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## Systems Modeling in ALS: A Simulation Based Optimization Approach to Model and Design Life Support Systems for Manned Space Missions

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## SYSTEMS MODELING IN ALS: A SIMULATION BASED OPTIMIZATION APPROACH TO MODEL AND DESIGN LIFE SUPPORT SYSTEMS FOR MANNED SPACE MISSIONS

A life support system for manned missions is subject to many operating degrees of freedom. The choice of optimal values for these, e.g. values which would minimize the amount of re-supplies or would provide a safe environment for the crew members, can only be made by considering the performance objectives of the integrated system. Furthermore, the system will be subject to many dynamic factors such as time-varying boundary conditions, system parameters that drift with mission time, and unplanned operating events. A novel approach, SIMulation based OPTimization (SIMOPT), is proposed to design the life support system for manned missions and understand the dynamics of it.

Development of the SIMOPT framework for studying the behavior of different life support systems. The architecture includes an optimization module, which combines a diet optimization and crop planting scheduler, a simulation module, which is used to determine the behavior of the system, and a time-series data-mining module, which scans the data. It is concluded that with the current technology levels, for a 600 day mission to Mars, PC (physical-chemical) waste recovery technology seems to be the most promising one.

Development of the SIMOPT framework for life support system process synthesis. The main driver for a life support system for manned space missions is the crew. Specifically, the life support system should satisfy the crewmember requirements or demands for the basic life support elements, such as O<sub>2</sub>, H<sub>2</sub>O and food. The conceptual design of the framework has been completed and it is implemented using Java. Currently, the case studies are being run. A manuscript will be prepared with the detailed results of this study.

Analysis of Effect of Water loads on long-term space missions through modeling the possible operational states as Markovian Process. Due to expensive transportation cost, utilization of waste water treatment technologies is regarded as more cost effective than shipping all the clean water required from Earth for long term space missions. Results show that increase in water treatment capacity can effectively reduce water storage tank ESM (Equivalent System Mass) to a certain extent. After that the ESM value remains constant although water treatment capacity increases. Mission duration affects water storage tank ESM. However, it does not if water removal technology and ISRU (in-situ resource utilization) is added into crewmembers-only and crewmembers-and-crops scenario, respectively, in addition to the water treatment process at optimal capacity. Introduction of crops into the system increases the ESM by 1.3 times when compared to crewmembers-only scenario. Although the results are system specific, it demonstrates that trade study analysis can be performed to evaluate the trade off of water treatment technologies, water removal technologies and ISRU technologies against water storage tank and supply using ESM.

The study also found that water demand and its corresponding storage tank ESM value are the highest, compared to oxygen and carbon dioxide. Therefore, the subsequent study focuses on the water subsystem only.

Food subsystem is also considered in this work. A linear program was built to determine the best crop combination for crewmember consumption based on crewmember energy requirement and their crop preference. The results give an insight to the total crop area and water needed to grow the crops.

*Modeling and Control of Breathe I system.* Two dynamic equations describing the mass balance of air/water treatment system (Breathe I) have been set up. Based on these two equations, we have developed a simplified bilinear plant model for analyze and synthesize appropriate control algorithms. We have developed a model predictive control strategy to maintain system output to within acceptable range under prescribed power constraints.

## Control of PAABLO (Plant-based Anaerobic-Aerobic Bioreactor Linked Operation) system.

Conducting experiments to determine the amount of methane produced and thermal energy used with respect to temperature, residence time and moisture concentration from plant residues. We intend to use the data to characterize the response surface of the methane-production system to those 3 parameters. Based on this data, a control strategy will be developed to minimize energy while maximizing methane production. Based on our comprehensive literature review from different sources, under different conditions, and compared each of their experiment setups, we have fixed our experiment plan, including variables to be measured, sample rate and number, equipment to be used, and thermodynamics of the reaction. We further refined our experimental plan in collaboration with Statistical Consultant Service at NASA. The plan uses the Central Composite Design to characterize the response surface.

*System control and energy analysis.* Model Predictive Control (MPC) formulation will be used to develop a subsystem level control strategy to maintain adequate life support capacity but minimize energy consumption or maximize subsystem level efficiency. A phenomenological dynamic model for the NSCORT water/air treatment systems will be developed based on existing data and estimations. This model will be used to formulate and design the MPC controller. The result of the investigation will provide capacity and efficiency requirements and the associated control strategy to maintain adequate air and water reclamation for the crew. It will also provide the necessary dynamic response for other systems that are directly connected to the air/water treatment systems.

*Process Map Development.* A process model of all mass flows in a life support system relying uniquely on proposed NSCORT technologies was developed in 2003. The purpose of this activity was to answer the question whether the ALS/NSCORT technologies can act as a system or not. The model has an Excel interface to unify all specifications of process connectivity, stream compositions, mass and concentration values, reaction stoichiometry, phase equilibria, and other relations. The model finds feasible solutions including operation of all air, water, and waste recovery processes, growth of crops, edible fungi, tilapia, and biosolids dewatering plants. The air and water loops are evidently closed, and food is mainly supplied based on the current choice of costs for supply vs. growth. Biomass production is minimized in general.

In September 2005 through February 2006 the process map was updated and modified based on changes to the center and findings from process analyses. For this project the systems group reviewed previously obtained data and collected more detailed data about the ALS/NSCORT projects. An early and simplified version of the process map was presented at the September 30, 2005 NSCORT retreat and at Habitation 2006. The investigation revealed interface compatibility issues between processes; the investigation also indicated potential areas of savings, such as only treating water to the required state instead of treating all water to potable standards. Based on these analyses, the process map was updated, and several new collaboration projects were started to provide data for experimental design and to assess potential ripple effects of sub-system changes in an integrated life support system.

*Impact of Plant Transpiration on Integrated System.* From our detailed discussion with the Biomass Production group we realized that current estimates of plant transpiration (1400 Litres/day) meaningfully impact the sizing of condensing and water treatment units. Given the lower radiative burden of the LED (Lighted Emitting Diode) lighting systems plant transpiration under LEDs could be significantly less than current lighting conditions. These potential savings further capitalize on the reduced power and cooling requirements to operate the LEDs lighting systems. In collaboration with the biomass production project James Russell conducted a literature search and evapotranspiration experiments to evaluate the plant transpiration under different lighting conditions.