jettison. Only one system needs to trigger the jettison to jettison the tower.



The LES MOTOR FIRE switch will manually fire the Launch Escape Motor.

2. EARTH LANDING SYSTEM

The Earth Landing System (ELS) is the system responsible for landing the crew safely back on Earth. The ELS consists of eigth parachutes (three main chutes, two drogues, and three pilot chutes), and the mortars to deploy them.

The Apex Cover is used to protect the ELS during ascent and flight. It needs to be removed for the ELS to function.

The drogues are used to slow the capsule down and stabilize it before the mains are released

The main chutes are used to slow the capsule down to a speed designed to safely land the crew in the ocean.

For a safe recovery, the helium from the RCS needs to be removed during landing.

2.1. OPERATING THE ELS

The ELS contains an ELS LOGIC system that can automatically or manually. The ELS requires the SECS and Pyros to be powered.

The ELS is controlled using the following controls:

The ELS LOGIC switch needs to be UP to enable the logic of the ELS system. ELS AUTO/MAN will select if you want to land using automatic controlls or manual controls.

The manual controls are APEX COVER JETT, DROGUE DEPLOY, MAIN DEPLOY and CM RCS He DUMP. Trigger the respective button to perform the manual step.

The APEX COVER JETT will jettison the Apex Cover/Forward Heat-shield from the Command Module, exposing the parachutes.
The DROGUE DEPLOY will deploy the drogue parachuts.
The MAIN DEPLOY will deploy the main parachutes.
The CM RCS He DUMP will dump the tockig Helium gas from the CM RCS.

3. PROCEDURES

The ELS starts its main activites at 50,000 feet and less, just after the re-entry is complete. Activating the ELS during re-entry can be catastrophic as you release part of the heat shield.

The ELS is automatic, but manual control can be used. For manual control, the following EARTH/POST LANDING checklist should be followed.

```
EARTH/POST LANDING

                                                    Start Watch
RRT (__:__)  STEAM PRESS - pegged at 90K                (00:00)
50K'(__:__)  CABIN PRESS REL vlv (2) - BOOST/ENTRY      (00:52)
             [SECS PYRO ARM (2) - ARM]
             Check Altimeter

40K'(__:__)         *       CM UNSTABLE                *(01:08)
                    *RCS CMD - OFF                     *
                    * 40K' APEX COVER JETT PB-PUSH     *
                    *DROGUE DEPLOY PB - PUSH (2 sec    *
                    *after apex cover jett)            *

30K'     [ELS LOGIC - on (up)]                          (01:24)
         [ELS - AUTO         ]                    Start DAC

24K'(__:__)  RCS disable (auto)                         (01:30)
                    *RCS CMD - OFF*

         Apex cover jett (auto)
                    *APEX COVER JETT PB - PUSH*
         (WAIT 2 SECS)
         Drogue parachutes deployed (auto)
                    *DROGUE DEPLOY PB - PUSH*

         If Both Drogues Fail:
                    *ELS - MAN                 *
                    *Stabilize CM              *
                    *5K' MAIN DPLY PB - PUSH*
                    *ELS - AUTO                *

23.5K'   Cabin Pressure increasing
                    *If not increasing by 17K':     *
                    *CABIN PRESS REL vlv (RH) - DUMP*

10K'(__:__)  Main parachutes deployed (Drogues +48s)(02:29)
(Cab Press =     MAIN DEPLOY PB - PUSH (within 1 sec)
  10 psia)       VHF ANT - RECY
                 VHF AM A - SIMPLEX
                 VHF BCN - ON
                 DIRECT O2 vlv - OPEN (if suited)
```

The checklist is available in-game.

3. PYROTECHNICS

The pyros are the explosive devices used to jettison components, and perform staging. They work with a small explosive with a wire connected to the pyro bus. Providing electrical power to these wires, they will heat up and trigger the explosion.

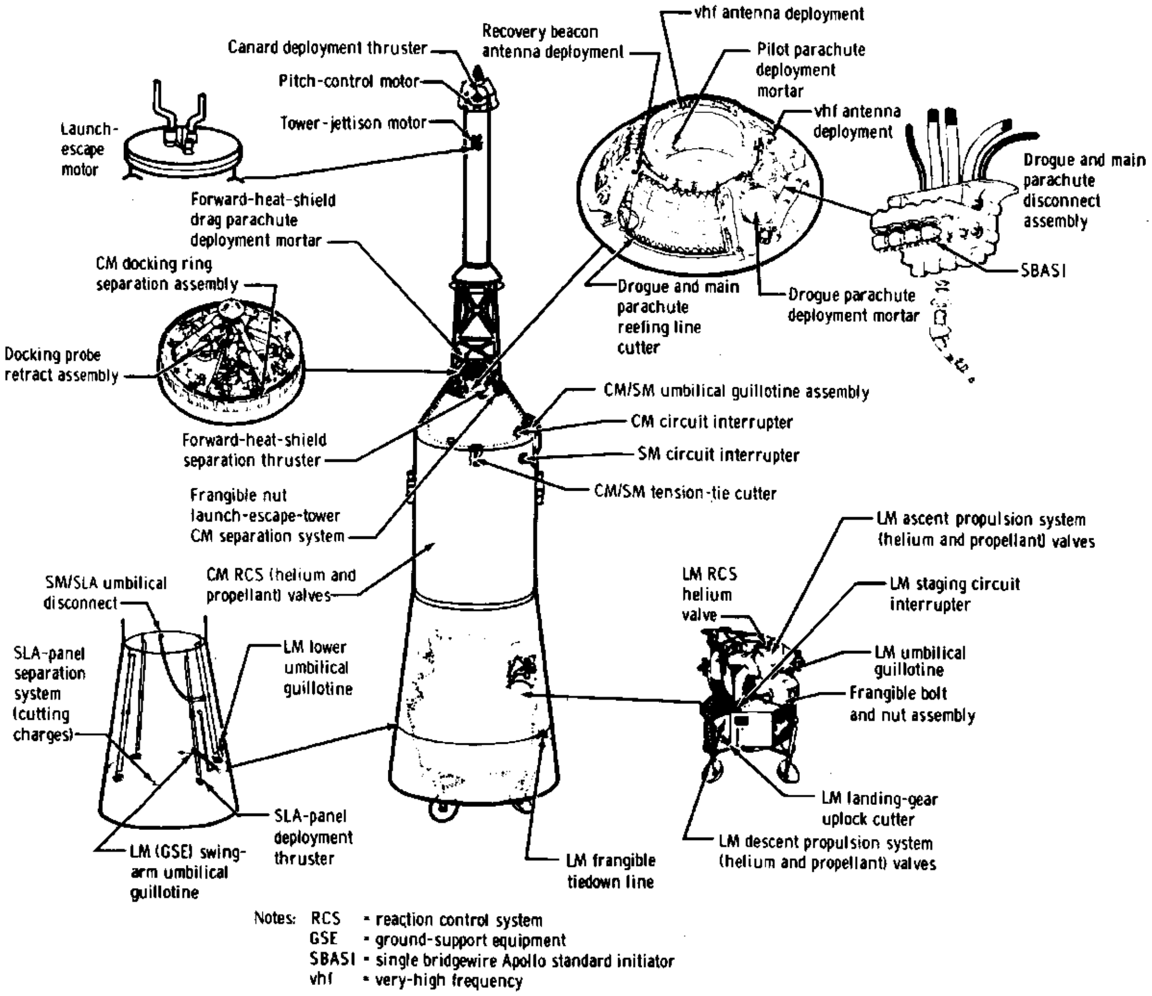
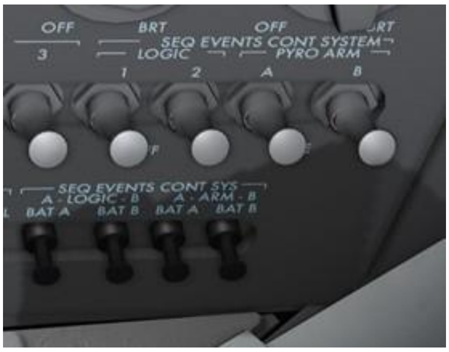


Figure 1. - Locations of Apollo pyrotechnic devices.

Operating the pyros is simple.



Two switches named PYRO ARM will ARM the pyros. It requires the pyro bus to be powered by either the pyro batteries or the main batteries.
The charge will usually last a few moments while the pyro bus provides energy to the wires. These are located on MDC-8.

MISSION TIMER
HOURS
MIN
SEC
EVENT TIMER
MIN
SEC
RESET
DOWN
STOP
START
EVENT TIMER
MIN - TENS - SEC
MISSION
TIMER
START
STOP
RESET
- UNITS -
CM RCS
HTRS
OFF
OFF

XII. TIMERS

XII. TIMERS

1. GENERAL

The Mission Timer and Event Timers can be seen and controlled on MDC-1 and MDC-2. The Mission Timer is used to show the elapsed time since liftoff and the Event Timer is used either automatically or manually to count up/down between events. Think of it like a stopwatch.

2. MISSION ELAPSED TIMER

The Mission Elapsed Timer (MET) is located on MDC-2 and counts upwards from launch. It can be controlled using the following controls:

It displays hours, up to 999, minutes and seconds. The HOURSE, MIN and SEC switches can set the time manually. TENS will move the amount up by 10 units, while UNITS will move it up by 1 unit.

This is usually left alone.

Another Mission Timer is available in the lower equipment bay on panel 306.

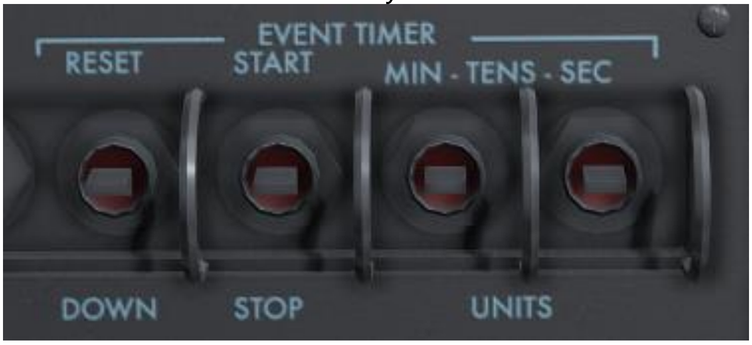
3. EVENT TIMER

The Event Timer is a tool you can use to measure time to an event, both couting up or down.

Two event timers are available. One is located on MDC-1 and another is located on panel 306. The event timer is a stop watch and shows minutes and seconds.

At liftoff this is set to 00:00 and starts counting up.

The timer can be controlled by the EVENT TIMER switches on MDC-1 or panel 306:



The RESET/UP/DOWN switch controls the direction. RESET will stop and reset the timer, UP will make it count up and DOWN will make it count down.
STOP will pause the timer and START will continue the timer. MIN/SEC will set the time just as the Mission Elapsed Timer.