Environmental Control and Life Support System (ECLSS)

System Engineering Workshop

Life Sciences Department

ISU SSP 2009

Ames Research Center, USA
Agenda

• Recap SSP09 Lecture on ECLSS
  ✓ ECLS Subsystems
  ✓ Non Regenerative (Backpacking) vs. Regenerative
    • Open loop vs. Closed Loop
    • Physical-chemical vs. Bioregenerative
  ✓ Equivalent System Mass (ESM)
    • Applications for ECLS subsystem design

• US Spacecraft ECLS Subsystem component description
  ✓ Mercury, Gemini, Apollo, Skylab, Shuttle, ISS, CEV, LL, LO
    • Detail Air Revitalization, Pressure Control, and Water

• Team Projects
  ✓ Split into 4 teams ➔ Shop at “ECLS-mart” ➔ Determine ESM
    • 2 teams with Mission Scenario #1
    • 2 teams with Mission Scenario #2
  ✓ Out brief ESM to Department and discuss variations
The Human “Box”

- Mass/Energy Balance around a Human Being

**Food**
- Solid: ~0.620 kg/p/day

**Water**
- Liquid: ~3.530 kg/p/day

**Oxygen**
- Gas: ~0.830 kg/p/day

**Fecal**
- Solid: ~0.110 kg/p/day

**Urine/Sweat**
- Liquid: ~3.870 kg/p/day

**Respiration**
- Gas: ~0.830 kg/p/day

**CO2 + O2**
- Gas: ~1.130 kg/p/day

**Regulation (Metric)**
- Temp & Humidity: ~18°C - ~27°C
- Water Input: ~25% - ~75% H2O

**Atmospheric Composition**
- Ptot: 51711 Pa < Ptot ≤ 103421 Pa
- ppO2: 128 mm Hg < ppO2 ≤ 178 mm Hg
- ppCO2: ≤ 5 mm Hg

**Regulation (English)**
- Temp & Humidity: ~64°F - ~81°F
- Water Input: ~25% - ~75% H2O

**Atmospheric Composition**
- Ptot: 7.5 psia < Ptot ≤ 15.0 psia
- ppO2: 2.48 psia < ppO2 ≤ 3.44 psia
- ppCO2: ≤ 0.096 Hg
Recap on ECLSS (1/4)

You already learned...

- **Why we need ECLSS?** → To **SUSTAIN human life and workability**
- **Main Subsystems (Functions) of ECLSS**
  - Atmosphere Revitalization and/or Pressure Control Subsystem (ARS, ACS, or PCS)
    - CO₂ and trace gas removal
    - Pressure control (gas storage, relief valves, introduction valves, pressure gages)
    - Atmospheric constituents monitoring (O₂, N₂, H₂O, CO₂, trace gasses)
    - Forced convection air flow
  - Potable Water Recovery and Management Subsystem (PWS or WRM)
    - Potable water processing and/or storage
    - Alternate water processing and/or storage
    - Water quality monitoring (TOC, pH, Microbiology)
  - Temperature and Humidity Control (THC)
    - Depending on vehicle, may be performed with ARS + Active Thermal Control Subsystem
    - Atmospheric control of temperature and humidity with heat exchanger and forced convection
    - Passive equipment cooling (via cabin airflow)
  - Waste Management and/or Collection Subsystem (WMS or WCS)
    - Human waste management – solid, liquid, and gas separation
  - Fire Detection and Emergency Management Subsystem (FDS)
    - Smoke detectors, fire extinguishers, portable breathing masks
    - Strategy for cabin fire, chemical release, and/or depressurizing cabin
Recap on ECLSS (2/4)

You already learned...(continued)

- **Non Regenerative / Open Loop**
  - Backpacking mission (high consumables / resupply usage)
  - Simple, reliable
  - Resources are linearly dependent on flight time

- **Regenerative / Closed Loop**
  - Recycling of resources (low consumables / resupply usage)
  - Minimized overboard losses
  - Increased power, thermal, and initial mass requirements
  - Lower reliability, based on higher complexity
  - Trade off for closed loop occurs for missions of ~3 months in duration
    - Varies dependent on number of crew, spacecraft volume, in situ resources, etc.

- **“Physical – chemical – mechanical”**
  - Uses physical, chemical, and mechanical devices for ECLS processing

- **Bioregenerative**
  - Uses living organisms to produce or break down organic molecules for ECLS processing
  - “Put the Earth in a little box” so we can go somewhere else
Recap on ECLSS (3/4)

- You already learned...(continued)
  - One of many analysis tools used to trade spacecraft system optimization is...
  - **Equivalent System Mass (ESM)**
    - Evaluates trade study options for spacecraft life support systems
    - Identifies which option meets all the requirements while providing the lowest launch cost
      - Mass
      - Volume
      - Power
      - Cooling
      - Crew Time
    - Provides a ‘total system impact’ for comparison in overall vehicle life support system selection
You already learned...(continued)

- \( ESM = M + \left( V \cdot V_{eq} \right) + \left( P \cdot P_{eq} \right) + \left( C \cdot C_{eq} \right) + \left( CT \cdot D \cdot CT_{eq} \right) \)

where \( ESM \) = the equivalent system mass value of the system of interest [kg],

- \( M \) = the total mass of the system [kg],
- \( V \) = the total pressurized volume of system \([m^3]\),
- \( V_{eq} \) = the mass equivalency factor for the pressurized volume infrastructure \([kg/m^3]\),
- \( P \) = the total power requirement of the system \([kW_e]\),
- \( P_{eq} \) = the mass equivalency factor for the power generation infrastructure \([kg/kW_e]\),
- \( C \) = the total cooling requirement of the system \([kW_{th}]\),
- \( C_{eq} \) = the mass equivalency factor for the cooling infrastructure \([kg/kW_{th}]\),
- \( CT \) = the total crewtime requirement of the system \([CM-h/y]\),
- \( D \) = the duration of the mission segment of interest \([y]\),
- \( CT_{eq} \) = the mass equivalency factor for the crewtime support \([kg/CM-h]\)
US Spacecraft ECLSS – Mercury (1960-1963)

- First flight – May 5th, 1961, Alan Shepard, 15 min sub-orbital flight
- Six total manned flights with 1 crewmember
  - Longest was 34 hours, 19 minutes, 49 seconds
- Crewmembers wore suit for duration of flight
  - Suit revitalized atmosphere, controlled temperature & relative humidity
- Spacesuit normally unpressurized during flight
  - If necessary, crewmember could pressurize suit by closing visor
- Pressurized Volume = 1.56m³

<table>
<thead>
<tr>
<th>Subsystem Feature</th>
<th>Air Revitalization (CO₂ Removal)</th>
<th>Pressure Control</th>
<th>Potable Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>CO₂ chemically removed with consumable</td>
<td>Stored O₂ Atmosphere: 100% O₂ @ 34.5kPa (5psia)</td>
<td>Stored H₂O Disinfection by residual chlorine</td>
</tr>
<tr>
<td>Hardware (kg)</td>
<td>Lithium Hydroxide (LiOH) parallel (redundant) path</td>
<td>O₂ in 2 x 1.8kg Ni plated tanks at 51.7MPa (7500psia)</td>
<td>6lb Bladder tank back pressurized via squeeze bulb</td>
</tr>
</tbody>
</table>

- Two unmanned flights + Ten manned flights
  - Manned flights were ~5 hours to ~14 days
  - Two crewmembers on each flight
  - Crewmembers again wore suits for the duration of the flight
    - Air revitalization, temperature, and humidity controlled separately in suit and in cabin
  - Improvements to life support system vs. Mercury
    - Supercritical O2 storage vs. high pressure
    - Integrated heat exchanger + water separator
    - Modularity in components for easier in-flight maintenance

- Pressurized Volume = 2.26m$^3$

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<tr>
<td>Method</td>
<td>CO2 chemically removed with consumable</td>
<td>Stored O2 Atmosphere: 100% O2 @ 34.5kPa (5psia)</td>
<td>Stored H2O Cl biocide added prelaunch</td>
</tr>
<tr>
<td>Hardware (kg)</td>
<td>Lithium Hydroxide (LiOH) parallel (redundant) path</td>
<td>Supercritical cryogenic O2 in 1 spherical tank at 5.86MPa (850psia)</td>
<td>Bladder tank back pressurized with O2</td>
</tr>
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</table>
US Spacecraft ECLSS – Apollo (1968 – 1972)

- Eleven crewed missions
  - Two Earth orbiting & two Lunar orbiting
  - One Lunar “swing by”
  - Six Lunar landings

- Apollo missions split into two sections
  - **Command and Service Module (CSM)**
    - Transported crew of 3 from Low Earth Orbit (LEO) to Low Lunar Orbit (LLO) and back to Earth
    - SM unpressurized with water, gas, electrical, etc.
    - Similar to CEV Crew Module (CM) & Service Module (SM)
  - **Lunar Excursion Module (LEM) or Lunar Module (LM)**
    - Ferried two crewmembers to the lunar surface and back to CSM
  - Both contained separate life support systems
US Spacecraft ECLSS – Apollo (CSM)

- **CSM Life Support**
  - Capable of providing life support for 3 crewmembers for 14 days
  - Fuel cells provided energy + drinking water
  - Oxygen tanks in SM fed CM for crew consumption as well as fuel cells

- **Pressurized volume = 5.9m³**

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<tr>
<td>Method</td>
<td>CO2 chemically removed with consumable</td>
<td>Stored O2 Atmosphere: 100% O₂ @ 34.5kPa (5psia)</td>
<td>Fuel cell provided + Cl biocide added daily</td>
</tr>
<tr>
<td>Hardware (kg)</td>
<td>Lithium Hydroxide (LiOH) parallel (redundant) path</td>
<td>Supercritical cryogenic O₂ in 2 x 145kg spherical Inconel Dewar tanks at 6.20MPa (900psia)</td>
<td>Al alloy tank with polyisoprene bladder, back pressurized w/ O₂</td>
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US Spacecraft ECLSS – Apollo (LEM)

- Allowed 12 astronauts to walk on the surface of the moon
  - 2 crewmembers
  - Pressurized volume = 4.5m³

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<td>Method</td>
<td>CO₂ chemically removed with consumable</td>
<td>Stored O₂ Atmosphere: 100% O₂ @ 34.5kPa (5psia)</td>
<td>Stored H₂O with iodine biocide (Cl corrosion concerns) added via “MCV”</td>
</tr>
<tr>
<td>Hardware (kg)</td>
<td>Lithium Hydroxide (LiOH) parallel (redundant) path</td>
<td>Descent: compressed O₂ at 18.6MPa (2700psia) Ascent: Supercritical cryogenic O₂ in Inconel bottles at 5.86MPa (850psia)</td>
<td>3 tanks (1 descent, 2 ascent) silicone rubber bladder</td>
</tr>
</tbody>
</table>

- First U.S. Space Station (pressurized volume = 361m³)
  - Study effects of long-duration space flight on humans
  - Three Skylab missions of 28, 59, and 84 days
  - 3 crewmembers on each mission

- Skylab life support (updates)
  - Added a 2 canister molecular sieve vs. LiOH
  - Method for monitoring water biocide (iodine) in-flight
  - UV smoke detectors

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<tr>
<td>Method</td>
<td>Partially closed loop (some overboard loss) CO2 chemically removed via regenerative source</td>
<td>Stored O2/N2 Atmosphere: Mixed 72%O2 / 28%N2 @ 5psia (34.5kPa)</td>
<td>Stored H2O (iodine biocide, added in-flight, but removed prior to drinking)</td>
</tr>
<tr>
<td>Hardware (kg)</td>
<td>2 canister molecular sieve, regenerative Zeolite combination adsorbs CO2 + H2O &amp; desorbs when exposed to vacuum</td>
<td>O2/N2 stored in gaseous form @ 3000psia (20.7MPa) in bottles</td>
<td>10 stainless steel metal bellows tanks back pressurized with N2</td>
</tr>
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</table>

- 4 – 7 crewmembers per mission
- Varying mission durations of ~14 days
  - Early missions were ~4 days, and missions have been as long at 18 days.
- Always Low Earth Orbit Operations
- Pressurized Volume = 132m³

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<td>Method</td>
<td>CO₂ chemically removed with consumable</td>
<td>Stored O₂/N₂ Atmosphere: Mixed 21.7%O₂ / 78.3%N₂ @ 14.7psia (101kPa)</td>
<td>Stored H₂O (iodine biocide, added pre-flight, and during with MCV, but removed prior to drinking)</td>
</tr>
<tr>
<td>Hardware (kg)</td>
<td>Lithium Hydroxide (LiOH) parallel (redundant) path</td>
<td>O₂/N₂ stored in gaseous form @ 3300psia (22.8MPa) in bottles. 4N₂ tanks, O₂ cryogenic storage.</td>
<td>4 stainless steel metal bellows tanks back pressurized with N₂</td>
</tr>
</tbody>
</table>

- Crewed since Oct 31st, 2000
- Currently provide life support for 6 person crew
- US Operating Segment designated “National Laboratory”
- 6 month expeditions (current human limit requirement)
- Pressurized Volume = 711 m$^3$ (as of July 2009)

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<td>Method</td>
<td>Partially closed loop (some overboard loss) CO2 chemically removed</td>
<td>Atmosphere: Mixed 21.7%O2 / 78.3%N2 @ 14.7psia (101kPa)</td>
<td>Stored water (iodine or AgF biocide) or processed via WPA/UPA</td>
</tr>
<tr>
<td>Hardware (kg)</td>
<td>4 bed molecular sieve with 2 regenerative Zeolite beds to remove CO2, desorbed with heat and pressure</td>
<td>Oxygen @ max 3000psia for EVAs or generated with Oxygen Generation Assembly (electrolysis)</td>
<td>Stored in WPA tanks fed to the US water bus or stored in collapsible containers (CWCs/PWRs)</td>
</tr>
</tbody>
</table>

- **Initial Operational Capability, ~2015**
- **Similar split to Apollo**
  - CM = Crew Module (pressurized volume 15.6m³ [~550cu ft])
  - SM = Service Module (unpressurized, storage volume)
- **ISS mission**
  - Expected 4 person crew to ISS with 6 months quiescent operations + ~6 days maximum active crew time
- **Lunar mission ~2020**
  - ~21 days maximum active crew time + ~6 months quiescent operations during lunar habitation

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<tr>
<td>Method</td>
<td>Partially closed loop (some overboard loss) CO₂ chemically removed</td>
<td>Mixed O₂/N₂ @ 14.7psia – ISS, ~10.2psia – lunar</td>
<td>Stored water (baselined AgF biocide)</td>
</tr>
<tr>
<td>Hardware (kg)</td>
<td>Regenerative pressure swing assembly w/ solid amine adsorbs CO₂ + H₂O &amp; desorbs when exposed to vacuum</td>
<td>O₂/N₂ stored @ ~5000psia in Composite Overwrap Pressure Vessels</td>
<td>~5 Inconel bellows tanks in service module</td>
</tr>
</tbody>
</table>
US Spacecraft ECLSS Altair/Lunar Lander (~2020)

- **Initial Operational Capability, ~2020**
- **Lunar sortie (~8 days on the Moon)**
  - Expected 4 person crew on CEV to the Moon, with ~8 days active operations in Altair/Lunar Lander
  - No support from pre-positioned surface assets, primarily suited operations
- **Lunar habitation (~6 months on the Moon)**
  - 4 person crew on CEV to the Moon, with ~6 months active operations on the moon (mixed between Lunar Lander and Lunar Outpost)

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<tr>
<td>Method</td>
<td>CO2 chemically removed with consumable</td>
<td>Stored O2/N2 Atmosphere: Mixed O2/N2 @ ~10.2psia</td>
<td>Stored water</td>
</tr>
<tr>
<td>Hardware (kg)</td>
<td>Lithium Hydroxide (LiOH) parallel (redundant) path</td>
<td>N2/O2 stored in descent stage Only O2 stored in ascent stage</td>
<td>Expected in suit drink bag</td>
</tr>
</tbody>
</table>
US Spacecraft ECLSS Lunar Outpost (TBD)

- Initial Operational Capability, TBD
- Lunar habitation (~6 months on the Moon)
  - 4 person crew on CEV to the Moon, with ~6 months active operations on the moon (mixed between Lunar Lander and Lunar Outpost)
  - Expected to include power, habitats, surface mobility (LER), and resource utilization
- Opportunity for closed loop, bioregenerative life support
  - Will most likely stage the approach
  - Initial capability/construction (similar to Altair life support)
  - Interim capability/construction physical/chemical life support (similar to ISS but relying on 1/6 g)
  - Final capability/sustaining bioregenerative mixed with physical/chemical
Team Projects

Split into teams of 4 (count off)

- **2 teams = Mission Scenario #1**
  - 6 crewmembers, 30 days, 0 g, pressurized volume
    - $V_{eq} =$
    - $P_{eq} =$
    - $C_{eq} =$
    - $C_{eq} =$

- **2 teams = Mission Scenario #2**
  - 4 crewmembers, 180 days, Lunar Gravity (1/6 g), pressurized volume
    - $V_{eq} =$
    - $P_{eq} =$
    - $C_{eq} =$
    - $C_{eq} =$
  - No Discussion between teams with the same scenarios

Assumptions

- All infrastructure is the same (not included in ESM calculation)
  - Ducts, pipes, crew interfaces, power interface, etc.
References (1/2)

- Constellation Program (CxP) document 70024 Rev C, “Human-Systems Integration Requirements”
- ISU SSP 2008 Presentation by Dr. Douglas Hamilton, “Environmental Control and Life Support”
References (2/2)

- ISU SSP 2008 Presentation by Dr. N. Tolyarenko, “Environmental Control and Life Support System”
- ISU SSP 2009 Presentation by Dr. Angie Buckley and Dr. Gilles Clement, “Life Support Systems during Space Missions”