
MELISSA - A Graphical Environment for Life-Support Systems Simulation

Jan Osburg, Reinhold Bertrand and Ernst Messerschmid

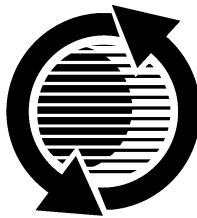
Institut für Raumfahrtssysteme, Universität Stuttgart, Pfaffenwaldring 31, D-70550 Stuttgart, Germany

The appearance of this ISSN code at the bottom of this page indicates SAE's consent that copies of the paper may be made for personal or internal use of specific clients. This consent is given on the condition, however, that the copier pay a \$7.00 per article copy fee through the Copyright Clearance Center, Inc. Operations Center, 222 Rosewood Drive, Danvers, MA 01923 for copying beyond that permitted by Sections 107 or 108 of the U.S. Copyright Law. This consent does not extend to other kinds of copying such as copying for general distribution, for advertising or promotional purposes, for creating new collective works, or for resale.

SAE routinely stocks printed papers for a period of three years following date of publication. Direct your orders to SAE Customer Sales and Satisfaction Department.

Quantity reprint rates can be obtained from the Customer Sales and Satisfaction Department.

To request permission to reprint a technical paper or permission to use copyrighted SAE publications in other works, contact the SAE Publications Group.



GLOBAL MOBILITY DATABASE

All SAE papers, standards, and selected books are abstracted and indexed in the Global Mobility Database

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

ISSN 0148-7191

Copyright 1998 Society of Automotive Engineers, Inc.

Positions and opinions advanced in this paper are those of the author(s) and not necessarily those of SAE. The author is solely responsible for the content of the paper. A process is available by which discussions will be printed with the paper if it is published in SAE Transactions. For permission to publish this paper in full or in part, contact the SAE Publications Group.

Persons wishing to submit papers to be considered for presentation or publication through SAE should send the manuscript or a 300 word abstract of a proposed manuscript to: Secretary, Engineering Meetings Board, SAE.

Printed in USA

MELISSA - A Graphical Environment for Life-Support Systems Simulation

Jan Osburg, Reinhold Bertrand and Ernst Messerschmid

Institut für Raumfahrtssysteme, Universität Stuttgart, Pfaffenwaldring 31, D-70550 Stuttgart, Germany

Copyright © 1998 Society of Automotive Engineers, Inc.

ABSTRACT

A new software tool, MELISSA, has been developed for the simulation of life-support systems and other network-type subsystems. MELISSA features an intuitive graphical modeling environment and interactive simulation execution. Applications of MELISSA range from the analysis and validation of new ECLSS designs, to parametric optimization studies, to failure mode effects and criticality analysis of life-support systems. Additionally, MELISSA can be employed for training ECLSS developers and users, and as a teaching tool for lectures and seminars on systems design. As a demonstration, an ECLSS similar to the one of the International Space Station has been modeled and simulated.

INTRODUCTION

The Environmental Control and Life Support System (ECLSS) is one of the most prominent features distinguishing manned spacecraft and space stations from satellites and unmanned platforms. Due to a multitude of internal couplings, combined with highest performance demands, the subsystem design process is quite demanding.

At the same time, various opportunities for synergistic linkages of the ECLSS with other subsystems, e.g. with the Attitude and Orbit Control System (AOCS) or the Electrical Power System (EPS), exist.

To support the task of the engineer in this sector, a "Modular Environment for Life-Support Systems Simulation and Analysis" (MELISSA) has been developed at the Institute for Space Systems (Institut für Raumfahrtssysteme, IRS) at the University of Stuttgart.

In this section, a brief overview of the basic concepts of life-support and system simulation, as required for the understanding of this paper, is presented. The following sections describe the specifications of the simulation software and the selection of the software tool used for its implementation. Then, MELISSA is described and demon-

strated using a simulation of an ECLSS similar to that of the International Space Station (ISS). Finally, conclusions and references are given.

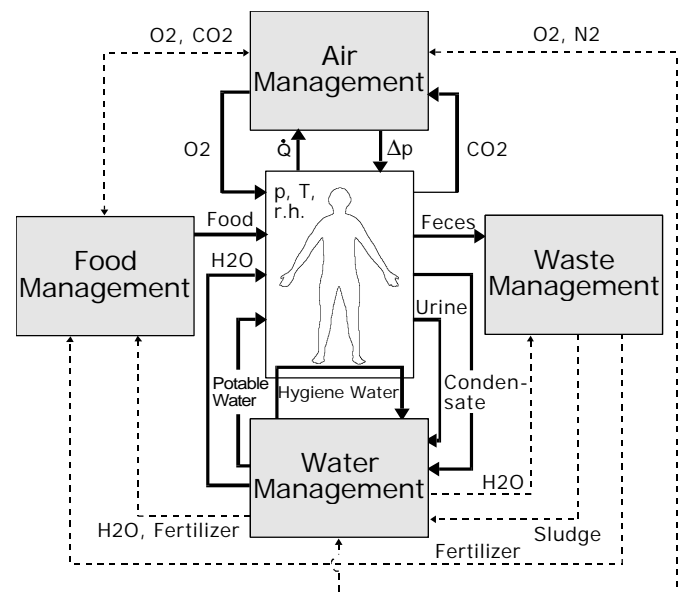


Figure 1. Basic ECLSS functions [2]

LIFE SUPPORT SYSTEMS – ECLSSs are not only used in manned space flight but also in other areas where humans need to survive under adverse environmental conditions. Their purpose is to enable human presence by providing essentials such as food, water, and breathable air. Figure 1 shows the diagram of a generic ECLSS, emphasizing the high number of linkages among the individual functional components.

Designing an ECLSS is a challenging engineering task. The combined action of the various devices has to be optimized while respecting the boundary conditions for power demand, mass and logistics. The life-support system, itself a part of the overall "space station" system, thus represents a synergistic subsystem, where overall advantages can be obtained by linking or partially merging components.

MODELING AND SIMULATION – Computer-based simulation is especially important with regard to the analysis of synergistically linked systems, as the behavior of such systems cannot be determined from simple superimposition of the individual behavior of their components.

This means for the design process that optimization of all subsystems does not necessarily result in optimum overall system performance [1].

In order to achieve such an optimum system performance, the engineer needs a model that defines the subsystems as well as their links. With such a tool, the behavior of a system can be analyzed depending on its configuration and the associated parameters of its components, thus often enabling the designer to find an optimum solution by applying his intuition.

Simulation software also supports engineering education, especially in systems design. Graphical programming, in particular, permits an appealing, true-to-reality modeling of linked systems. Interactive simulations allow for a quick and intuitive grasp of system interrelations and overall system behavior (hands-on education).

Therefore, the "Space Station Design Workshop" (SSDW) software package has been developed by the Institute for Space Systems at the University of Stuttgart, which, by using various simulation components, allows the analysis of the overall system "space station" from different points of view [3]. MELISSA was developed and integrated into that package to improve SSDW functionality in the area of linked subsystems design (Figure 2).

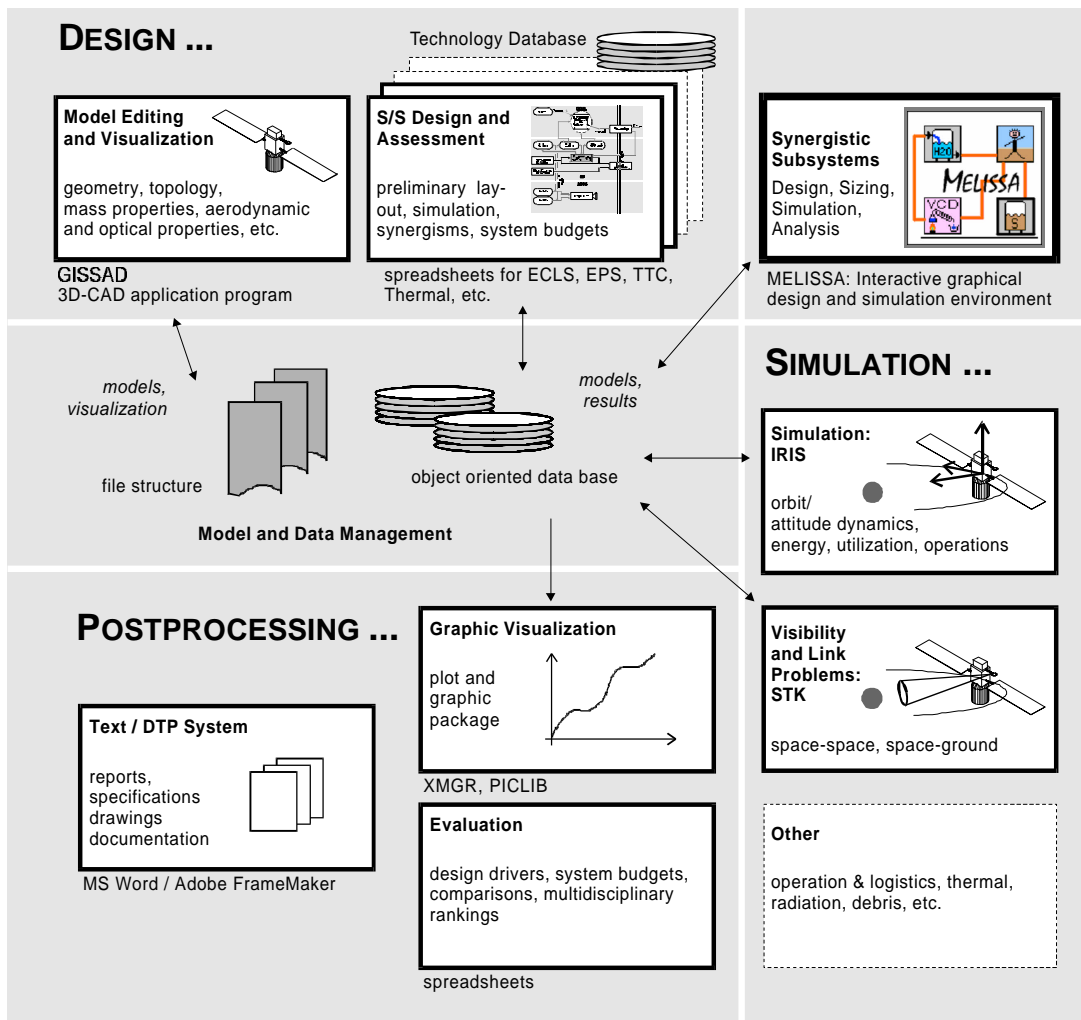


Figure 2. MELISSA's role in the SSDW systems design environment [2]

SOFTWARE FEATURES DEFINITION

For the development of MELISSA, the "Quality Function Deployment" design process was used ([4], [5]). Therefore, the initial definition of design features or characteristics received special attention. Figure 3 shows how the

characteristics were derived from the customer requirements using a "House of Quality" diagram ([4]).

The requirements capture the voice of the customer and thus serve to check the quality of work performed. The customer in this case was the potential research or educational user.

The following software characteristics were considered most important with respect to the user demands:

- Intuitive operation, interactive preparation and execution of simulations
- Object-oriented modular design with easy expandability
- Support for modeling objects with varying depths of description

- Graphical display and easy postprocessing of results
- Context-sensitive help and thorough documentation
- Automated data transfer from and to other SSDW components
- High-speed execution of code, multi-processor capability
- Multi-platform readiness

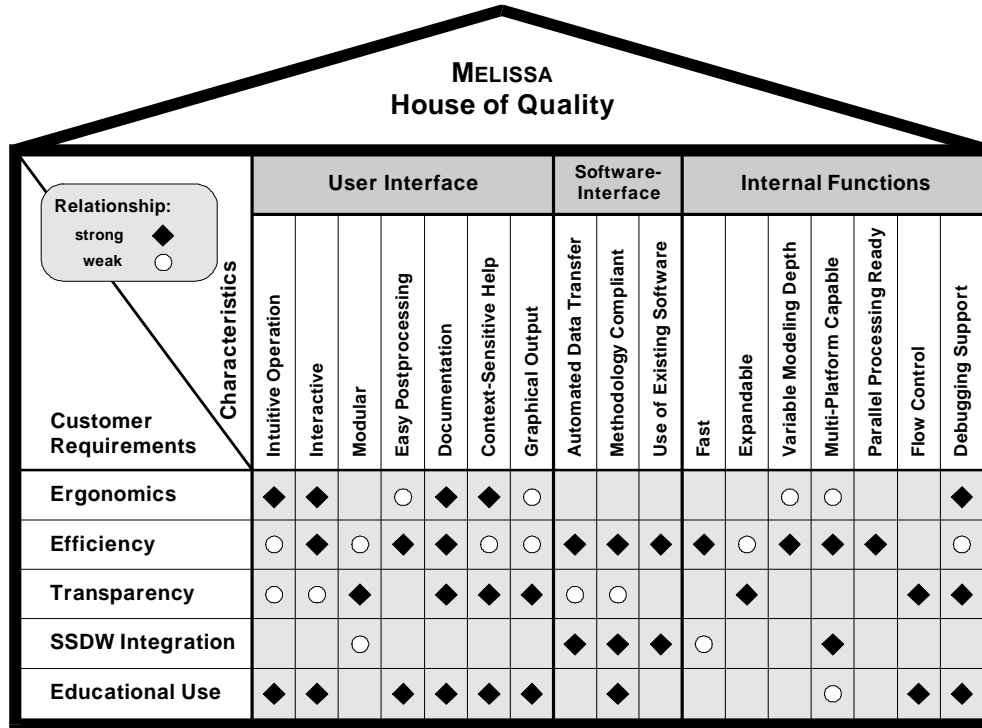


Figure 3. The House of Quality matrix used for the MELISSA software design

SELECTION OF THE SOFTWARE USED FOR MELISSA IMPLEMENTATION

Development and implementation of the simulation environment was facilitated by using an existing software that provided programming and graphical interfacing functionality. Several available programs were examined with respect to their usefulness.

These programs, all of which were featuring a graphical user interface, were taken from the following fields:

- Process engineering flowsheet simulators
- Automation and control simulation software
- General purpose graphical programming languages
- Dedicated ECLSS simulation software

Table 1 presents a synopsis of the individual programs together with their most significant advantages and disadvantages. The selection of the software to be used was guided by considering the following criteria: the software's underlying modeling philosophy, its expandability, the features and limitations of its user interface, its platform compatibility, and also its availability.

As a result, LabVIEW was selected as a basis for MELISSA, as it seemed to be most favorable to the implementation of the customer requirements.

The selected software is designed for computer-based data acquisition and measurement hardware control. However, it also features a general-purpose graphical programming language, including a graphical user interface library; MELISSA uses only these components. Integration of actual life-support hardware into the system model for hardware-in-the-loop-style simulations remains feasible, if the appropriate interface libraries and data acquisition hardware are used.

IMPLEMENTATION OF THE SIMULATION ENVIRONMENT

BASIC CONCEPT – The MELISSA simulation environment uses the graphical programming and user interfaces provided by the base software. To perform a simulation, the user first models the system to be analyzed in a graphical window ("diagram", see Figure 5). For this purpose, MELISSA provides several libraries with ECLSS- and EPS-specific components, which are implemented as modular subroutines (Figure 4).

Simulation data to be tracked are visualized using instrument-style displays on a corresponding interface window ("front panel").

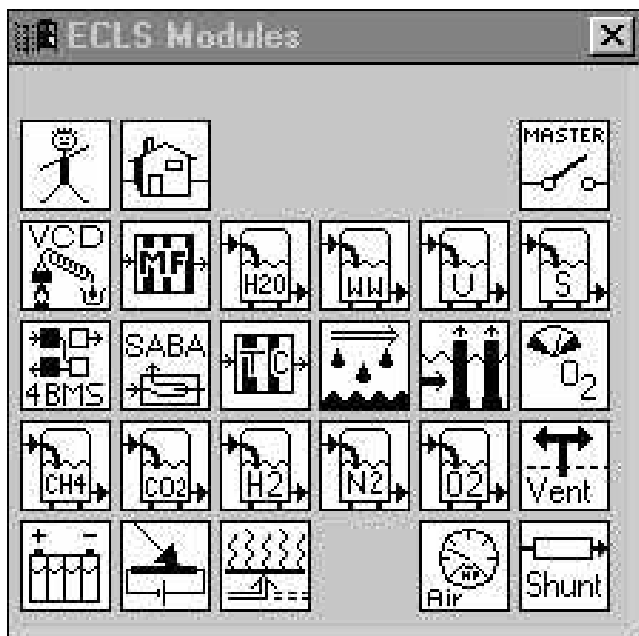


Figure 4. MELISSA-Menu with ECLSS and EPS modules

Both modules and instruments are inserted into the respective windows using a drag-and-drop approach. Linking them with virtual wires defines the data flows between them. Due to the graphical programming language, no further programming is needed. All information required to perform simulation runs is contained in the graphical model. Additional simulation components, such as controllers governing the activity of individual modules, can also be inserted on this level.

After completing the model, the simulation can be started by executing the graphical code. During run-time, the simulation can be controlled using the interactive controls provided by the corresponding front panel. This facilitates simulation and analysis of time-variant system states.

For simulation-specific tasks, like logging of data into a file or controlling the time-step used in the simulation, MELISSA service subroutines are provided, which can be activated through a centralized simulation control panel.

Simulation calculations are based on numeric iteration. Explicit solving of differential equations, as done in simulation tools designed for process engineering, is avoided. Instead, the species and energy flows, which are circulating in the system, are modeled directly by passing on flow values between modules.

Table 1. Summary of the software examined for use as a basis for MELISSA

Program	Type	Advantages	Disadvantages
AspenPlus	Flowsheet	detailed modeling of chemical and physical processes	only steady-state simulation possible, detailed knowledge of system and components required, flat learning curve
DIVA	Flowsheet	detailed modeling of chemical and physical processes, dynamic simulation (non-steady state)	detailed knowledge of system and components required, flat learning curve
Matlab/ Simulink	Automation and Control	time-continuous simulation through state-space modeling	primitive graphical user interface, large resulting state vector
LabVIEW	Graphical Programming	general-purpose graphical programming language, intuitive user interface, enables customized implementation of MELISSA	was not developed for simulation applications, but for data acquisition and instrument control
CASE/A	ECLSS-Simulation	ECLSS-specific libraries	platform specific, difficult to expand, expensive
ECOSIM	ECLSS-Simulation	ECLSS-specific libraries	platform specific, difficult to expand

Every module has standardized in- and outputs for each flow it may influence. Related flow values are combined in a flow vector: the "air" flow, for example, contains sub-flows for oxygen, nitrogen, carbon dioxide, water vapor and trace contaminants as well as common pressure and temperature data. These flows are integrated only where needed, e.g. for the tank modules, using a straightforward time-discrete algorithm ($\Delta m = F \cdot \Delta t$, with Δm being the increment/decrement of e.g. a tank level for each simulation step, F representing the flow value, and Δt being the simulation time step).

A simulation run, therefore, consists of subsequent simulation steps, which correspond to time increments of a certain, user-selectable duration. The calculations to be performed in each step are completely defined by the diagram components and their linkages. The results of each simulation step serve as initial data for the subsequent one.

If, during a simulation run, an error condition occurs (e.g. a storage tank running dry, or some component delivering faulty results), the simulation is halted, and the user can investigate the problem and – if desired – continue the simulation after fixing it.

AVAILABLE MODULES – MELISSA provides components for all functions of a life-support system as depicted in Figure 1. These are modeled as subroutines and inserted into the system model diagram via icon-based menus. Additionally, components of the EPS are available to allow the examination of ECLSS-EPS interactions. Figure 4 depicts the available modules, which include:

- a vapor-compressed distillation unit (VCD),
- a multifiltration unit (MF),
- a four-bed molecular sieve (4BMS),
- a Sabatier reactor (SABA),

- a trace contaminant control unit (TC),
- a condensing heat exchanger,
- an electrolyzer,
- batteries and solar arrays for power supply,
- and various species-specific tanks.

EXAMPLE ECLSS MODEL – Figure 5 gives an example of the application of such modules in a model of a simple life-support system with an open air loop and a closed water loop.

Air enters the crew module and is led through a condensing heat exchanger (CHX) after exiting the module. The CHX removes from the air stream a certain fraction of the water vapor that was produced by the crew. This water is then forwarded to the multifiltration unit for processing.

The waste water from the crew is also recycled in the multifiltration unit. The clean water leaving the multifiltration unit is stored in a water tank, for reuse by the crew.

If the processing capacity of the multifiltration unit should be momentarily exceeded, the surplus waste water is stored in a waste water tank, and recycled when the processing capacity becomes available again. A battery set serves as a non-regenerative power supply in this simple model.

Parameters such as crew size and crew comfort level (which determined water and food consumption as well as waste production rates), filtration and CHX efficiencies, and so on, can easily be set by double-clicking on the respective icons.

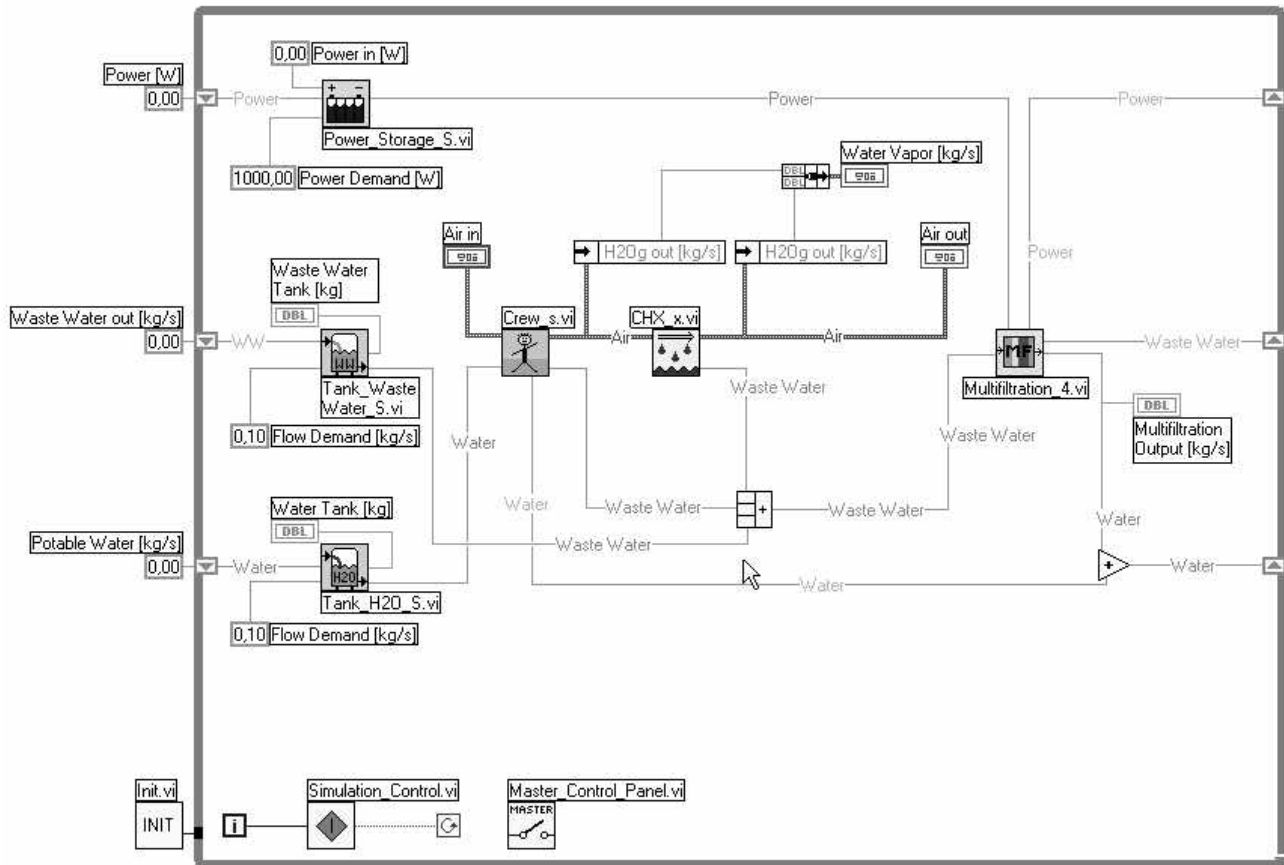


Figure 5. MELISSA model of a simple generic life-support system with closed water loop

DOCUMENTATION AND STANDARDIZATION – All components provided by MELISSA are documented extensively. Apart from the information supplied by a user manual, each module subroutine contains a description as well as usage hints that the user can display in a context-sensitive help window.

To further facilitate system modeling, all subroutines were programmed in accordance with detailed guidelines in order to ensure consistency and user friendliness, even over multiple generations of developers. These guidelines define e.g. the measuring units to be used, establish the generic layout of MELISSA diagrams, standardize icon

design, and prescribe documentation contents and format.

EXAMPLE APPLICATION: SIMULATION OF AN ISS-LIKE ECLSS

As a further example of MELISSA application, an ECLSS similar to the one planned for the US part of the International Space Station (ISS), in its "assembly complete" configuration, was modeled, and its startup behavior analyzed.

The underlying ISS specifications were extracted from the ISS Technical Data Book [6]. The following ECLSS components were used to support a crew of four:

- **Air loop:** oxygen tank, electrolyzer for oxygen generation, oxygen partial pressure regulator, condensing heat exchangers for dehumidification, four-bed molecular sieves for carbon dioxide removal, and filters for trace contaminant control.
- **Water loop:** separate tanks for potable and waste water as well as for urine and solid waste, vacuum compressed distillation (VCD) units, and multifiltration (MF) equipment for water and urine recycling.

Tracked system states were the air composition in the form of volumetric fractions of the main species oxygen and carbon dioxide, as well as the levels of the waste water, urine and solid waste tanks.

DISCUSSION OF SIMULATION RESULTS – Figure 6 shows the development of the O₂ and CO₂ fractions as

well as waste water, urine and solid waste tank levels, over simulation time.

The carbon dioxide level asymptotically approaches an equilibrium value, which depends on the efficiency of the carbon dioxide filtering process.

The oxygen level first declines due to the crew's oxygen consumption before the oxygen regulator kicks in and keeps the oxygen content of the cabin air at the preselected minimum threshold.

The tank contents show linear behavior. Due to a slightly underdesigned water filter, the waste water tank level is slowly rising. The vapor compressed distillation unit used for urine recycling has sufficient processing capacity, and thus no urine is accumulating in the urine tank.

Additional investigations of system behavior during long-term operation, as well as regarding failure modes and failure tolerance, are necessary for sizing and qualification of a life-support system design. These tasks are facilitated significantly by the graphical and interactive simulation concept used by MELISSA.

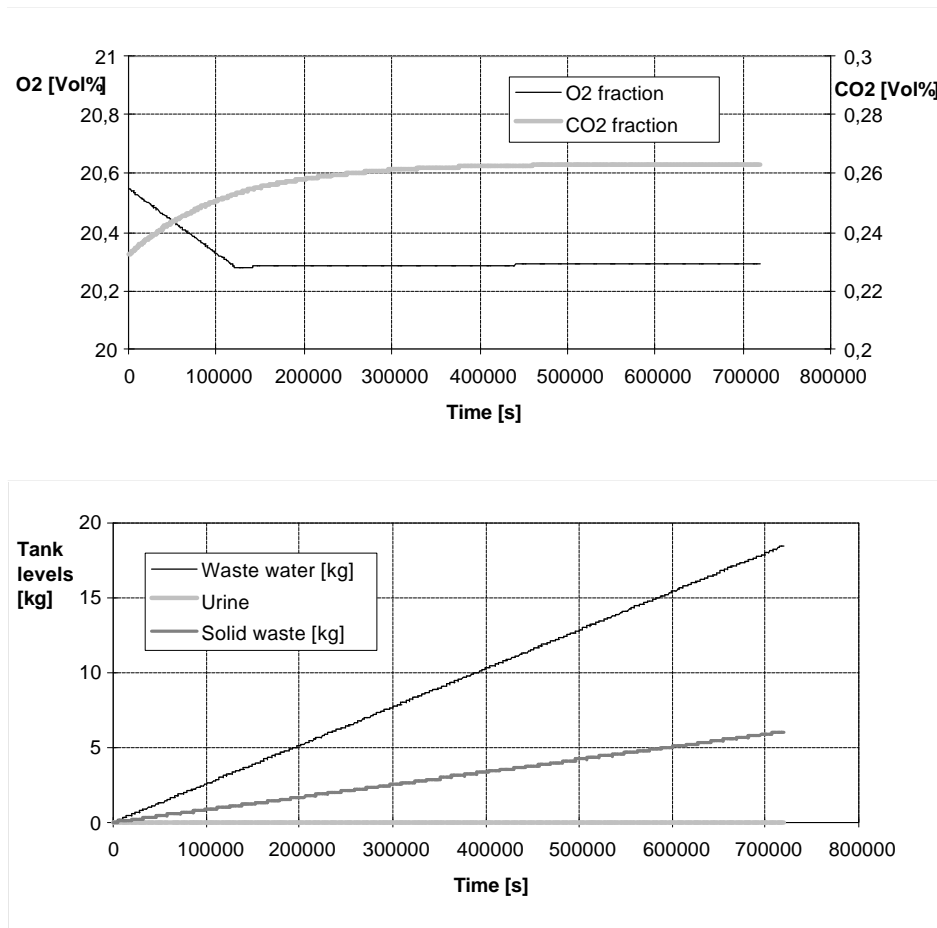


Figure 6. Initial development of air composition and waste tank levels

CONCLUSION

Based on an existing graphical programming environment, MELISSA, an application for interactive graphical modeling and simulation, was developed.

The software serving as its basis was originally designed for data acquisition and measuring equipment control but is used here in an unconventional, software-only mode.

The simulation calculations use a numerical iterative algorithm which, in contrast to other simulation software, works without explicitly solving differential equations.

Module libraries with predefined components of the ECLSS and EPS are provided; they facilitate system definition using a graphical modeling environment.

During simulation execution, the user is also supported by the intuitive graphical environment. The modular concept used ensures easy expandability and supports variable depths of description.

As an exemplary application of MELISSA, a life-support system comparable to that of the International Space Station was modeled and simulated. The results confirm the validity of the chosen simulation approach and its user-friendly implementation using off-the-shelf software.

ACKNOWLEDGMENTS

The authors would like to thank National Instruments Germany GmbH, Munich, for providing a free license of their product LabVIEW, which made this work possible.

REFERENCES

1. Blanchard, Benjamin S.; Fabrycky, Wolter J.: Systems Engineering and Analysis. 2nd ed. Prentice-Hall, London 1996. p. 12. ISBN 0-13-880758-2.
2. Messerschmid, Ernst; Bertrand, Reinhold; Pohlemann, Frank: Raumstationen – Systeme und Nutzung. 1st ed. Springer, Heidelberg 1997. p. 346. ISBN 3-540-60992-X
3. Bertrand, Reinhold: Conceptual Design and Flight Simulation of Space Stations. Dissertation. Institut für Raumfahrt-systeme, Stuttgart 1998.
4. Hauser, John: The House of Quality. From: Harvard Business Review, May - June 1988, p. 63 ff.
5. Sanchez, Susan M.; et al.: Quality by Design. From: Kusiak, Andrew (Ed.): Concurrent Engineering – Automation, Tools and Techniques. John Wiley & Sons, New York 1993. ISBN 0-471-55492-8.
6. ISS Technical Data Book: Sub-System Environmental Control and Life Support System (ECLSS) on Flight 19A. NASA, web-published 20 March 1995. <http://issa-www.jsc.nasa.gov/ss/techdata/ECLSS/19A.html>.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

AOCS: Attitude and Orbit Control System

ECLSS: Environmental Control and Life Support System

EPS: Electrical Power Supply (System)

ISS: International Space Station

MELISSA: Modular Environment for Life-Support Systems Simulation and Analysis

SSDW: Space Station Design Workshop; software for space station conceptual design developed at the Institut für Raumfahrtssysteme