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MULTIDISCIPLINARY SIMULATION USING EcosimPro

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Abstract

ESA and EMPRESARIOS AGRUPADOS have been developing EcosimPro since 1989. The initial objective was to provide powerful capabilities to handle the simulation of Environmental Control and Life Support Systems (ECLSS) for the International Space Station. Because of the multi-disciplinary nature of ECLSS (thermal, fluids, chemical reactions, electrical and control features), EcosimPro has been designed as a generic, flexible and modular tool. It is capable of solving a large set of Differential Algebraic Equations (DAEs) both for steady and transient states. The new EcosimPro 3.0 release (available on PC-Windows platform) uses the powerful concept of Object-Oriented Simulation Language, which enables the definition of components that can be re-used as libraries. The look and feel of EcosimPro is identical to Microsoft software (tree browser for instance) and is very user-friendly. The User Interface has been designed to define and connect the system components either using the EcosimPro language or using a professional 2D CAD package (Smartsketch from Intergraph).
This paper presents recent results obtained in the simulation of ECLSS and other systems (propulsion, fuel cells), as well as improvements and future capabilities.

KEYWORDS: multidisciplinary simulation, DAE solvers, fluids, chemical models, object-oriented modelling, numerical analysis, continuous systems, dynamic systems, discrete events

1 INTRODUCTION

EcosimPro is a generic simulation tool initially developed for the simulation of ECLSS (Environmental Control and Life Support Systems). It would seem to be a contradiction in terms, stating that EcosimPro is a generic simulation tool and then indicating that its initial purpose was ECLSS simulation. Not so, however, since EcosimPro's main characteristic is its adaptability to a variety of fields through the creation of reusable modeling component libraries representing parts or equipment of a system. EcosimPro's applicability to ECLSS was achieved by developing a library providing the key components and functions necessary to model this kind of system.
The ECLSS library is also being used to model different ECLSS modules of the International Space Station (ISS) by ESA, NASA, Astrium, Alenia, etc.

1.1 EcosimPro Language (EL)

Modeling component libraries are developed with a powerful yet simple language called EL (EcosimPro Language), which is at the core of the tool. Libraries are currently available for the modeling of ECLSS systems, thermal control systems, electrical circuits, satellite propulsion systems, hydraulic balances, heat balances and hydraulic transients, and more libraries are under way for the simulation of waste process systems and water treatment plants.

The user can create new components from scratch or by modifying the standard components provided in the libraries; there is no difference between a standard library component and a user-defined component, since both types of components are created using EL and the mathematical processing is identical in both cases.

1.2 Applicability of EcosimPro to ECLSS

The advantage of this simulator architecture is its flexibility, essential in the field of ECLSS, which is constantly seeking inherently safer, more powerful and efficient technologies, while looking to reduce total mass, volume, overall power consumption and cost, and where the complexity of future systems for long-term missions is nearing that of the biosphere.

This constant evolution of ECLSS systems makes it impossible to develop a software tool with predefined models and components for the purpose of modeling any type of ECLSS; the user must be free to extend and adapt the component library to suit his specific requirements.

1.3 Other cases where EcosimPro is applicable

As a general tool enabling construction of reusable component libraries, EcosimPro has demonstrated extraordinary usefulness for ECLSS, as well as in all fields lacking specific, well-rounded simulation tools and in the design of multidisciplinary systems. For example, even though EcosimPro can efficiently simulate electronic circuits, it is not best suited to this field of application, since there are electronic circuit simulators such as Spice, featuring very comprehensive component libraries and solving algorithms adapted to the physics of the problem. EcosimPro provides a less comprehensive library of electrical components, and the solving algorithms are general. However, in a field such as ECLSS, where there are no well-established tools that can be adapted to user requirements, the flexibility of EcosimPro is quite advantageous.

Another clear-cut case of EcosimPro applicability is the simulation of multidisciplinary systems, ie, systems containing a variety of subsystems of a very different nature. For instance, a robot has a mechanical part, a hydraulic subsystem to drive the actuators, and a control subsystem that can be made up of electronic circuits. An integrated analysis of all the robot's subsystems and of their interactions could only be achieved with a tool of EcosimPro's characteristics, since field-specific simulation tools make it necessary to study subsystems separately and to ignore their interactions.

2 PHYSICAL MODELING WITH EcosimPro

EcosimPro is a continuous system simulator that provides the support required for physical modeling of the systems, and to follow an object-oriented modeling method.

By physical modeling, we indicate that an EcosimPro model is identical or very similar to a flow chart representing the system. Components representing actual system equipment are used to build the model and are interconnected in the same fashion as they are in the real system.

EcosimPro components represent equipment items in the system and are reusable in any context, meaning that they can be connected to any other component to which the equipment represented could be connected in a real system.

2.1 Limitations of Classic Simulation Tools

Very few tools provide physical modeling and reusable components in any context. For example, in tools based on the block diagram concept, the user does not draw the components of the model, but a mathematical block representation of it. This is a significant limitation: if there is a change in the physical organization of the system being modeled, the block representation can undergo serious changes. It is therefore quite difficult to work with non-trivial examples unless system configuration will never be changed.

Simulation tools based on simulation languages such as ACSL and ESL can provide modeling components to represent system equipment, but these components are not reusable in any context. In such tools, equations are written as an assignment of variables imposing a calculation sequence. In other words, there is implicit computation causality in the component that is not valid in all contexts. A typical example would be the case of a dynamo or DC motor: the equations representing the behavior of this equipment are the same, whether or not the element operates as dynamo or as motor. However, the computation causality implicit in this kind of tool makes it necessary to have two different models for the same physical element: one in which the input variable is torque and output variable is voltage (representing motor operation), and the other with changed input and output variables to represent the dynamo.

2.2 Object Oriented Modeling

EcosimPro has two typically object-oriented features for the creation of new components based on existing components: component aggregation and inheritance.

2.3 Component Aggregation

EcosimPro is designed to facilitate hierarchical organization of models into submodels in a way that closely resembles the way that the system is physically assembled. This feature is commonly found in software for steady-state analysis, but it is not very common in general simulation software. Few systems provide this functionality, which is essential for users who have to build models of complex systems. This EcosimPro feature has enabled to use the commercial CAD package *Smartksketch* as a tool for the graphical definition of models (see figure 1).

2.4 Inheritance

Inheritance consists in refining an existing component by adding new data and variables, as well as new equations. For example, a basic component representing turbulent pressure drops in a pipe fitting can be refined by inheritance to represent different types of fittings such as bottleneck, elbow, orifice, etc, simply by adding the equations with the correlation for calculating the pressure drop coefficient corresponding to the specific fitting element.

3 OVERVIEW OF THE ECLSS LIBRARY

3.1 Components

The ECLSS library provides a set of components to model the equipment and process most typical of ECLSS systems: cabins, crew members, hatches, condensing heat exchangers, water separators, pipes and fittings, fans, pumps, etc.

3.2 Fluid Property Functions

The ECLSS library includes functions to calculate the properties of the following fluids: 0_2, N_2, H_20, $C0_2$, CO, NH_3, CH_4, Ar, R11, R12, R21, R22, R114 and R502.

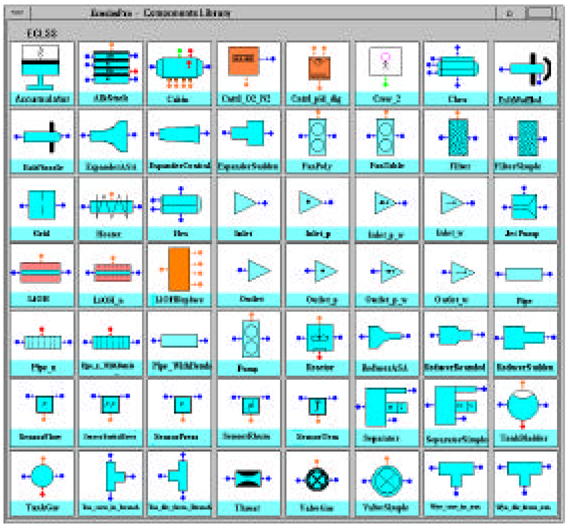

Figure 1: Palette of Components of the ECLSS Library

It also includes features for the calculation of the fluid properties of moist gas mixtures, in which water can condensate into liquid or solid phase, depending on temperature.

3.3 Features of the Thermal Library

The THERMAL CONTROL library contains the necessary components to develop lumped parameter thermal models, i.e. diffusive thermal nodes, boundary thermal nodes, linear thermal conductors, and radiative thermal conductors.

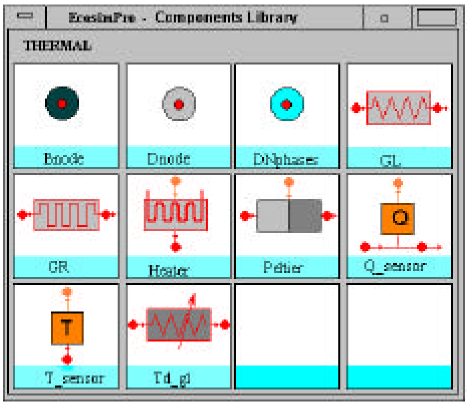

Figure 2: Palette of Components of the Thermal Library

The library also provides more specialized components to represent materials with temperature-dependent properties, Peltier elements, and multi-node walls.
Finally, a library of thermal properties for materials is defined, that the user can add to.

3.4 Advantages of EcosimPro for ECLSS and TCS

The best characteristic of EcosimPro in the simulation of ECLSS and TCS systems is its flexibility in the definition of new components and processes. The user can easily define new components with the help of an intuitive simulation language. The definition of new components can be based on already-existing components, using the aggregation and inheritance functionalities provided by the language.

EcosimPro has been applied to the simulation of the temperature and humidity control in the APM and MPLM modules of the ISS (references 1 and 2).

4 SIMULATION OF FUEL CELLS

Fuel cells are a technological area in which there are no well-established simulation tools applicable to the different types of cells. EcosimPro is therefore an excellent tool, helping to achieve the simulation of fuel cells with minimal effort, as it is possible to reuse many of the ECLSS library components, such as pumps, pipes, controllers, heat exchangers. All that is required is the development of specific models for the fuel cells themselves.

EcosimPro has been used for the simulation of an alkaline fuel cell system (reference 3) of the type employed in space vehicles; the model of this system is shown in Figure 3. The tool has also been applied to the simulation of molten carbonate fuel cells in the commercial production of electric power.

5 SIMULATION OF GAS TURBINES

As a rule, manufacturers of gas turbines and aeronautic engines have used proprietary software for engine simulation. Such software programs are quite powerful in terms of numerical and physical representation of the problem. However, they have very basic or no graphical modeling interface, as they were developed in FORTRAN.

A tool such as EcosimPro offers proven flexibility for adaptation to simulation requirements, with the added advantage of a graphic interface for all modeling activities, model definition, analysis of results, verification, etc, at a considerably lower cost than that of upgrading and modernizing the aforementioned programs.

The figure 4 shows a gas turbine model developed with EcosimPro.

5.1 Future Improvements

The International Space Station (ISS) will be a spacecraft of gigantic dimensions. EcosimPro has been applied to the analysis of the ventilation loops of the European modules such as the APM and MPLM, and is currently being used by ION Corporation in the modeling of US modules.
Current studies feature known boundary conditions in the interfaces of each module with the rest of the space station; however, greater knowledge of interactions among the different modules may lead to integrating the models of the different submodules into one global model.
Another potential analysis need is the integration of highly detailed component models in complete system models.

Both of the above objectives (a global model for the space station and the introduction of highly detailed component models) require considerable computational efficiency to achieve a reasonable response time. One of the development lines for subsequent EcosimPro releases is to improve computational efficiency for very large models with implicit solvers using sparse matrices. Since version 3.1 was released implementing the sparse solvers, EcosimPro is starting to be used with very large models. Version 3.2 includes new improvements in code generation that can lead to faster execution times.

6 CONCLUSIONS

As a generic simulation tool, EcosimPro can be adapted to different fields and supports the physical modeling of systems, a clear advantage in fields that do not feature specific and well-established simulation tools, as well as in the design of multidisciplinary systems.
The application of this tool to problems that have until now always been analyzed with a variety of separate tools represents substantial savings in the simulation cost; in addition, the engineer or analyst will not have to learn how to use multiple tools that really solve the same type of mathematical problems in different disciplines.

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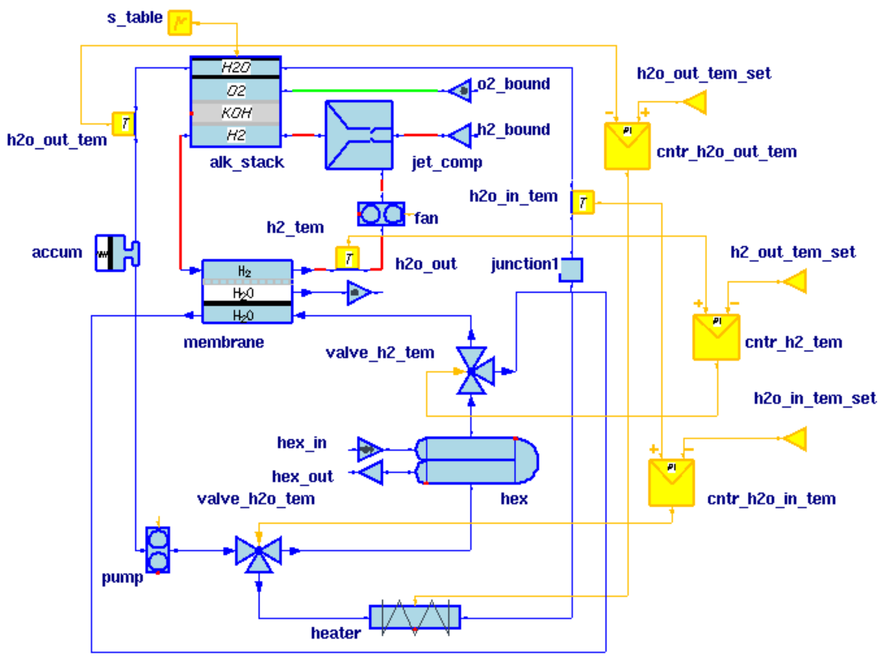

Figura 3: Fuel Cell model

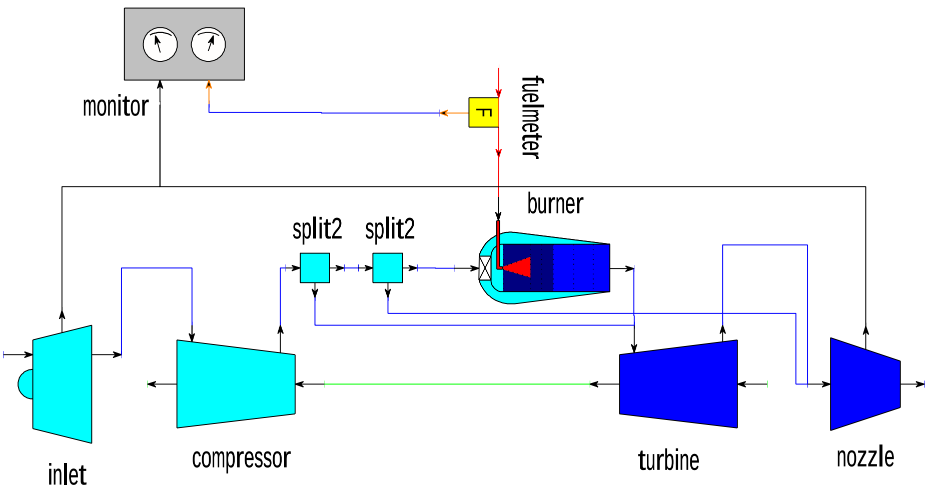

Figure 4: Propulsion model with EcosimPro