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Connecting MATLAB, EcosimPro and 20-sim to the Simulation Model Portability standard

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Executive summary

Connecting MATLAB, EcosimPro and 20-sim to the Simulation Model Portability standard

Knowledge Based Engineering with MOSAIC

Problem area

Aerospace engineers often use specific off-the-shelf model development environments (e.g. MATLAB/Simulink, Scilab, EcosimPro, Modelica, 20-sim) as their design environment for simulation models and control algorithms. At the same time many projects require that these models and algorithms are executed in real-time, e.g. with hardware and/or human-in the-loop using a specific real-time simulation environment. Furthermore, for portability and reuse, simulation models can be required to comply with the Simulation Model Portability standard (SMP2 and ECSS E40-07).

Porting the simulation models from one environment to the other and/or making them compliant to a standard by hand can be a cumbersome task. In order to reduce development costs and time it is widely acknowledged that automatic model transfer from the development tools to the real-time simulation environments and the simulation standards is essential.

NLR has developed a tool called Model-Oriented Software Automated Interface Converter (MOSAIC), which automates model transfer between commercial off-the-shelf simulation tools and simulation standards.

This report is based on a presentation held at the SESP 2012 Conference, ESTEC Noordwijk, September 26th 2012.

Up until recently the typical model transfer use case has reflected spacecraft (sub)system models which have been developed in Simulink. Now, other use cases have been brought up in which the models are developed using EcosimPro and 20-sim, which are tools for modelling of dynamic systems represented by differential-algebraic equations or ordinary-differential equations and discrete events.

Description of work
In the MOSAIC 9 project - funded by ESA/ESTEC - the automatic transfer tool has been extended from supporting one model input format (MATLAB) to three: MATLAB, EcosimPro and 20-sim. Supporting the three different types of input format and at the same time supporting five types of output format (four SMP2 compliant simulation environments and native EuroSim), has substantially influenced the architecture of the tool. The 'one-to-many' porting scheme has been replaced by a 'many-to-many' porting scheme. Furthermore the number of validation use cases has expanded significantly. The new architecture has been implemented and eleven validation cases have been used for the acceptance test of MOSAIC 9.

Results and conclusions
MOSAIC 9 supports automatic model conversion from MATLAB, EcosimPro and 20-sim to native EuroSim and to the SMP2 standard. The tool generates SMP2 compliant code as well as dedicated output code for the various SMP2 compliant simulation environments (EuroSim, SimVis/SIMSAT2, SIMSAT4 and Basiles) as it intends to support the model transfer process end-to-end. The new architecture of the tool allows for relatively easy plug-ins of even more input and output formats. In this way additional modelling tools and target simulation environments can be supported in the future to further facilitate the aerospace community.

Applicability
The application lies in the field of aerospace knowledge-based engineering. The intended use is for developers of systems who wish to benefit from commercial modelling and simulation tools (MATLAB, EcosimPro, 20-sim), the hard real-time capabilities of EuroSim and the potential of the SMP2 standard. In particular, the concurrent engineering environment SimVis is supported as SMP2 compliant modelling and simulation tool.

Many aerospace projects use and have used MOSAIC for more than a decade. Examples of applications include ESA/ESTEC's Concurrent Design Facility and the space projects Herschel-Planck, Automated Transfer Vehicle and Virtual Spacecraft Reference Facility.

MOSAIC is available as a licensed NLR product.

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Summary

In space industry, simulation model developers use specific tools to create and test their dynamic behaviour models. Typical tools for such purposes are MATLAB/Simulink, Scilab, Modelica, EcosimPro and 20-sim. At the same time many projects require that the simulation models are executed in real-time, e.g. with hardware and/or human-in the-loop. Furthermore, for portability and reuse, the models can be required to comply with the Simulation Model Portability standard (SMP2 and ECSS E40-07). In order to reduce development costs it is widely acknowledged that automatic model transfer between development tools and real-time simulation environments and simulation standards is essential. The tool MOSAIC automates model transfer between commercial off-the-shelf simulation tools and the SMP2 standard. It has been used by the European space industry for more than a decade in a large number of projects. The success of applying automatic model transfer is based on a continuous interaction with the space community, taking into account user experience.

Up until recently the typical model transfer use case has reflected spacecraft (sub)system models which have been developed in Simulink and converted automatically into SMP2-compliant models. In the target simulation environment the models are reconnected with each other (by restoring the dataflow) and integrated with other SMP2-compliant models into a complete spacecraft simulator. Now, other use cases have been brought up in which the models are not only developed using Simulink, but using other specific tools for modelling of dynamic systems represented by differential-algebraic equations or ordinary-differential equations and discrete events: EcosimPro and 20-sim. EcosimPro is used, e.g. for simulation of propulsion and power systems. 20-sim is used, e.g. for dynamics and control simulation of robot systems or for thermal simulation. The latest version of MOSAIC (Release 9) supports automatic model conversion from MATLAB as well as from EcosimPro and 20-sim to the SMP2 standard. MOSAIC 9 generates SMP2 compliant code as well as dedicated output code for the various SMP2 compliant simulation environments as it intends to support the model transfer process from end-to-end. Supporting the three different types of input format, instead of only one, has substantially influenced the architecture of the tool. In the latest version the 'one-to-many' porting scheme has been replaced by a 'many-to-many' porting scheme. The new architecture of the tool allows for relatively easy plug-ins of even more input and output formats. In this way additional modelling tools and target simulation environments can be supported in the future to further facilitate the aerospace community.

This paper details the architectural changes as well as the use cases and new applications of the tool.

Contents

Abbreviations

API	Application Programming Interface
Basiles LP	Basiles Logiciel de Production
CDF	Concurrent Design Facility
ECSS	European Cooperation for Space Standardization
ERT	Embedded Real-time Target
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre of the European Space Agency
EuroSim	European Real-Time Operations Simulator
GRT	Generic Real-time Target
GUI	Graphical User Interface
Mk	Mark
MOSAIC	Model-Oriented Software Automatic Interface Converter
NLR	National Aerospace Laboratory NLR
RTW	Real-Time Workshop
R	Release
SIMSAT	Software Infrastructure for the Modeling of SATellites
SimVis	Simulation and Visualisation in Support of Concurrent Engineering
SMP(1)	Simulation Model Portability
SMP2	Simulation Model Portability 2
VSRF	Virtual Spacecraft Reference Facility

1 Introduction

In space industry, simulation model developers use specific tools to create and test their dynamic behaviour models. Typical tools for such purposes are for instance MATLAB/Simulink, Scilab, Modelica, EcosimPro or 20-sim. At the same time many projects require that the simulation models are executed in real-time, e.g. with hardware and/or human-in the-loop. Furthermore, for portability and reuse, the models can be required to comply with the Simulation Model Portability [1] standard (SMP2 and ECSS E40-07). Converting models from one format to the other by hand is a time consuming and error prone task. In order to reduce development costs it is widely acknowledged that automatic model transfer between development tools and real-time simulation environments and simulation standards is essential. The tool Model-Oriented Software Automated Interface Converter - for short MOSAIC - automates model transfer between commercial off-the-shelf simulation tools and the SMP2 standard. Its design is based on the philosophy that model changes and model decomposition should be done in the originating development environment. The tool treats the model as a black-box and adds interfacing code to it. It does not affect the mathematical logic of a model. MOSAIC has been used by the European space industry for more than a decade in a large number of projects. The success of applying automatic model transfer is based on a continuous interaction with the space community, taking into account user experience.

Up until recently a typical model transfer use case has reflected spacecraft (sub)system models which have been developed in Simulink and converted automatically into SMP2-compliant models. In the target simulation environment the models are reconnected with each other (by restoring the dataflow) and integrated with other SMP2-compliant models into a complete spacecraft simulator. Now, other use cases have been brought up in which the models are not only developed using Simulink, but using other specific tools for modelling of dynamic systems represented by differential-algebraic equations or ordinary-differential equations and discrete events: EcosimPro and 20-sim. EcosimPro [2] is used, e.g. for simulation of propulsion and power systems. 20-sim [3] is used, e.g. for dynamics and control simulation of robot systems or for thermal simulation. The latest version of MOSAIC (Release 9) [4] supports automatic model conversion from MATLAB to EuroSim (native format) and the SMP2 standard, as well as from EcosimPro and 20-sim to the SMP2 standard (see Fig. 1).
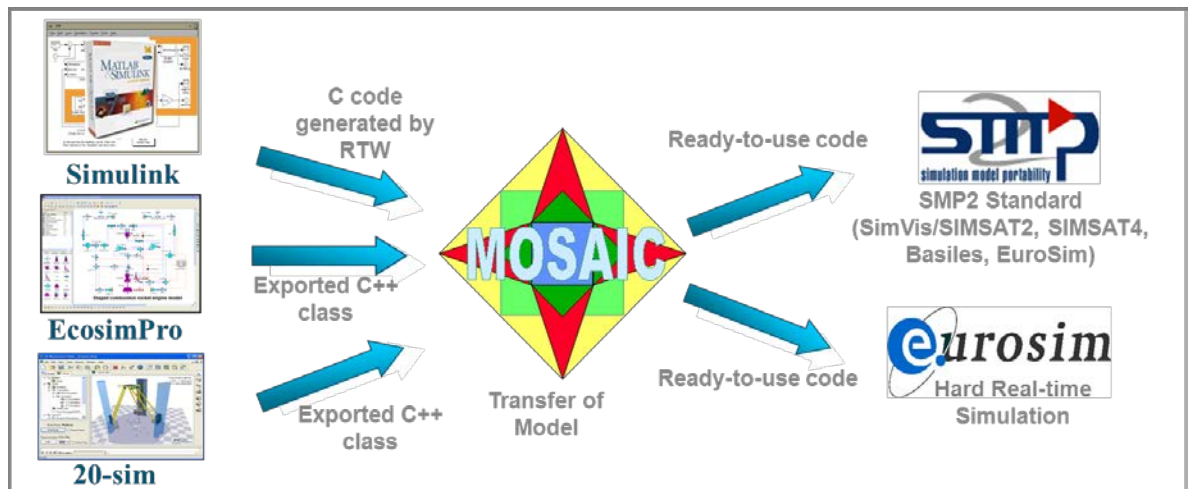
5

Fig. 1. Illustration of MOSAIC 9 conversion: input and output model formats

EuroSim has been chosen as target environment for hard real-time simulation. For SMP2-compliant simulation SimVis/SIMSAT2, SIMSAT4, Basiles, and again EuroSim have been chosen.

2 A new MOSAIC architecture

A key requirement of the MOSAIC 9 project was to support multiple model input formats MATLAB/Simulink (R2010b), EcosimPro 4.8, 20-sim 4.1, and possibly more in the future, while preserving the usability and maintainability of the tool. In line with previous versions, MOSAIC 9 generates SMP2 compliant code as well as dedicated files (e.g. makefiles, configuration files) for the various SMP2 compliant simulation environments (EuroSim, SimVis/SIMSAT2, SIMSAT4 and Basiles) as it intends to support the model transfer process from end-to-end. Supporting now the three different types of input format, instead of only one formerly, has substantially influenced the architecture of the tool. In MOSAIC 9 the 'one-to-many' porting scheme (see Fig. 2) has been replaced by a 'many-to-many' porting scheme (see Fig. 3). In the 'one-to-many' case the tool takes as input the exported C code from the MATLAB/Simulink model, as created with the Real-Time Workshop (RTW). The MOSAIC 'MATLAB module' parses the code for parameter values and meta information that will be relevant to SMP2 interfacing later on. For example the model time step, structure fields with input and output variables are captured from the model. The 'SMP2 module' or the 'EuroSim Native module' add the interfacing code to the model as required by the SMP2 standard or by the native EuroSim format. After that specific adaptations to the format and specific files as required by the target simulation platforms are added by separate modules. In case of the

'Many-to-many' architecture the 'Standard support' and the 'Simulation platform support' steps are similar to the 'One-to-many' case. However, there are now three possible input formats which need to be connected to SMP2 in a modular way. Additional modules have been created that can handle EcosimPro and 20-sim input formats. Similar to the 'MATLAB module' they retrieve the model parameter values and meta data relevant to SMP2 later on. However their implementation is different because in case of EcosimPro a model API is provided to query the model during MOSAIC conversion. In case of 20-sim an XML file that contains the model information is parsed by MOSAIC. The three MATLAB, EcosimPro or 20-sim modules of MOSAIC are invoked by the MOSAIC 'Model description module' depending on the input format that is selected by the end user. In this way a tool independent model description is derived during the model transfer process, which is used to create the interface code for the SMP2 or native EuroSim output formats.
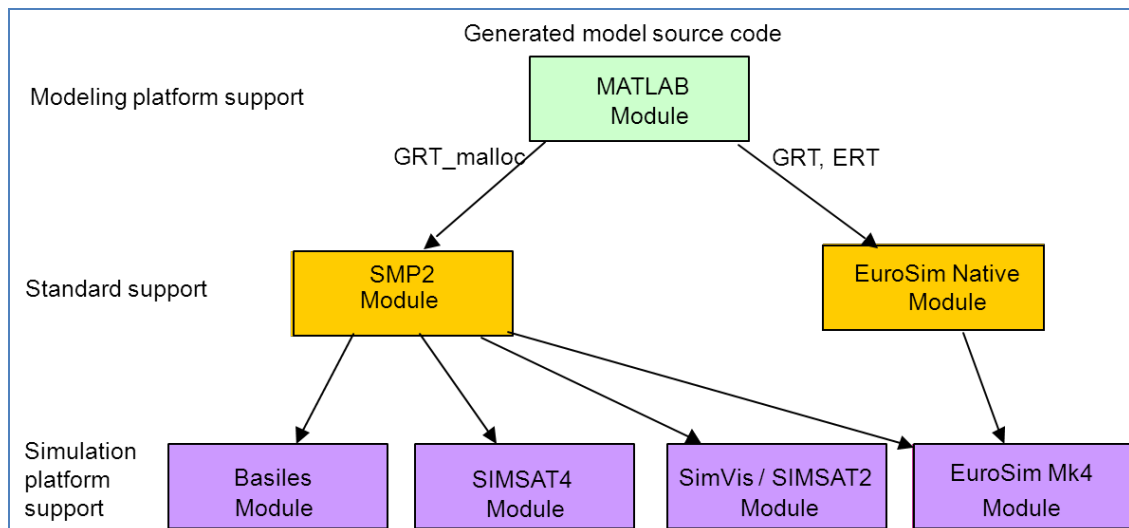

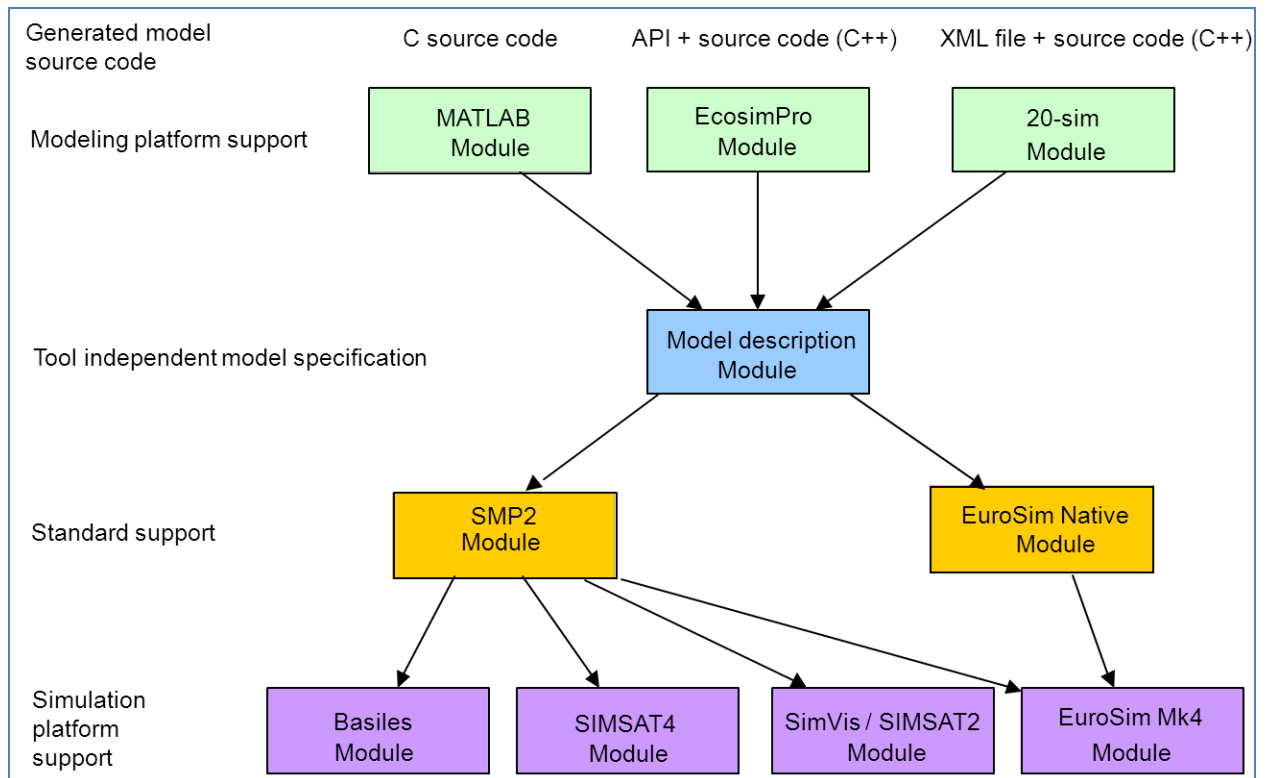*Fig. 2. Previous MOSAIC 'One-to-many' architecture*

Fig. 3. New MOSAIC 'Many-to-many' architecture in MOSAIC 9

The redesigned architecture of the tool allows for relatively easy extension to even more input and output formats. In this way additional modelling tools and target simulation environments can be supported in the future to further facilitate the space community.

3   Collaborative development approach

Because usability (and effective maintainability) of the tool was a major condition to the MOSAIC 9 development, a collaborative approach has been chosen. Envisaged end-users of MOSAIC (from ESTEC) have been involved in the project to get user feedback on the development of the tool from various use case perspectives. Furthermore, the developers of EcosimPro and 20-sim (Empresarios Agrupados and Controllab respectively) have been involved in the project - as the support of these tools is new for MOSAIC- to advise on the use of these simulation tools in the model transfer process and to discuss feedback from the MOSAIC developers on the possibilities of these tools to further facilitate automatic model transfer in the future. In this way developments of EcosimPro, 20-sim and MOSAIC are streamlined as far as automatic model transfer is concerned.

During the first project phase different MOSAIC9 prototypes have been developed that facilitate three main use cases as identified by ESTEC:

- MATLAB to EuroSim transfer (Virtual Spacecraft Reference Facility (VSRF) / Automatic Test Bed (ATB) use case).
- EcosimPro to SimVis/SIMSAT2 transfer (Concurrent Design Facility (CDF) use case).
- 20-sim to SIMSAT4 transfer (Robotics Lab use case).

The prototypes have been created quickly, still without the 'many-to-many' architecture of MOSAIC9. Each of them facilitated only one transfer combination. The prototypes (including documentation with guidelines for use) have been tested and reviewed by the end users. The documentation has also been reviewed by the EcosimPro and 20-sim developers as it included first feedback on the use of these tools with automatic model transfer. All feedback has been discussed and processed as much as possible into the final version of MOSAIC9 that integrated enhanced versions of the prototypes into the 'many-to-many' architecture.

NLR is also involved in the development of EuroSim. Parallel to MOSAIC 9 a project was on-going in which SMP2 support by EuroSim was further enhanced, resulting in EuroSim 4.4 [9]. To be able to realize an end-to-end solution for automatic model transfer, the development of SMP2 support both by MOSAIC and EuroSim have been adjusted to each other, so that at the end of both projects both resulting tool versions are compatible. MOSAIC9 is able to generate SMP2-compliant code compatible with EuroSim 4.4 (including configuration files and makefiles), while on the other hand during EuroSim 4.4 development, MOSAIC 9 has been used as a tool to quickly generate complex models for EuroSim verification & validation.

4 MOSAIC 9 implementation results

The modular architecture of MOSAIC 9 has allowed various transfer combinations (see also Fig. 1). However, not all combinations have been supported yet or have been validated yet. An overview of the supported transfer combinations is given in Table 1. The key requirement for MOSAIC 9 was to facilitate model conversion from MATLAB, EcosimPro and 20-sim to SMP2. Therefore transfer from EcosimPro and 20-sim to the native EuroSim format is not yet supported, although this would be feasible. Transfer from MATLAB to native EuroSim is supported (and validated) as this has always been supported by MOSAIC.

Transfer from EcosimPro to SIMSAT4 or Basiles was not validated in the frame of MOSAIC 9 because these target SMP2 simulation environments where provided on a Linux platform, whereas EcosimPro was provided on the Windows platform and the EcosimPro libraries that need to be copied during the model transfer process where only Windows based. However this could be enhanced in future versions. In some other cases (EcosimPro to EuroSim-SMP2 or 20-sim to EuroSim-SMP2, Basiles or SimVis/SIMSAT2) the transfer combination is possible with MOSAIC 9 but was also not validated yet. The validation of MOSAIC 9 has been based on the three main use cases as described in the previous section.

Table 1. MOSAIC9 implemented transfer combinations.
(V = Validated, NV = Not validated, NS = Not supported)

		Output format				
		SMP2				Native
		EuroSim	SIMSAT 4	SimVis/ SIMSAT 2	Basiles	EuroSim
Input format	MATLAB R2010b	V	V	V	V	V
	EcosimPro 4.8	**NV**	**NV**	**V**	**NV**	**NS**
	20-sim 4.1	**NV**	**V**	**NV**	**NV**	**NS**

MOSAIC 9 is executable both from a Graphical User Interface (GUI) and from a command-line version on Windows and Linux. As a result of the newly supported transfer combinations, the MOSAIC GUI needed a redesign with a focus on the usability. Several features related to the supported simulation platforms or to the SMP2 standard are presented to the end user in a manner compact and easy to understand. Additional, seldom used options are available in the command line version. An overview of the MOSAIC user interface is given in Fig. 4 below.
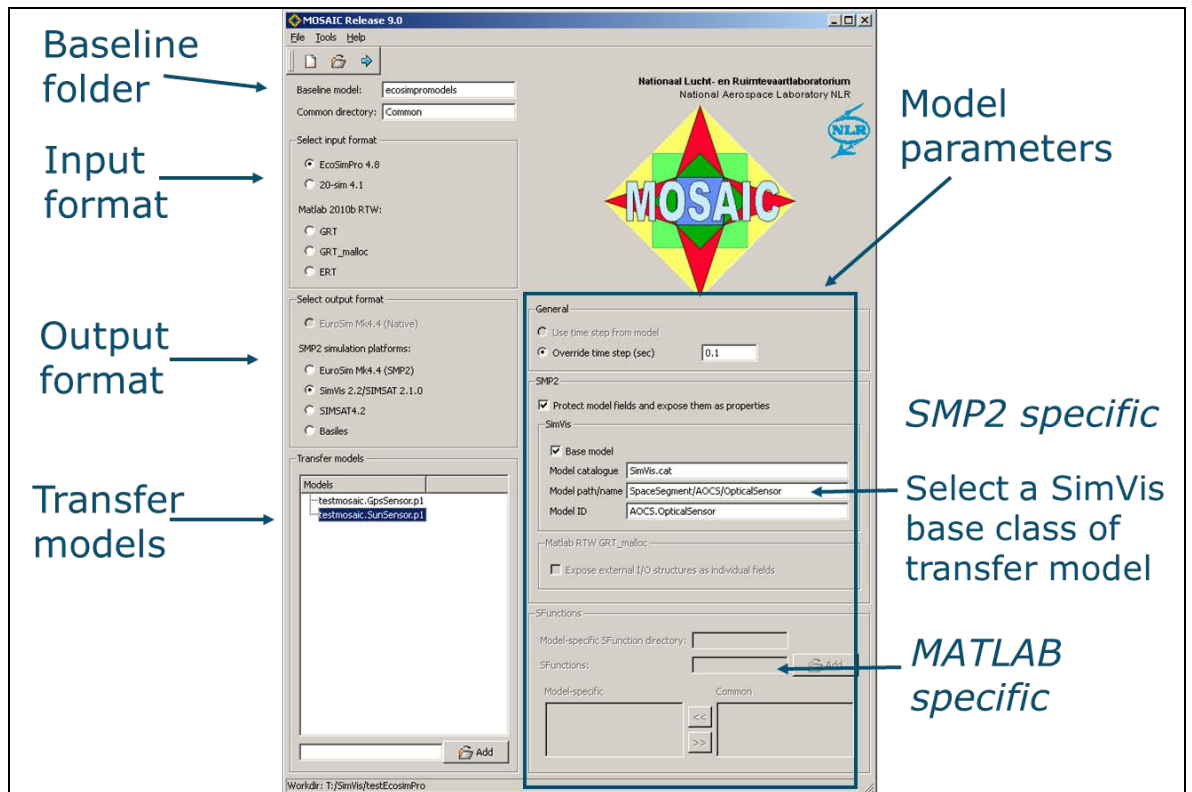
Fig. 4. Overview of MOSAIC 9 user interface

5 Verification & Validation

A considerable amount of effort in the MOSAIC 9 project has been put into the verification and validation of the tool. Testing was already started with the prototypes and the final version has been tested internally at NLR using an extensive set of test models. The compliancy of the MOSAIC generated SMP2 specific files (catalogue, assembly and schedule) has been verified by means of the SMP2 Conformance Suite (CS) [8]. Only a few non-conformances of the code were encountered that are justifiable. Each (justifiable) non-conformance has been documented for future MOSAIC development [7]. Eleven acceptance test cases have been formulated for MOSAIC 9, mainly based on the use cases as described before. All acceptance models have been created by ESTEC. All acceptance tests have been passed by MOSAIC. Below details are given about the acceptance tests structured by the use cases as well as further application examples that relate to these use cases.

5.1 MATLAB to Eurosim (Native) and SMP2 Use Cases

An open loop VSRF model has been provided that includes sub-models of sensors, controllers and actuators without the environment model. This model has been converted by MOSAIC in

one step as a whole to native EuroSim and to the SMP2 compliant simulation environments Basiles, SIMSAT4 and EuroSim. Sub-models of the VSRF of a sun sensor and a Global Positioning System (GPS) sensor have been ported by MOSAIC to SimVis/SIMSAT2 and integrated with the SimVis spacecraft model to simulate a blinding analysis mission [5].

MOSAIC 9 has already been applied successfully to provide an acceptance model for the EuroSim development project. A Simulink model containing a GPS sensor and an environment model has been decomposed. The two sub-models have been transferred as two separate black-boxes in one step to SMP2 compliant EuroSim models. In EuroSim the models have been reconnected and simulated using the features of the new EuroSim version. The dataflow between the models has been restored using SMP2 features.

Furthermore, the NLR space department has applied MOSAIC 9 to convert MATLAB models of a spacecraft attitude and orbit control simulator into SMP2 compliant models, which were reconnected and simulated in EuroSim. This is described in [6].

5.2 EcosimPro to SimVis Use Case

A sun and GPS sensor model, similar to the VSRF sub-models (as described above) were implemented in EcosimPro by ESTEC. These models have been converted by MOSAIC to SimVis/SIMSAT2 and integrated with the SimVis spacecraft model into the same blinding analysis mission [5]. Furthermore a multi-purpose EcosimPro model has been used that covers EcosimPro modelling features as widely as possible (e.g. use of bounds, discrete, continuous, string variables). The correctness of the mapping of the different EcosimPro variable categories and types on to the SMP2 field and property attributes has been verified by inspecting the generated catalogue. Furthermore - next to the verification of the dynamic behaviour of the model before and after conversion - some other advanced features like events handling, zero-crossing detection or discrete behaviour have been also tested. Further application of EcosimPro model transfer to SMP2 is expected in the context of the CDF now MOSAIC 9 is available.

5.3 20-sim to SIMSAT4 Use Case

Three behaviour models implemented in 20-sim representing different types of physics have been provided by the ESTEC Robotics Lab for MOSAIC acceptance.

- An Inertial Measurement Unit (IMU) model was subdivided into two sub-models in 20-sim and exported into two C++ code. The models have been converted by MOSAIC to SMP2 and reconnected and simulated in SIMSAT4. The dataflow has been restored using one of the two generated SMP2 assembly files.

- A 5 Degrees of Freedom robotic manipulator (kinematics, dynamics and a simple control scheme) using the 3D mechanics feature of 20-sim has been transferred as a whole to SMP2 and simulated in SIMSAT4. The model input signals have been read in from a text file.
- A model for a thermal node of a planetary rover system implemented in 20-sim has been converted to SMP2 and simulated in SIMSAT4. In this case new parameters have been inserted into the simulation by changing the SMP2 assembly file.

The ESTEC Robotics Lab will further apply MOSAIC 9 for model transfer from 20-sim to SIMSAT4 in the future.

6 Conclusions and recommendations

It has been proven that the new enhanced version of MOSAIC can be used for automatic model conversion from MATLAB, EcosimPro and 20-sim to SMP2 compliant simulation environments and native EuroSim, with support from end-to-end. It can handle complex simulation models and serves various use cases. One can conclude that
- the MOSAIC 9 project has provided a fundamental enhancement of MOSAIC capabilities,
- the success of the project was based on continuous interaction between tool developers and end users from the space community,
- automatic model transfer is of strategic importance for ESTEC and the space community.

Recommendations for future development have been documented based on user experience [7]. These are candidate for inclusion in a future version of MOSAIC. A selection is listed here:
- MOSAIC could provide a catalogue browser for selection of base classes of transfer models from existing catalogues.
- A more extensive use of EcosimPro model meta information could be used, either to an enhanced EcosimPro API or by parsing additional files.
- The new version of 20-sim exports models with variable step solvers into C++ code. Conversion of this type of models to SMP2 could be supported by MOSAIC.

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