Lunar Module ECS
(Environmental Control System)
Design Considerations & Failure Modes
Part I
Upon completion of the lesson, the student will be able to:

- Describe the Lunar Module (LM) Environmental Control System (ECS) generic design considerations philosophy.

- Summarize the LM ECS general testing regime.
For the best understanding of this material, the student should have viewed the Lunar Module (LM) Environmental Control System (ECS) Familiarization lesson prior to viewing this lesson.
Overview of LM ECS

- Oxygen Supply and Cabin Pressurization Section
- Atmosphere Revitalization Section
- Water Management Section
- Heat Transport Section
Overview of LM ECS

- Oxygen Supply and Cabin Pressurization Section

Diagram showing the system with labels for Ascent Stage, Oxygen demand regulator, Oxygen repressurization valve, Shutoff valves (4), Oxygen control module, Ascent oxygen tank, To suit loop, Interstage disconnect, Overboard relief valve, Burst diaphragm, Pressure regulator, Descent oxygen tank, High-pressure assembly, and R denotes redundant component.
Overview of LM ECS

- Oxygen Supply and Cabin Pressurization Section

[Diagram showing the oxygen supply and cabin pressurization system with labels for oxygen supply, cabin pressurization, and various components like oxygen tanks, valves, and regulators.]

Oxygen Supply and Cabin Pressurization Section
Oxygen Supply and Cabin Pressurization Section

Overview of LM ECS

- Oxygen Supply
- Cabin Pressurization Section
Overview of LM ECS

- Oxygen Supply and Cabin Pressurization Section

Diagram showing the flow of oxygen supply and pressurization system with labels for components like oxygen demand regulator, oxygen repressurization valve, oxygen control module, and various tanks and valves.
Overview of LM ECS

- Atmosphere Revitalization section

Atmosphere Revitalization Section Simplified Schematic
Overview of LM ECS

- Atmosphere Revitalization section

Atmosphere Revitalization Section Simplified Schematic
Atmosphere Revitalization section

- Heat Exchanger
- Accumulator
- Water pump
- Regenerative heat exchanger
- Isolation valve
- Relief valve
- Diverter valve
- CO2 sensor
- LIOH canister
- LIOH canister
- LIOH canister
- Fan
- Cabin gas return valve
- Cabin recirculator assembly
- H2O separator
- H2O separator
- H2O sublimator
- Fan

Atmosphere Revitalization Section Simplified Schematic
Overview of LM ECS

- Atmosphere Revitalization section

Atmosphere Revitalization Section Simplified Schematic
Overview of LM ECS

Atmosphere Revitalization section

Atmosphere Revitalization Section Simplified Schematic
Overview of LM ECS

Water Management Section

Ascent H2O tanks
- Shutoff valves (5)
- H2O hose
  - PESS refill
  - Drinking
  - Food preparation
  - Fire extinguisher

Pressure regulator
- Water tank selector valve
- Water control module
- Ascent stage
- Descent stage
- Guillotine

Reclaimed metabolic H2O
- Pressure regulator
- Secondary coolant H2O sublimator
- Suit-circuit H2O sublimator
- Primary coolant H2O sublimator

Descent H2O tank
Overview of LM ECS

Water Management Section

- Ascent H2O tanks
- Shutoff valves (5)
- H2O hose
  - PLESS refill
  - Drinking
  - Food preparation
  - Fire extinguisher
- Water tank selector valve
- Pressure regulator
- Reclaimed metabolic H2O
- Pressure regulator
- Secondary coolant H2O sublimator
- Suit-circuit H2O sublimator
- Primary coolant H2O sublimator

R denotes redundant component.

Ascent stage
Descent stage
Guillotine

Water control module
Water Management Section
Overview of LM ECS

- Water Management Section

- Ascent H2O tanks
- Reclaimed metabolic H2O
- Pressure regulator
- Secondary coolant H2O sublimator
- Suit-circuit H2O sublimator
- Primary coolant H2O sublimator
- Water tank selector valve
- Pressure regulator
- R denotes redundant component.
- Ascent stage
- Descent stage
- Water control module
- Descent H2O tank

H2O hose
- PLESS refill
- Drinking
- Food preparation
- Fire extinguisher

Guillotine
Overview of LM ECS

Water Management Section

- Ascent H2O tanks
- Reclaimed metabolic H2O
- Pressure regulator
- Secondary coolant H2O sublimator
- Suit-circuit H2O sublimator
- Primary coolant H2O sublimator
- Water tank selector valve
- Pressure regulator

Water hose:
- PLEE refill
- Drinking
- Food preparation
- Fire extinguisher

Ascent stage
- Water control module
- R denotes redundant component

Descent H2O tank
- Guillotine
- Descent H2O tank

Water Management Section
Heat Transport Section

- Coolant recirculator assembly
- Pump
- Low-temperature electronics
- Aft equipment bay electronics
- Ascent batteries
- Descent batteries
- Coolant accumulator
- Suit heat exchanger
- Suit water cooling assembly
- Suit regenerative heat exchanger
- Primary sublimator
- Secondary sublimator
- To coolant recirculator assembly

R denotes redundant component

Heat Transport Section
Heat Transport Section

- Coolant recirculator assembly
- Low-temperature electronics
- Aft equipment bay electronics
- Primary sublimator
- Secondary sublimator
- Ascent batteries
- Descent batteries
- Coolant accumulator
- Suit heat exchanger
- Suit water cooling assembly
- R denotes redundant component
Overview of LM ECS

Heat Transport Section

- Coolant recirculator assembly
- Pump
- Low-temperature electronics
- Aft equipment bay electronics
- Ascent batteries
- Descent batteries
- Coolant accumulator
- Secondary sublimator
- Primary sublimator
- Suit regenerative heat exchanger
- Suit water cooling assembly
- Suit heat exchanger

R denotes redundant component

Heat Transport Section
Overview of LM ECS

Heat Transport Section

- Coolant recirculator assembly
- Pump
- Suit heat exchanger
- Suit water cooling assembly
- Primary sublimator
- Secondary sublimator
- Ascent batteries
- Descent batteries
- Coolant accumulator
- To coolant recirculator assembly

R denotes redundant component
Generic Design Considerations

- Reliability
- Flight Instrumentation
- Modularization
- The change from fuel cells to batteries

Conrad & Bean
Generic Design Considerations -- Reliability

◆ Reliability

Aldrin
Generic Design Considerations -- Reliability

“Perfect” is the enemy of “good enough”
Generic Design Considerations -- Reliability

- “Perfect” is the enemy of “good enough”
- Redundancy
Generic Design Considerations -- Reliability

- “Perfect” is the enemy of “good enough”
- Redundancy
  - Cause & effect analysis vs. mean time to failure
Generic Design Considerations -- Reliability

- "Perfect" is the enemy of "good enough"
- Redundancy
- Cause & effect analysis vs. mean time to failure
  ➔ Shelf-life control
Generic Design Considerations -- Reliability

- “Perfect” is the enemy of “good enough”
- Redundancy
- Cause & effect analysis vs. mean time to failure
- Shelf-life control

➡ Failure reporting
Generic Design Considerations - Flight Instrumentation

- Reliability
- Flight Instrumentation
Generic Design Considerations – Flight Instrumentation

◆ Minimum needed to monitor performance
Generic Design Considerations - Flight Instrumentation

- Minimum needed to monitor performance
  - Control position telemetry switches
Generic Design Considerations – Flight Instrumentation

- Minimum needed to monitor performance
  - Control position telemetry switches
  - Most not needed
Generic Design Considerations – Flight Instrumentation

- Minimum needed to monitor performance
  - Control position telemetry switches
    - Most not needed
  - Switch plunger travel length
Generic Design Considerations – Flight Instrumentation

- Minimum needed to monitor performance
  - Control position telemetry switches
    - Most not needed
  - Switch plunger travel length
Generic Design Considerations – Flight Instrumentation

- Minimum needed to monitor performance
  - Control position telemetry switches
    - Most not needed
    - Switch plunger travel length
  - Difficult to install
Generic Design Considerations – Flight Instrumentation

- Minimum needed to monitor performance
  - Control position telemetry switches
    - Most not needed
    - Switch plunger travel length
  - Difficult to install
Generic Design Considerations - Modularization

- Reliability
- Flight Instrumentation

◆ Modularization

Armstrong
Generic Design Considerations - Modularization

→ Modularized by subsystem
Generic Design Considerations - Modularization

- Modularized by subsystem
  ➛ Dense packaging
Generic Design Considerations - Modularization

- Modularized by subsystem
- Dense packaging

→ Replacement in the field
Generic Design Considerations -
The Change to Batteries

- Reliability
- Flight Instrumentation
- Modularization

◆ The change from fuel cells to batteries
Generic Design Considerations - The Change to Batteries

→ Change to high pressure oxygen vs. LOX
Change to high pressure oxygen vs. LOX

→ Very high pressure/high capacity O2 tank in descent stage
Generic Design Considerations - The Change to Batteries

- Change to high pressure oxygen vs. LOX
- Very high pressure/high capacity O₂ tank in descent stage

⇒ Staging and cutter assemblies (guillotine)
Generic Design Considerations - The Change to Batteries

- Change to high pressure oxygen vs. LOX
- Very high pressure/high capacity O2 tank in descent stage
- Staging and cutter assemblies (guillotine)

→ Interstage quick disconnects (QDs)
- Cutoff valves not needed, as will automatically seal
- Cutoff valves not needed, as will automatically seal

- No retention mechanism
Generic Design Considerations - QDs

- Cutoff valves not needed, as will automatically seal
- No retention mechanism
- No risk of impact ignition
Generic Design Considerations - The Change to Batteries

- Change to high pressure oxygen vs. LOX
- Very high pressure/high capacity O2 tank in descent stage
- Staging and cutter assemblies (guillotine)
  - Interstage quick disconnects (QDs)

→ Original design
Generic Design Considerations - Original QDs

Ascent stage

Descent stage

Original design of interstage disconnect
Poppet seal was on the ascent stage portion
Exterior leak path seal was on the descent stage portion
Redundant seal was needed on the glycol loop because it leaked. Not needed on the oxygen QD.
Very susceptible to installation damage
- Very susceptible to installation damage
- External leak path seal can impact here
- Very susceptible to installation damage
- Poppet seal can be impacted by head of descent stage portion
Generic Design Considerations -
The Change to Batteries

- Change to high pressure oxygen vs. LOX
- Very high pressure/high capacity O2 tank in descent stage
- Staging and cutter assemblies (guillotine)
- Interstage quick disconnects (QDs)
  - Original design
  - Final design
Generic Design Considerations - Final QDs

Final design of interstage disconnect
Built in redundancy
Built in redundancy

Generic Design Considerations - Final QDs
Generic Design Considerations - Final QDs

Built in redundancy

- Primary poppet seal
- Secondary poppet seal
- Primary exterior leak path seal
- Secondary exterior leak path seal

Ascent stage
Descent stage

Final design of interstage disconnect
- Highly resistant to installation damage

The poppet seals are protected behind metal
Better protection to the sealing surfaces

Exterior leak path seals embedded in grooves
Upon completion of this part of the lesson, the student will be able to:

- Describe the Lunar Module (LM) Environmental Control System (ECS) generic design considerations philosophy.

- Summarize the LM ECS general testing regime.
General Testing -- Feasibility

◆ Feasibility
General Testing -- Feasibility

🔹 Feasibility

⇒ Original concept to use pre-production hardware
Feasibility

- Original concept to use pre-production hardware
- Tests conducted on component, logic group, and system levels
Feasibility

- Original concept to use pre-production hardware
- Tests conducted on component, logic group, and system levels

- Pre-production hardware very much resembled eventual production hardware, reducing the need for design verification testing
General Testing - Design Verification

- Feasibility
- Design verification
General Testing - Design Verification

- Design verification
  ➔ Performance
General Testing - Design Verification

- Design verification
  - Performance
  - Structural
General Testing - Design Verification

- Design verification
  - Performance
  - Structural
  - Leakage/stability
General Testing - Design Verification

- Design verification
  - Performance
  - Structural
  - Leakage/stability
  - Endurance
General Testing -- Qualification

- Feasibility
- Design verification
- Qualification
General Testing -- Qualification

- Qualification
  - Design limit testing
General Testing -- Qualification

- Qualification
  - Design limit testing
  - EMI
General Testing -- Qualification

- Qualification
  - Design limit testing
  - EMI
  - Vibration
General Testing -- Qualification

- Qualification
  - Design limit testing
  - EMI
  - Vibration
  ➔ Functional
General Testing -- Qualification

- Qualification
  - Design limit testing
  - EMI
  - Vibration
  - Functional
  - Endurance
General Testing -- Qualification

- Qualification
  - Design limit testing
  - EMI
  - Vibration
  - Functional
  - Endurance
- Integration and checkout
General Testing - Man Rating

- Feasibility
- Design verification
- Qualification

◆ Integrated Subsystems & Vehicle (Man-Rating)
General Testing - Man Rating

- Integrated Subsystems & Vehicle (Man-Rating)
  ➔ Unmanned
General Testing - Man Rating

- Integrated Subsystems & Vehicle (Man-Rating)
  - Unmanned
  - Manned (contractor)
General Testing – Man Rating

- Integrated Subsystems & Vehicle (Man-Rating)
  - Unmanned
  - Manned (contractor)
  - Manned (astronauts)
General Testing - Man Rating

- Integrated Subsystems & Vehicle (Man-Rating)
  - Unmanned
  - Manned (contractor)
  - Manned (astronauts)
- Special
General Testing - Thermal Vacuum

- Feasibility
- Design verification
- Qualification
- Integrated Subsystems & Vehicle (Man-Rating)
  - Thermal-vacuum
General Testing - Thermal Vacuum

- Thermal-vacuum
  - LTA-8 cold case
General Testing - Thermal Vacuum

- Thermal-vacuum
  - LTA-8 cold case
  - LTA-8 hot case
General Testing - Thermal Vacuum

- Thermal-vacuum
  - LTA-8 cold case
  - LTA-8 hot case
  - LTA-8 lunar landing sim
General Testing - Vehicle and Acceptance

- Feasibility
- Design verification
- Qualification
- Integrated Subsystems & Vehicle (Man-Rating)
- Thermal-vacuum

◆ Vehicle and Acceptance
Review of Objectives

- Describe the Lunar Module (LM) Environmental Control System (ECS) generic design considerations philosophy.

- Summarize the LM ECS general testing regime.
Apollo Experience Report – Lunar Module Environmental Control Subsystem

Wiki on this website: http://modspops.jsc.nasa.gov/mod/DA4/CxTraining/Apollo/Apollo%20Wiki/Home.aspx

More references found under link below