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The Virtual Habitat – A tool for dynamic life support system simulations

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Abstract

In this paper we present the *Virtual Habitat* (V-HAB) model, which simulates on a system level the dynamics of entire mission scenarios for any given life support system (LSS) including a dynamic representation of the crew. We first present the V-HAB architecture. Thereafter we validate in selected case studies the V-HAB submodules. Finally, we demonstrate the overall abilities of V-HAB by first simulating the LSS of the International Space Station (ISS) and showing how close this comes to real data. In a second case study we simulate the LSS dynamics of a Mars mission scenario. We thus show that V-HAB is able to support LSS design processes, giving LSS designers a set of dynamic decision parameters (e.g. stability, robustness, effective crew time) at hand that supplement or even substitute the common Equivalent System Mass (ESM) quantities as a proxy for LSS hardware costs. The work presented here builds on a LSS heritage by the exploration group at the Technical University at Munich (TUM) dating from even before 2006.

Keywords: LSS; ECLSS; Life support system; Virtual Habitat; International Space Station; Mars mission

1. Introduction

Manned exploration of our solar system depends on efficient, safe, and robust life support systems (LSS). Current LSS design processes are often based on static concepts assuming steady states energy and mass flows. In complex technical systems, such as a LSS, uncertainties from inherent dynamics are usually accounted for by incorporating large buffers. To compare different architectures the Equivalent System Mass (ESM) is commonly used. It allows for selecting technologies with the lowest mass, volume, power, cooling, and maintenance requirements (Levri et al., 2000, 2003; Czupalla et al., 2004). A Virtual Habitat (V-HAB) simulation environment has been created to extend the ESM concept, adding dynamic analyses investigating the robustness of life support system architectures (Czupalla et al., 2007). To provide the necessary transient parameters, the relevant LSS subsystems, including the crew, are represented in a dynamic manner. Since an experimental characterization of dynamic LSS parameters is rarely possible without building the proposed system, computer simulations have already been suggested as a possible solution for several decades (Babcock et al., 1984) and repeatedly confirmed in further publications (e.g. Jones, 2009). In order to establish a solid foundation for V-HAB, the following LSS simulations, current and legacy systems were extensively studied (Czupalla, 2011b).

– G-189A (Barker, 1968; Coggi et al., 1973)
– CASE/A (Knox, 1996)
– BioSim (Kortenkamp and Bell, 2003)
– EcoSimPro (Ordonez, 2003)
– ALSSAT (Yeh et al., 2009)

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– ELISSA (Osburg, 2002)
– ALISSE (Brunet and Gerbi, 2009)

V-HAB incorporates the lessons learned from these previous LSS simulations and includes all necessary modules to dynamically simulate LSS operations for complete missions. In the early design phases of LSS architectures it provides fast answers to "what if" questions in a changing environment. Thus V-HAB supplements classic steady state LSS design efforts by providing fully dynamic LSS simulations. V-HAB permits to simulate the impact of subsystem or technology failures or a changing crew schedule such as crew overlap. This allows optimizing the buffer sizes while preserving the stability and robustness of the system. This paper is a proof-of-concept that such an approach is feasible for a system as complex as an ECLSS.

2. Virtual Habitat architecture

The V-HAB simulation is an engineering tool enabling the user to simulate entire mission scenarios, including transfers between mission phases, for a given LSS configuration. It allows considering criteria such as system stability, controllability and effectiveness in order to assess the dynamic robustness of systems designed to the averages of mass and energy flows, e.g. with the ESM approach. To be compatible with any LSS architecture, V-HAB is designed in a modular fashion. It is programmed using the object-oriented programming framework in MATLAB® (Mathworks Inc.). The modules of the Virtual Habitat simulation (see Fig. 1) are grouped into functional modules simulating the crew, the biological components, and the physico/chemical (P/C) LSS parts. These are assigned to one global module, which handles the interfaces. All modules of V-HAB are outlined in greater detail in the remainder of this paper.

Since no dynamic models of LSS subsystems or technologies were existing prior to the V-HAB project, all V-HAB subsystem models were created from scratch. Every such model was validated against published data or data provided by international space agencies developing LSSs. The human subsystem model is based on existing models and extended by the V-HAB team. The plant and algae models are based on modeling approaches as published in literature. More details are given in the following. Verification examples are provided in Section 3.1. A complete list of references used for the creation of the dynamic models in V-HAB can be found in Czupalla (2011b).

The nomenclature of V-HAB and the substructure of the top-level modules are shown in Fig. 2, which serves as the basis for the following module descriptions.

2.1. Closed-environment module

The closed-environment module (CEM) is the backbone of the V-HAB simulation. The two top level tasks of the CEM are the setup of boundary conditions for a simulation and the monitoring and control of all mass flow in the simulated habitat. It serves as the main controller of all habitat buffers, resources (power, mass, heat, etc.) and of all mass flows within the system. An overview of the tasks of the CEM is shown in Fig. 3 where the main two node groups are shown with the

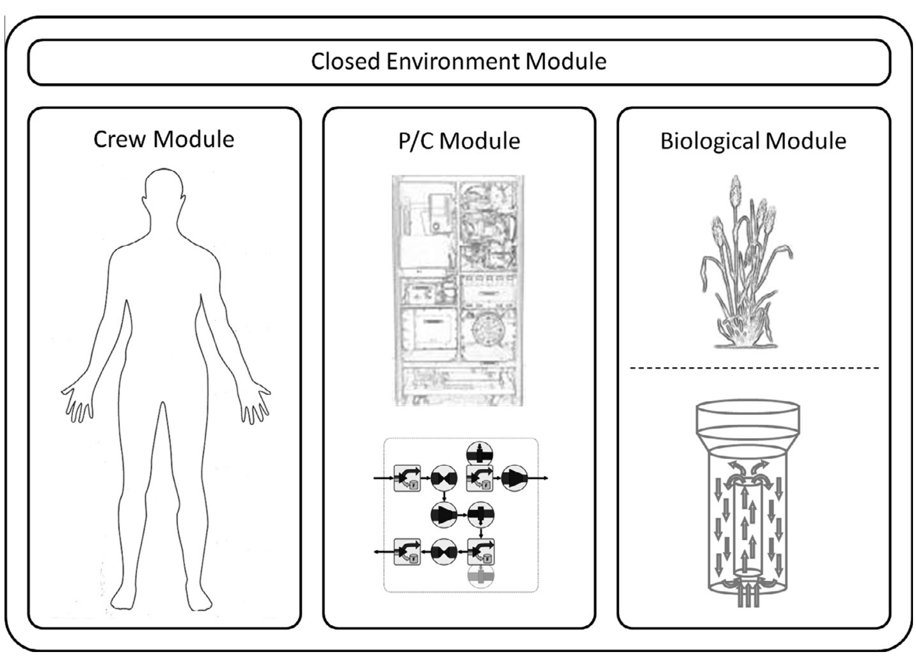

Fig. 1. Virtual Habitat – global modules overview.