What we can contribute to the conceptual design of Advanced Life Support System by using computer simulation

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Outline

- Introduction
- Life Support System simulation
- Design of CEEF material circulation system and simulation
- Operation of CEEF material circulation system and simulation
- Design of Life Support System
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Schedule of human habitation experiment in CEEF
- FY1999 Design and development steps
FY2000 - FY2004 Preparatory steps for human habitation experiment
FY2005 - FY2007 Human habitation experiment steps

Introduction (1/2)

- Two types of Life Support Systems.
  - An Environmental Control and Life Support System (ECLSS) is the system maintaining environment for humans, and it is not necessary that the system include perfect regenerative system.
  - A Closed Ecological Life Support System (CELSS) is a closed system maintaining environment for humans with an almost perfect regenerative system.
    - Recently, CELSS has been replaced by an Advanced Life Support System (ALSS) which means moderate regenerative system.
- Although enough technology and knowledge have been accumulated for an ECLSS in 50 years manned space activity, they have not yet been accumulated for CELSS.
- A conceptual design method for CELSS has not yet been well systematized, so Closed Ecology Experiment Facilities (CEEF) design and operation must become considerably important for designing CELSS.

Introduction (2/2)

- Although the CEEF was constructed to study the propagation and accumulation of C-14 released from a reprocessing site of spent nuclear fuel, the CEEF is also available as a test bed obtaining design data for the ALSS which is used as a lunar and Mars base.
- In addition, there were a few large experiment facility for CELSS/ALSS in the U.S. and Russia. But, they aren't often designed and developed.
- Although the countries have a long history of manned space activity, design engineers do not always design a new LSS. Probably they design a new LSS approximately every 20 years.

Therefore, we summarize what we can contribute to the conceptual design of ALSS by using simulation based on research papers for CEEF, which we and other researchers have written.

History of LSS simulation

Purpose	ECLSS	CELSS/ALSS
Trade Studies	ECLSS's Assessment Program (ESAP) for S. S. Freedom.	Equivalent System Mass (ESM) is often used, which can be calculated by MS-Excel.
System model Steady state analysis	Mass balance analysis for O_2 and CO_2.	Element modeling by Averner. Chemical formula modeling by Tyler Volk and John D. Rummel which is Biochemical stoichieometry.
System model Transient analysis	Thermal and fluid analysis. SINDA'85/FLUINT, G189A, CASE/A, and Aspen.	Mass flow analysis. ECOSIM, BioSim, Matlab/Simlink, and WITNESS.
Actual systems / Experimental Facilities	Space shuttle and International Space Station (ISS)	BIOS3, Lunar-Mars Life Support Test Project (LMLSTP), BIO-Plex, and CEEF

Design

Operation

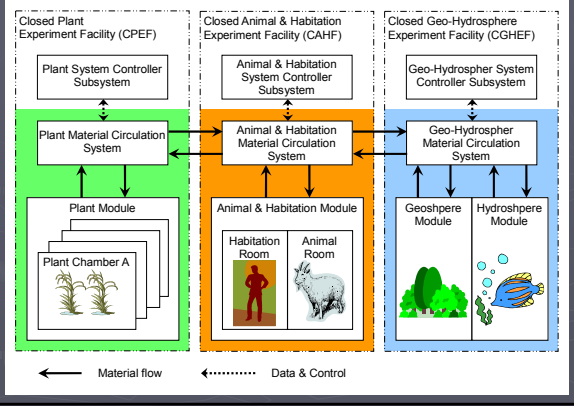
CEEF Design Procedure

1. Setting human metabolism and environment requirement.
2. Decision of combinations of crops for human needs, cultivation quantity, and cultivation area.
3. Mass balance analysis.
4. Study of regenerative processes such as waste process and nutrient production.
5. Decision of subsystem design baseline

References

1. K. Nitta, System Configuration Problems for Material Balancing in CELSS, CELSS Journal Vol.4 No.1, 1991
2. K. Nitta, Material Flow Estimation in CELSS, Acta Astronutica Vol. 27. pp. 205-210, 1992
3. K. Nitta, A. Ashida, Construction of Closed Ecology Experiment Facilities (CEEF), Proceeding of CELSS annual conference, pp. 97-99, 1995

CEEF material circulation system



CEEF material circulation system model

Steady state model

Human model

$$e_1 \cdot C_4H_5ON + e_2 \cdot C_6H_{12}O_6 + e_3 \cdot C_{16}H_{32}O_2 + e_4 \cdot H_2O + e_5 \cdot O_2 \rightarrow e_6 \cdot C_2H_6O_2N_2 + e_7 \cdot C_{42}H_{69}O_{13}N_5 + e_8 \cdot C_{13}H_{28}O_{13}N_2 + e_9 \cdot CO_2 + e_{10} \cdot H_2O$$

Crop model

$$a_1 \cdot CO_2 + a_2 \cdot H_2O + a_3 \cdot NH_3 + a_4 \cdot HNO_3 \rightarrow b_1 \cdot C_4H_5ON + b_2 \cdot C_6H_{12}O_6 + b_3 \cdot C_{16}H_{32}O_2 + b_4 \cdot H_2O + b_5 \cdot O_2$$

$$a_5 \cdot CO_2 + a_6 \cdot H_2O + a_7 \cdot NH_3 + a_8 \cdot HNO_3 \rightarrow b_7 \cdot C_4H_5ON + b_8 \cdot C_6H_{10}O_5 + b_9 \cdot C_{10}H_{14}O_2 + b_{10} \cdot H_2O + b_{11} \cdot O_2$$

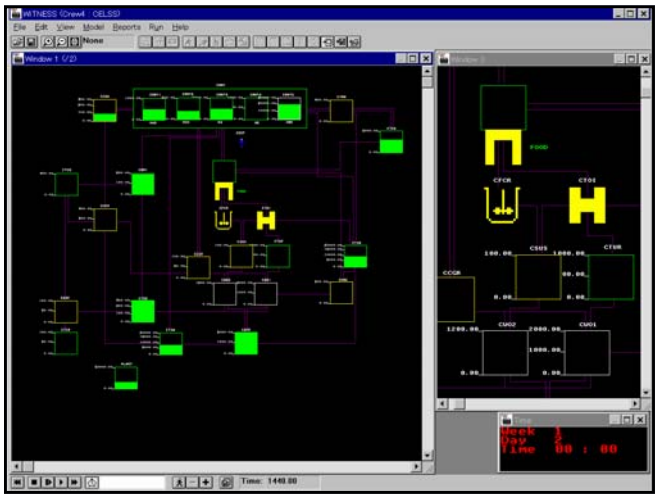
Subsystem model

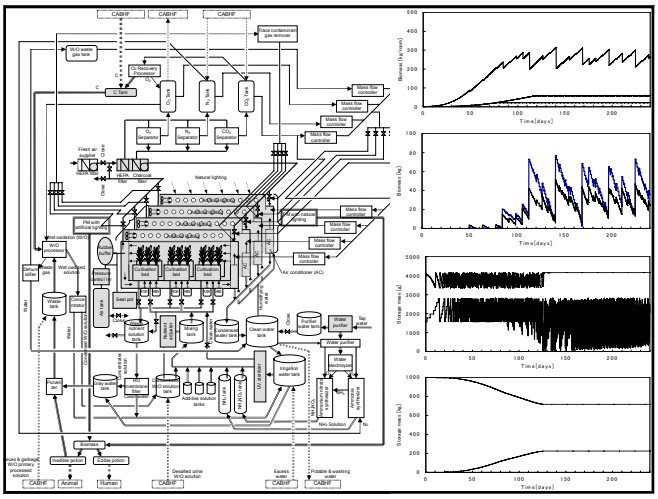
Transient model

Human metabolism model
Crop growth model
Subsystem model

$$\mathbf{X}(t+1) = \mathbf{X}(t) + \Delta\mathbf{X}$$

$$\Delta\mathbf{X} = \mathbf{B} \cdot \Delta\mathbf{F} + \Delta\mathbf{E}$$





Design of CEEF material circulation and simulation

- CEEF material circulation system was designed using biochemical stoichiometry assuming 20% margin of mass flow.
- In this design step, lack of crops and inedible portion data were indicated, so those data were accumulated in subsequent experiments.
- These data could improve accuracy of steady state analysis model.

References

1. K. Nitta, Material Flow Estimation in CELSS, Acta Astronutica Vol. 27. pp. 205-210, 1992.
2. K. Nitta, A. Ashida, Construction of Closed Ecology Experiment Facilities (CEEF), Proceeding of CELSS annual conference, pp. 97-99, 1995.
3. A. Ashida, Y. Tako, K. Nitta, Material Circulation Design for a Closed Ecological System based on Organic Element Analysis of Edible-Inedible Part Plant, Proceeding of CELSS annual conference, pp. 117-119, 1995.

Operation of CEEF material circulation and simulation

- We examined whether a necessary performance which the design engineer intended could be demonstrated based on design conditions.
- We also examined a set of initial values such as buffer tanks for stable closed operations and when the closed operation could start.
- We conducted a simulation to integrate equipment that had not yet been integrated for closed habitation experiments.
- Data about the metabolism of humans, plants, animals and the performance of equipment was accumulated.
- These data could improve the accuracy of transient analysis model.

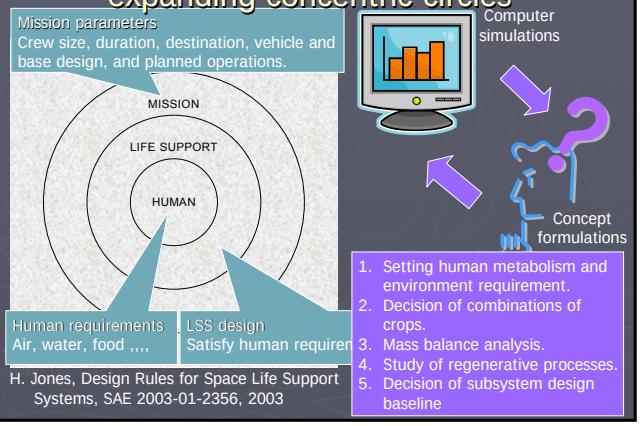
References

1. H. Miyajima, Y. Ishikawa, A. Ashida and K. Nitta, Development of Simulation Model and its Application to an Integration Test Project of CEEF, SAE 2000-01-2334, 2000
2. H. Miyajima, K. Abe, Y. Ishikawa, A. Ashida and K. Nitta, Simulation to Support an Integration Test Project of CEEF, SAE 2001-01-2130, 2001
3. H. Miyajima, Y. Ishikawa, R. Arai, Y. Tako, K. Nitta, Considerations of Material Circulation in CEEF Based on the Recent Operation Strategy, SAE Technical Paper Series 2003-01-2453, 2003

Possibility of simulation for CELSS/ALS material circulation system design and operation

- Simulations are expected to play a major role in the investigation of the system prior to the establishment of experimental conditions.
- The reason is that in the case of CELSS/ALS, experiments can extend over periods lasting from several months to years, and computer simulations are therefore useful for both establishing experimental conditions and predicting the results of experiments that could not actually be carried out.
- Before using the simulation, this requires that we improve the accuracy of predictions using suitable data obtained from experiments, and that we recognize differences between simulation and actual operation conditions.

LSS design through using three expanding concentric circles



H. Jones, Design Rules for Space Life Support Systems, SAE 2003-01-2356, 2003

Summary

- Here are my conclusions for conceptual design of CELSS/ALS using computer simulation.
  1. It becomes possible to confirm system performance based on design and experiment data.
  2. It becomes possible to study experimental conditions by conducting staged integration experiment before actual experiments.
  3. It becomes possible to study experiments which need a long time without actual experiments.
  4. A simulation has the important role of supporting trial and error for the design engineer to create a complex system in conceptual design step.
- These results can contribute to the conceptual design of CELSS/ALS in the future.