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Environmental Control and Life Support System (ECLSS)

System Engineering Workshop

Life Sciences Department

ISU SSP 2009

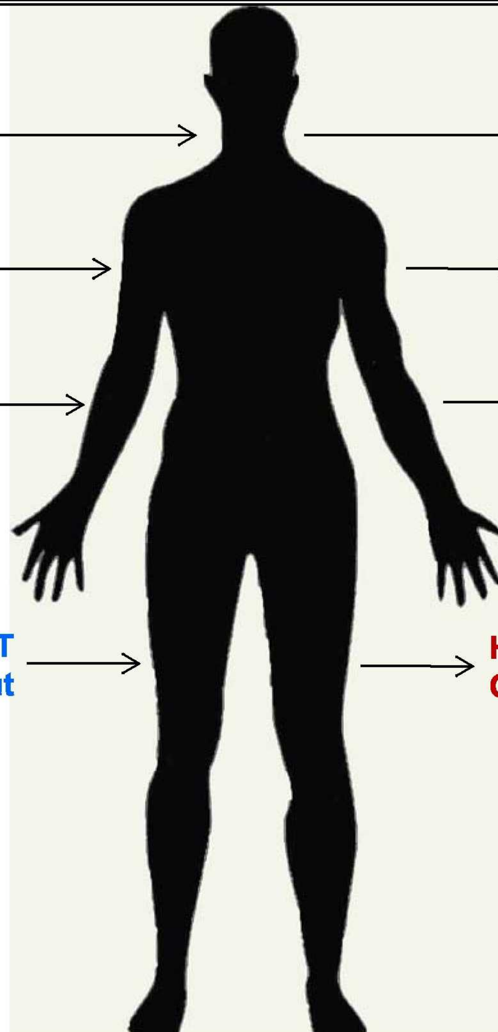
Ames Research Center, USA

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



Input			Output		
SOLID	FOOD	~0.620kg/p/day	FECAL	~0.110kg/p/day	*SOLID*
LIQUID	WATER	~3.530kg/p/day	URINE/SWEAT/ RESPIRATION	~3.870kg/p/day	*LIQUID*
GAS	OXYGEN	~0.830kg/p/day	CO2 + O2	~1.130kg/p/day	*GAS*

HEAT Input → → HEAT Output

REGULATION (Metric)

Temp & Humidity

~18°C - ~ 27°C

~25 %- ~75% H_2O

Atmospheric Composition

51711Pa < P tot ≤ 103421Pa

128mm Hg < ppO_2 ≤ 178mm Hg

≤ 5mm Hg $ppCO_2$

REGULATION (English)

Temp & Humidity

~64°F - ~ 81°C

~25 %- ~75% H_2O

Atmospheric Composition

7.5psia < P tot ≤ 15.0psia

2.48psia< ppO_2 ≤ 3.44psia

≤ .096 Hg $ppCO_2$

Recap on ECLSS (1/4)

❑ You already learned…

- **<u>Why we need ECLSS?</u>** → ***To SUSTAIN human life and workability***
- **<u>Main Subsystems (Functions) of ECLSS</u>**
  - ✓ Atmosphere Revitalization and/or Pressure Control Subsystem (ARS, ACS, or PCS)
    - CO_2 and trace gas removal
    - Pressure control (gas storage, relief valves, introduction valves, pressure gages)
    - Atmospheric constituents monitoring (O_2, N_2, H_2O, CO_2, 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 seperation
  - ✓ 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

Recap on ECLSS (4/4)

❑ You already learned…(continued)

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

  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]* [6]*,*
  - P_{eq}= *the mass equivalency factor for the power generation infrastructure [kg/kW_e],*
  - C = *the total cooling requirement of the system [kW_{th}]* [7]*,*
  - 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 = 1.56m^3

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

US Spacecraft ECLSS – Gemini (1964 – 1966)

- **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**

Subsystem Feature	***Air Revitalization (CO2 Removal)***	***Pressure Control***	***Potable Water***
Method	CO2 chemically removed with consumable	Stored O2 Atmosphere: 100% O2 @ 34.5kPa (5psia)	Stored H2O Cl biocide added prelaunch
Hardware (kg)	Lithium Hydroxide (LiOH) parallel (redundant) path	Supercritical cryogenic O2 in 1 spherical tank at 5.86MPa (850psia)	Bladder tank back pressurized with O2

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 = 5.9m^3**

Subsystem Feature	*Air Revitalization (CO2 Removal)*	*Pressure Control*	*Potable Water*
Method	CO2 chemically removed with consumable	Stored O2 Atmosphere: 100% O2 @ 34.5kPa (5psia)	Fuel cell provided + Cl biocide added daily
Hardware (kg)	Lithium Hydroxide (LiOH) parallel (redundant) path	Supercritical cryogenic O2 in 2 x 145kg spherical Inconel Dewar tanks at 6.20MPa (900psia)	Al alloy tank with polyisoprene bladder, back pressurized w/ O2

US Spacecraft ECLSS – Apollo (LEM)

- Allowed 12 astronauts to walk on the surface of the moon
  - 2 crewmembers
  - Pressurized volume = 4.5m^3

Subsystem Feature	*Air Revitalization (CO2 Removal)*	*Pressure Control*	*Potable Water*
Method	CO_2 chemically removed with consumable	Stored O_2 Atmosphere: 100% O_2 @ 34.5kPa (5psia)	Stored H_2O with iodine biocide (Cl corrosion concerns) added via "MCV"
Hardware (kg)	Lithium Hydroxide (LiOH) parallel (redundant) path	*Descent*: compressed O_2 at 18.6MPa (2700psia) *Ascent*: Supercritical cryogenic O_2 in Inconel bottles at 5.86MPa (850psia)	3 tanks (1 descent, 2 ascent) silicone rubber bladder

US Spacecraft ECLSS – Skylab (1973 – 1974)

- **First U.S. Space Station (pressurized volume = 361m^3)**
  - **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**

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

US Spacecraft ECLSS – Shuttle (1981 – present)

- 4 – 7 crewmembers per mission
- Varying mission durations of ~14days
  - Early missions were ~4 days, and missions have been as long at 18days.
- Always Low Earth Orbit Operations
- Pressurized Volume = 132m^3

Subsystem Feature	*Air Revitalization (CO2 Removal)*	*Pressure Control*	*Potable Water*
Method	CO_2 chemically removed with consumable	Stored O_2/N_2 Atmosphere: Mixed 21.7%O_2 / 78.3%N_2 @ 14.7psia (101kPa)	Stored H_2O (iodine biocide, added pre-flight, and during with MCV, but removed prior to drinking)
Hardware (kg)	Lithium Hydroxide (LiOH) parallel (redundant) path	O_2/N_2 stored in gaseous form @ 3300psia (22.8MPa) in bottles. 4N_2 tanks, O_2 cryogenic storage.	4 stainless steel metal bellows tanks back pressurized with N_2

US Spacecraft ECLSS – USOS ISS (2000 – present)

- **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 = 711m^3 *(as of July 2009)***

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

US Spacecraft ECLSS Orion/CEV (~2015)

- Initial Operational Capability, ~2015
- Similar split to Apollo
  - CM = Crew Module (pressurized volume 15.6m^3 [~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

Subsystem Feature	Air Revitalization (CO2 Removal)	Pressure Control	Potable Water
Method	Partially closed loop (some overboard loss) CO2 chemically removed	Mixed O2/N2 @ 14.7psia – ISS, ~10.2psia – lunar	Stored water (baselined AgF biocide)
Hardware (kg)	Regenerative pressure swing assembly w/ solid amine adsorbs CO2 + H20 & desorbs when exposed to vacuum	O2/N2 stored @ ~5000psia in Composite Overwrap Pressure Vessels	~5 Inconel bellows tanks in service module

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)

Subsystem Feature	Air Revitalization (CO_2 Removal)	Pressure Control	Potable Water
Method	CO_2 chemically removed with consumable	Stored O_2/N_2 Atmosphere: Mixed O_2/N_2 @ ~10.2psia	Stored water
Hardware (kg)	Lithium Hydroxide (LiOH) parallel (redundant) path	N_2/O_2 stored in descent stage Only O_2 stored in ascent stage	Expected in suit drink bag

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
    - Veq=
    - Peq=
    - Ceq=
    - $CTeq$=
- 2 teams = Mission Scenario #2
  - ✓ 4 crewmembers, 180 days, Lunar Gravity (1/6 g) , pressurized volume
    - Veq=
    - Peq=
    - Ceq=
    - $CTeq$=
- **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.

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