Environmental Control and Life Support System Evolution

Paul Wieland
Life Support Branch/ED62

Environmental Control And Life Support System Evolution

I. Introduction: Space Station *Freedom* Evolution Impact on the ECLSS

The Space Station *Freedom* Environmental Control and Life Support System (ECLSS) will have to accommodate the changes to *Freedom* as it evolves over the design life of 30 years or more. Requirements will change as pressurized modules are added, crew numbers increase, and as the tasks to be performed change. This evolution will result in different demands on the ECLSS and the ECLSS will have to adapt. Technologies other than the baselined ones may be better able to perform the various tasks and technological advances will result in improved life support hardware having better performance, increased reliability, reduced power consumption, weight, and volume, greater autonomy, and fewer resupply requirements. A preliminary study was performed to look at alternative technologies for life support and evaluate them for their integration requirements, focusing on the fluid line interface requirements. (A follow–on study will expand greatly on the scope of this preliminary study.) The integration requirements of the alternative technologies may be different from those of the baselined technologies. If this is the case, then by designing the initial space station to have the necessary fluid lines, etc. required by the selected alternative technologies then the task of replacing the baselined ones will be greatly simplified, thereby reducing the cost in on–orbit time as well as dollars.

Space Station *Freedom* Evolution Impact on the ECLSS

- Space Station *Freedom* will evolve over its 30 year or more lifetime, as pressurized modules are added, crew numbers increase, and as the tasks to be performed change.

- Requirements placed on the ECLSS will also change.

- During this time technological advances will lead to improved life support hardware which is better able to meet the new requirements.

- Replacing the initial hardware with the improved technologies will be simplified if the integration requirements of the improved technologies are built into the initial *Freedom* design.

- To better understand the integration requirements a preliminary study was performed to identify the fluid line interface requirements of the advanced technologies most likely to replace the initial technologies.

This page intentionally blank.

Advanced ECLSS Technology: Benefits and Integration Requirements

- Benefits of Advanced ECLSS Technologies:
  - Better performance
  - Increased reliability
  - Reduced power consumption, weight, and volume
  - Greater autonomy
  - Fewer resupply requirements
- Integration Requirements of Advanced ECLSS Technologies:
  - System-level integration needs
  - Fluid interface requirements
  - Electrical power requirements
  - Thermal control requirements
  - Control/data requirements
  - Resupply needs

II. Objectives of the Study

The objectives of the preliminary study were to provide answers to some basic questions:

(1) What requirements will be placed on the ECLSS in the future?
(2) How will these requirements differ from the initial *Freedom* ECLSS requirements?
(3) What constraints will affect the ECLSS?
(4) What technologies will be available to meet the future ECLSS requirements?
(5) What are the integration requirements of the alternative technologies?
(6) How do these integration requirements differ from those of the baselined ECLSS subsystems?
(7) What "scars" would facilitate transparent incorporation of the alternative technologies?

Objectives of the Study

The objectives of the preliminary study were to answer some basic questions:

(1) What requirements will be placed on the ECLSS in the future?

(2) How will these requirements differ from the initial *Freedom* ECLSS requirements?

(3) What constraints will affect the ECLSS?

(4) What technologies will be available to meet the future ECLSS requirements?

(5) What are the integration requirements of the alternative technologies?

(6) How do these integration requirements differ from those of the baselined ECLSS subsystems?

(7) What "scars" would facilitate transparent incorporation of the alternative technologies?

III. Approach Used

A two–part approach was used to identify the requirements placed on the future ECLSS and to identify and evaluate alternative technologies for their abilities to meet those needs.

A. Identification of Future ECLSS Requirements

The NASA documents which define the initial space station design and possible growth scenarios were reviewed for identification of the ECLSS requirements. These documents include: Space Station Program Definition and Requirements Document (PDRD) SSP 30000, Sec. 3; Space Station Mission Requirements Data Base (MRDB); the Space Station Systems Requirements Document, SS–SRD–0001, Sec. 3; MSFC Logistics System Evolution Study; and Growth Requirements for Multidiscipline Research and Development on the Evolutionary Space Station, NASA TM 101497.

From these documents groundrules and assumptions were derived and scenarios which are representative of the most likely evolution paths were identified. It was then possible to identify ECLSS associated constraints.

Two–Part Approach

- ○ Identify Future ECLSS Requirements
  - Review of NASA documents defining the space station design and growth scenarios
  - Derive groundrules and assumptions affecting the ECLSS
  - Identify scenarios representative of the most likely evolution paths
  - Identify constraints associated with the ECLSS
- ○ Identify and Evaluate Alternative Technologies
  - Define the ECLSS functions to be considered
  - Identify alternative technologies to perform those functions
  - Evaluate the integration requirements of the alternative technologies
  - Determine the "scars" needed to allow for easy replacement of the baseline technologies

1. Groundrules and Assumptions

The groundrules and assumptions used as a basis for the study are:

(1) The ECLSS will provide the capability to depressurize and repressurize all airlocks and hyperbaric airlocks, and will be responsible for makeup of gases lost during airlock operations.

(2) The ECLSS will be responsible for the supply of Extravehicular Mobility Unit (EMU) potable water, oxygen, and air, and for processing of the EMU CO_2, urine, and condensate water.

(3) The ECLSS will be responsible for animal habitat requirements [but the Process Materials Management System (PMMS) will be responsible for experiment (ultrapure) water].

(4) The ECLSS will be responsible for animal laboratory requirements [but the Fluid Management System (FMS) will be responsible for experiment makeup water].

(5) The ECLSS will grow by module, i.e., all full sized Lab and Hab modules will contain the same ECLSS equipment as the baseline.

(6) All pressurized elements (modules, resource nodes, airlocks, pocket labs, etc.) will contain Temperature and Humidity Control (THC) subsystems.

(7) Intermodule ventilation will use a series/parallel scheme, with the resource nodes serving as plenums for supplying air to the attached pressurized elements.

(8) EMU-type ECLSS support will be provided to all manned transfer vehicles.

Groundrules and Assumptions

The groundrules and assumptions used as a basis for the study are:

(1) The ECLSS will provide the capability to depressurize and repressurize all airlocks and hyperbaric airlocks, and will be responsible for makeup of gases lost during air-lock operations.

(2) The ECLSS will be responsible for the supply of Extravehicular Mobility Unit (EMU) potable water, oxygen, and air, and for processing of the EMU CO_2, urine, and condensate water.

(3) The ECLSS will be responsible for animal habitat requirements.

(4) The ECLSS will be responsible for animal laboratory requirements.

(5) The ECLSS will grow by module, i.e., all full sized Lab and Hab modules will contain the same ECLSS equipment as the baseline.

(6) All pressurized elements (modules, resource nodes, airlocks, pocket labs, etc.) will contain Temperature and Humidity Control (THC) subsystems.

(7) Intermodule ventilation will use a series/parallel scheme, with the resource nodes serving as plenums for supplying air to the attached pressurized elements.

(8) EMU–type ECLSS support will be provided to all manned transfer vehicles.

2. Representative Evolution Scenarios and ECLSS Associated Constraints

Two evolution scenarios, the Multi-Discipline Research Scenario and the Transportation Node Scenario, were used as a basis for defining the requirements that will be placed on the ECLSS in the future. Constraints affecting the ECLSS could then also be identified.

a. Multi-Discipline Research Scenario

The Multi-Discipline Research Scenario provides: "pressurized volume, payload attach points, crew time, electrical power and other essential resources to a diverse user community in support of their scientific research, technology development and commercial endeavors in space." (NASA TM 101497)

For this scenario the number of connected pressurized modules could increase to as many as 6 Lab modules and 3 Hab modules, with the necessary nodes to connect them and up to 3 pocket labs in addition. The crew size could increase to as many as 24 or more, to operate the experiments and operate and maintain *Freedom*.

It is expected that some experiments may require large amounts of EVA time occasionally, for example, during setup or servicing.

Multi–Discipline Research Scenario

- The Multi–Discipline Research Scenario provides: "pressurized volume, payload attach points, crew time, electrical power and other essential resources to a diverse user community in support of their scientific research, technology development and commercial endeavors in space." (NASA TM 101497)

- Features Affecting the ECLSS:
  - Up to 6 Lab modules, 3 Hab modules, nodes, and 3 pocket labs
  - Crew size: 24 or more
  - Large amounts of EVA time occasionally (during experiment setup or servicing)

b. Transportation Node Scenario

The Transportation Node Scenario is less well defined at this time. For this scenario *Freedom* serves as a waypoint for missions beyond Low Earth Orbit (LEO). Tasks to be performed include servicing of transfer vehicles, assembly of large spacecraft, and processing of returned payloads.

Large amounts of EVA time on a regular basis are associated with using *Freedom* as a transportation node. Using the present airlock design, a two-person EVA transfer would involve up to 10% air loss by volume per cycle. For servicing of the Lunar Transfer Vehicle (LTV), which would require up to 40 hours per day, about 10 pounds of resupply air per day are required.

One scenario for the transportation node includes an isolated Hab module remote from the main cluster, with two nodes and an airlock, for use by four crew members dedicated to vehicle buildup and servicing tasks.

Transportation Node Scenario

- The Transportation Node Scenario is less well defined at this time. For this scenario *Freedom* would serve as a waypoint for missions beyond low Earth orbit. Tasks to be performed include servicing of transfer vehicles, assembly of large spacecraft, and processing of returned vehicles and payloads.

- Features Affecting the ECLSS:
  - Large amounts of EVA time on a regular basis (up to 40 hours per day for servicing of the Lunar Transfer Vehicle)
  - Increased resupply of lost air and water

c. ECLSS Associated Constraints

There are various constraints associated with different growth scenarios. Critical factors which affect the ECLSS include available power, crew time for maintenance, launch mass (for resupply needs), and requirement for two–failure tolerance. Safe haven considerations require that, in an emergency, a single ECLS subsystem group be capable of supporting eight people. Module growth patterns may be limited by the IMV system. Increases in crew size and the number of modules are to maintain a 4:1 crew to US module ratio or an 8:1 crew to US Hab module ratio.

Constraints Affecting the ECLSS

- Critical factors affecting the ECLSS include:
    - Available power
    - Crew time for maintenance
    - Launch mass for resupply
    - Requirement for two–failure tolerance
- Safe haven requirements
- Module growth
    - Growth patterns may be limited by the Intermodule Ventilation system
    - A ratio of 4:1 crew members to number of U. S. modules, or 8:1 crew to U. S. Hab modules, is to be maintained

B. Identification and Evaluation of Alternative Technologies

Alternative technologies for each ECLSS task were identified and those that could be developed to perform the ECLSS tasks were evaluated for their integration needs. The fluid line interface needs were then compared with those of the baseline ECLSS and the "scars" required to permit replacement subsystems with alternative subsystems were identified.

1. ECLSS Functions Considered

The ECLSS consists of several tasks, each consisting of one or more functions: Air Revitalization, Water Recovery and Management, Atmosphere Control and Supply, Temperature and Humidity Control, Fire Detection and Suppression, and Waste Management. The ECLSS functions considered in this study are: CO_2 removal, CO_2 reduction, O_2 generation, trace contaminant control, urine recovery, potable water recovery, hygiene water recovery, and waste management.

ECLSS

Atmosphere Revitalization (AR)

- CO_2 Removal
- CO_2 Reduction
- O_2 Generation
- Contaminant Control and Monitoring

Water Recovery and Management (WRM)

- Urine Processing
- Hygiene Water Processing
- Potable Water Processing
- Water Storage and Distribution
- Water Thermal Conditioning
- Water Quality Monitoring

Fire Detection and Suppression (FDS)

Atmosphere Control and Supply (ACS)

- O_2/N_2 Storage and Distribution
- Vent and Relief
- O_2/N_2 Pressure Control

Temperature and Humidity Control (THC)

- Air Temperature Control
- Humidity Control
- Ventilation
- Equipment Air Cooling
- Thermally Conditioned Storage
- Refrigerator/Freezer

Waste Management (WM)

- Return Waste Storage
- Fecal Processing and Management

2. Identification of Alternative Technologies

Alternative technologies for the ECLSS tasks were identified by reviewing technical papers and reports (NASA and other) and through contacts with scientists and engineers working on ECLSS technology development.

3. Evaluation of the Integration Needs of Each Technology

After identifying the alternative technologies and developing a basic understanding of how each works or would work the next step was identification of the integration requirements, focusing on the fluid interface requirements.

4. Determination of the "Scars" Required for Each Technology

The fluid interface requirements of the new technologies were then compared with those of the baseline technologies and the ones not needed by the baseline technologies were identified. These then determine the required "scars."

Identification and Evaluation of Alternative Technologies

- Identification of Alternative Technologies
  - Literature search: review of technical papers and reports
  - Contacts with scientists and engineers working on ECLSS technology development
- Evaluation of the Integration Needs
  - Basic understanding of the alternative technologies
  - Identify the integration needs of each, focusing on the fluid interface requirements
- Determination of the Fluid Interface "Scars" Required
  - Compare the interfaces of the alternative and baseline technologies
  - The interfaces not required by the baseline technologies then determine what "scars" will be required

BASELINE ECLSS TECHNOLOGIES

The technologies baselined for the ECLSS functions are:

Function	Technology
CO_2 Removal	Four-Bed Molecular Sieve
CO_2 Reduction	Bosch Reactor
O_2 Generation	Static Feed Water Electrolysis
Potable Water Recovery	Multifiltration
Hygiene Water Recovery	Reverse Osmosis
Trace Contaminant Removal	Expendable Carbon Beds with Catalytic Oxidizer
Atmosphere Monitoring	Gas Chromatograph/Mass Spectrometer
Urine Recovery	Thermoelectric Integrated Membrane Evaporation System
Waste Management	Biodegradation Cup/Storage
Temperature and Humidity Control	Condensing Heat Exchanger
Fire Suppression	CO_2
Air Control and Supply	Cryogenic/High Pressure Storage

BASELINE ECLSS TECHNOLOGIES

The technologies baselined for the ECLSS functions are:

Function	Technology
CO_2 Removal	Four–Bed Molecular Sieve
CO_2 Reduction	Bosch Reactor
O_2 Generation	Static Feed Water Electrolysis
Potable Water Recovery	Multifiltration
Hygiene Water Recovery	Reverse Osmosis
Trace Contaminant Removal	Expendable Carbon Beds with Catalytic Oxidizer
Atmosphere Monitoring	Gas Chromatograph/Mass Spectrometer
Urine Recovery	Thermoelectric Integrated Membrane Evaporation System
Waste Management	Biodegradation Cup/Storage
Temperature and Humidity Control	Condensing Heat Exchanger
Fire Suppression	CO_2
Air Control and Supply	Cryogenic/High Pressure Storage

For the air revitalization and water recovery functions of the ECLSS, alternative technologies were evaluated and compared with the baseline technology. Comparisons were made based on estimated weight, power requirements, volume, maturity, safety, and resupply requirements. Fluid interface needs were also defined for each alternative. As an example, for CO_2 removal the Two-Bed Molecular Sieve, Electrochemical Depolarized Cell CO_2 Concentrator, Air Polarized Concentrator, Solid Amine Water Desorbed CO_2 Concentrator, and membranes were compared with the Four-Bed Molecular Sieve. Additional fluid interfaces are N_2 and H_2 for the EDC and APC, and hygiene water and a vent for the SAWD.

CO_2 REMOVAL

FLUID INTERFACES

TECHNOLOGY	FLUID INTERFACES	
	LINE IN	LINE OUT
Four-Bed Molecular Sieve	Cabin Air Liquid Coolant	Return Air CO_2, Liquid Coolant
Two-Bed Molecular Sieve	Cabin Air Liquid Coolant	Return Air CO_2, Liquid Coolant
EDC	Cabin Air, N_2 Purge Liquid Coolant, H_2	Return Air, H_2/CO_2, Liquid Coolant
SAWD	Cabin Air Hygiene Water	Return Air CO_2, Pressure Vent
APC	Cabin Air Liquid Coolant H_2, N_2 Purge	Return Air, H_2/CO_2, Liquid Coolant
Membranes	Cabin Air	Return Air CO_2

System impacts include larger capacity for the O_2 generator for the EDC and a larger THC to remove the moisture added by the SAWD.

CO_2 REMOVAL

TECHNOLOGY SPECIFICATIONS

TECHNOLOGY	SPECIFICATIONS				SYSTEM IMPACTS		
	WEIGHT (LBM)	AVG POWER (W)	VOLUME (FT^3)	HEAT REJ. (W)	WEIGHT (LBM)	POWER (W)	VOLUME (FT^3)
Four-Bed Molsieve	240	(Baseline) 1176	22.3	550	①	①	①
Two-Bed Molsieve	180	447	12.7	②	①	①	①
EDC	169	230	5.4	562	30	435 (Electrolysis and THC)	0.3
APC	190	413	6.1	②	30	435 (Electrolysis and THC)	0.3
SAWD	228	610	14.1	600	65	30 (THC and WRM)	4.0

① Negligible impact
② Undetermined parameter

PRELIMINARY IDENTIFICATION OF FLUID INTERFACE SCARS

After evaluating the alternative technologies and the fluid interface requirements of those considered to be the most likely replacements on Space Station *Freedom*, the fluid line scars required by subsystems based on these technologies were identified. For the prime candidates for the air revitalization and water recovery functions the identified scars are:

Function	Identified Scars
CO_2 Removal	none
CO_2 Reduction	none
O_2 Generation	interface with coolant loop and H_2 vent
Trace Contaminant Control	none
Urine Processing	cabin air line and liquid coolant line
Brine Processing	in: brine/rejection concentrates and air out: return air and potable water

By designing the Phase I Space Station *Freedom* to include the capability for these additional interfaces, the useful life of *Freedom* will be extended. Incorporating subsystems which use less power, require less volume, or have fewer resupply needs will provide benefits for either the multidisciplinary research scenario or the transportation node scenario resulting in a more productive Space Station *Freedom* program.

PRELIMINARY IDENTIFICATION OF FLUID INTERFACE SCARS

Fluid line scars have been identified for the technologies most likely to replace the baseline technologies:

Function	Identified Scars
CO_2 Removal	none
CO_2 Reduction	none
O_2 Generation	interface with coolant loop and H_2 vent
Trace Contaminant Control	none
Urine Processing	cabin air line and liquid coolant line
Brine Processing	in: brine/rejection concentrates and air out: return air and potable water

IV. Results

A. Database of the Alternative Technologies

A database was created, and computerized, with descriptions of the alternative technologies and the references where the information was obtained. This database will be expanded as more information becomes available.

B. Types of "Scars" Identified

The "scar" requirements for the alternative technologies fall into three general levels: (1) intrarack, (2) interrack (rack interface plate), and (3) module or cluster level. It is assumed that replacement of the ECLSS hardware would occur at the rack level, therefore "scars" at the intrarack level can be ignored. At the interrack or rack interface plate level there may be a need to add extra fluid lines (for example, to provide cooling water not originally needed) or to oversize the tubing or ducting to accommodate a higher flow rate than initially required. On the module or cluster level, additional ECLSS resupply tanks or an additional tank farm (with associated valves, pressure regulators, instrumentation, etc.) may be needed in order to meet the requirements of high levels of EVA and airlock usage.

C. Issues and Areas for Further Study

The results of the preliminary study identified several issues and areas to be studied further. More definitive data is needed on the Transportation Node Scenario to adequately determine the requirements and constraints on the ECLSS. Additional Intermodule Ventilation (IMV) analyses are needed in order to evaluate the effects of adding modules in various configurations. The effects of various crew distributions on the pCO_2 and pO_2 levels is also needed. Safe haven requirements may change as *Freedom* evolves and this needs to be evaluated further.

D. Scope of the Follow-on Study

The follow-on study will greatly expand the scope of the preliminary study in several ways:
(1) Computer models of the alternative technologies will be developed and incorporated into existing analysis tools,
(2) A prioritized list of the potential technologies will be developed and a more thorough assessment of the software control "hooks" and hardware "scars" performed,
(3) A comparative analysis will be performed against the baseline system, and
(4) Cost/benefit trade studies will be performed to identify the best candidates to replace the baseline technologies.

Results

- Database of Alternative Technologies

- Three Levels of "Scars" Identified
  - Intrarack
  - Interrack
  - Module or cluster

- Issues and Areas for Further Study
  - More definition of the Transportation Node Scenario is needed
  - Additional analyses of Intermodule Ventilation are needed to evaluate the effects of adding modules in various patterns
  - Additional analysis of the effects of crew distribution is needed
  - Possible changes to Safe Haven requirements as *Freedom* evolves need to be evaluated

- Expanded Scope of the Follow-on Study
  - Computer models of the alternative technologies will be developed and incorporated into existing analysis tools,
  - A prioritized list of the potential technologies will be developed and a more thorough assessment of the software control "hooks" and hardware "scars" performed,
  - A comparative analysis will be performed against the baseline system, and
  - Cost/benefit trade studies will be performed to identify the best candidates to replace the baseline technologies.