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Automated model transfer in space applications

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Summary

MOSAIC (Model-Oriented Software Automated Interface Converter) automates transfer of simulation models from MATLAB/Simulink/Stateflow to EuroSim and ESA's Simulation Model Portability (SMP) standard. Many aerospace projects use MOSAIC for automatic model transfer. Examples of MOSAIC applications in the Netherlands are the Herschel-Planck project, ATV and VSRF which involve amongst others ESTEC, Dutch Space, Terma and NLR.

This paper describes recent MOSAIC developments and the application of MOSAIC in space projects. The PACS project and its application of MOSAIC are described in more detail. Finally future development plans of MOSAIC are presented.

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1 Introduction

The international simulation community is in the process of defining standards with respect to model portability [2]. One of the main objectives is to enable simulation models (source code) to run in any simulation tool, independent of which tool was used for model creation. The main concern in the short term is the willingness of tool vendors to make their product compliant to such a standard. Meanwhile, project milestones and deadlines in space programmes do not allow for unnecessary delays due to problems with the integration of models form different origin. As a remedy to this problem NLR has developed MOSAIC (Model-Oriented Software Automated Interface Converter) which automates atomic model transfer between Commercial Off-The-Shelf (COTS) tools and simulation standards [1].

Aerospace projects often use MATLAB/Simulink [6] as their design environment for simulation models and control algorithms. At the same time many projects require that these models and algorithms are tested in real-time, e.g. with hardware and/or human-in the-loop. To reduce development costs it is acknowledged that automatic model transfer between development tools and real-time simulation environments is essential. Many aerospace projects [4,5] use MOSAIC for automatic model transfer.

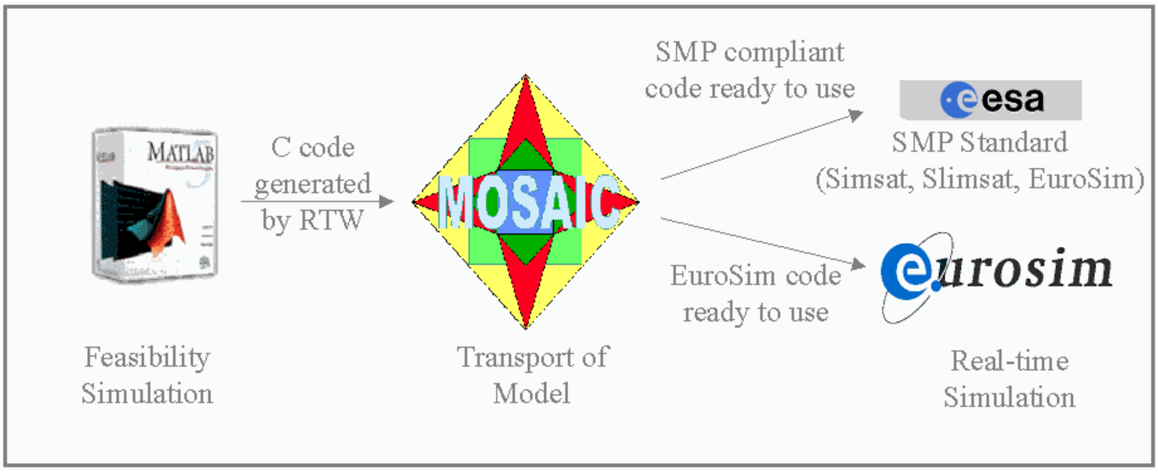

Fig.1. Context diagram of MOSAIC

MOSAIC automates transfer of simulation models from MATLAB/Simulink/Stateflow to EuroSim and ESA's Simulation Model Portability (SMP) standard [2], using the Real-Time Workshop (RTW) of MATLAB/Simulink, see Fig. 1. EuroSim [7] is a real-time simulation environment that supports a complete project life cycle from feasibility studies to tests with hardware and/or human-in the-loop. The SMP standard promotes portability and re-use of simulation models in different simulations with different simulation environments. SIMSAT

[9], SLIMSAT [8] and EuroSim are examples of simulation environments that currently support the SMP standard.

The design of MOSAIC is based on the philosophy that model changes, model decomposition and model segmentation should be done in originating environment, e.g. MATLAB/Simulink. MOSAIC treats the model as a black-box and adds interfacing code to it. Therefore MOSAIC does not in any way affect the mathematical logic of a model.

The remainder of this paper is as follows. First, recent MOSAIC developments are presented. Second, applications of MOSAIC in the space industry are described. Third, application of MOSAIC in the PACS project is described in more detail. Finally future plans on MOSAIC developments are presented.

2 New features of MOSAIC

The MOSAIC product is developed and maintained by the National Aerospace Laboratory NLR with support of ESTEC. The latest version, MOSAIC Release 6 has been finished under ESA contract in May 2004. MOSAIC 6 is developed using C++. The MOSAIC software is available for different operating systems. It has already been used successfully on IRIX, Windows (NT /2000/XP) and Linux. MOSAIC 6 can transfer single or multiple Simulink models in one step. This way a system simulation model can be tested in real-time as a whole or by building it gradually from sub-system models. Within EuroSim context this means that MOSAIC creates and updates a EuroSim model file that defines a set of (sub) models. For SMP this means that MOSAIC creates and updates a Model Manager that controls a set of (sub) models. Through SMP also hierarchical meta information is added to the set of system models. The actual use of MOSAIC is described in [3].

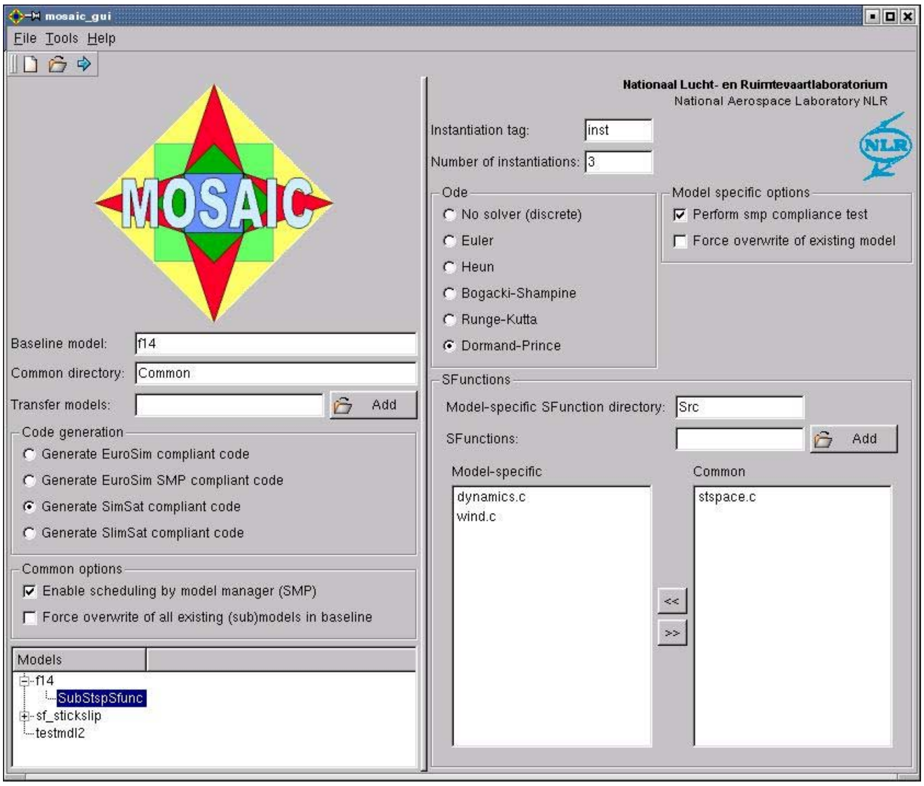

Fig. 2. MOSAIC Graphical User Interface

The target simulation environments for which MOSAIC can generate SMP compliant model code are SIMSAT, SLIMSAT and EuroSim. All environments are SMP 1.4 compliant, but do not always fully implement it. Therefore MOSAIC has different options to choose the target simulation environment in which the model(s) will be used, see Fig. 2. When using SMP code generation, MOSAIC will by default generate code in which the models and sub-models are responsible for the scheduling themselves during simulation. It is also possible to activate the scheduling option: “scheduling by model manager”. If this option is chosen, MOSAIC will generate code in which the generated Model Manager is responsible for the scheduling of the models. Furthermore, there is the option that MOSAIC automatically lets the generated SMP compliant model perform an SMP compliance test.

3 MOSAIC Applications

Many aerospace organisations recognise the model transfer capabilities of MOSAIC. Therefore MOSAIC is used in many space projects, e.g. in Herschel-Planck [10,11] and ATV. ESA/ESTEC applies MOSAIC in the framework of the Virtual Spacecraft Reference Facility (VSRF) [4] for testing the portability to EuroSim Mk3.1 of the sensor and actuator models. Within ESTEC's Concurrent Design Facility (CDF) MOSAIC has been used for the AeroCapture study [5]. A MATLAB/Simulink model has been developed to simulate the separation of bodies. MOSAIC has transferred the model to EuroSim for 3D visualisation, see Fig. 3.

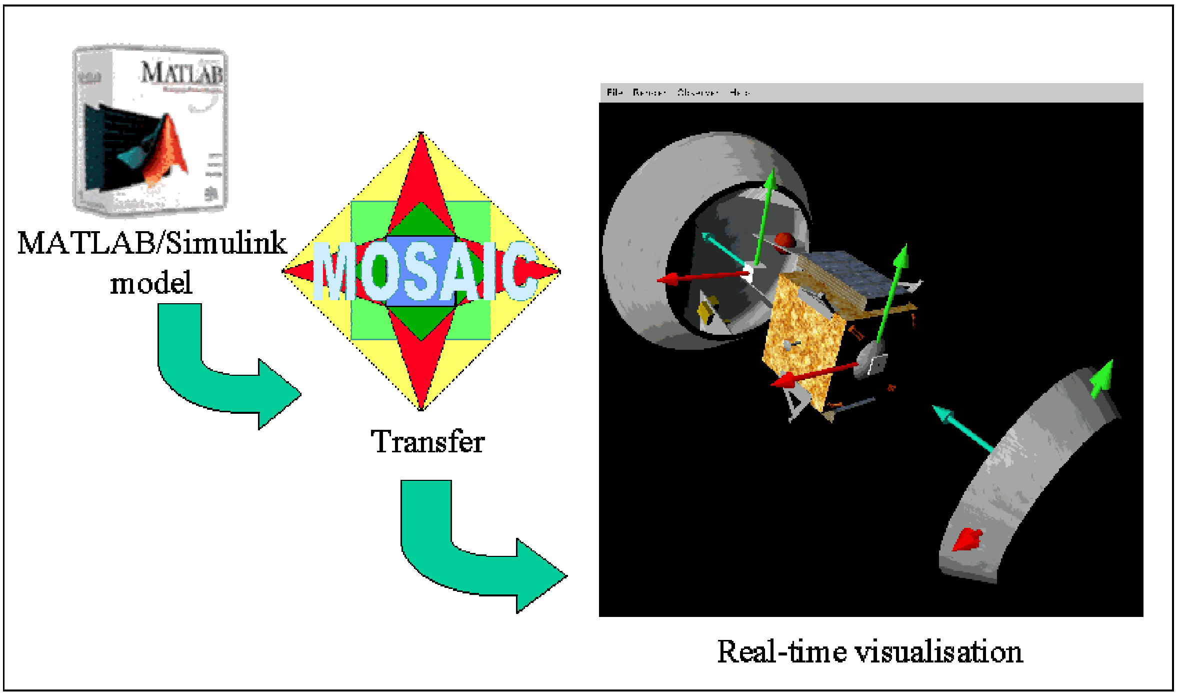

Fig. 3. MOSAIC applied in the AeroCapture study

Furthermore, NLR applies MOSAIC in its flight simulators, and for on-board software testing in its research aircraft. NLR's Space Department frequently uses MOSAIC, e.g. for their Test and Verification Equipment Next Generation (TVE NG) for spacecraft avionics. A basic version of TVE NG is applied in the PACS Project. The application of MOSAIC in the PACS project is described in detail in the next section.

4 The PACS project

The Precision Agile Control System (PACS) project is an ESA Technical Research Program. The PACS study is conducted by Alcatel Space as Prime Contractor, with Deimos and the National Aerospace Laboratory (NLR) as subcontractors. The overall goal of the PACS project is to develop and validate technology for an agile Attitude Control and Measurement System (ACMS), using on Control Moment Gyros (CMGs) as actuators, for LEO Earth Observation satellites. The SPECTRA s/c (spacecraft) is the first target for such a system. The foreseen SPECTRA ACMS incorporates as actuators a cluster of 4 CMGs, thrusters and magnetic torquer bars, as s/c attitude and rate sensors magnetometers, coarse sun-sensors, gyros and star trackers, and as s/c orbital position sensor a Global Positioning System (GPS) receiver. The ACMS on-board software (OBSW) will run on an on-board computer equipped with a Sparc ERC32 processor.

One objective of the PACS project is to demonstrate closed-loop real-time performance of an efficient CMG guidance algorithm for fine pointing and agile maneuvering, in a real-time test bench (RT-TB).
The RT-TB includes

- the ACMS OBSW running real-time on a target-representative on-board computer emulator (VME Sparc ERC32 board)
- a HW CMG breadboard model mounted on a three-axes rotation table.
- a Real-Time Simulation (RTS) of the ACMS running under the EuroSim simulation environment. The RTS includes models of the s/c orbit, s/c attitude dynamics, s/c disturbances and environment, and s/c sensors and actuators. The closed loop is formed by the OBCS reading out the simulated ACMS sensors and commanding the (simulated and real) actuators. The three-axes rotation table setpoints are commanded by s/c attitude data from the RTS.
- The ESA standard SpaceCraft Operations System (SCOS2000)

A second objective of the PACS project is to apply a state-of-the-art paradigm for software development and validation. The applied paradigm implies the development and early validation of the simulation software and on-board software in a graphical design and simulation tool, and the subsequent use of automatic C code generation and model transfer for the implementation of the two software subsystems in their respective real-time test target environments. This paradigm pertains to both the development of the simulation software as well as the development of the on board software. The graphical design tools used are MATLAB/Simulink/Stateflow, with MATLAB's Real-Time Workshop for automatic code generation. MOSAIC is used for model transfer. Design and development and early validation of software in a graphical design and simulation tool such as MATLAB or others and the use of automatic code generation promises efficiency improvements for software development and application of this paradigm is investigated by Alcatel Space. Use of automatic code generation and model transfer is also a subject of current ESA research. The application in the PACS project allows to learn lessons and draw conclusions about the state-of-the-art, and related development and programmatic risks, in the area of software engineering.

The on-board software includes the application software implementing the control algorithms as well as the rest of the software (SW) that has to be developed to support the execution of the control algorithms; i.e. the Basic SW and on-board application SW shell. The Basic SW is the lowest layer (apart from the Real Time Operating System and Board Support Package) in the OBASW architecture. The OBASW shell is a layer between the ACMS application software and the Basic SW, isolating the ACMS application software from the physical and real-time aspects of the software execution environment.

The real-time simulation software includes as mentioned above a compound model of the ACMS including (sub) models of the s/c orbit, attitude dynamics, disturbances and environment, and sensors and actuators. The inner structure of the compound simulation model in Simulink is given in Fig. 4 below.

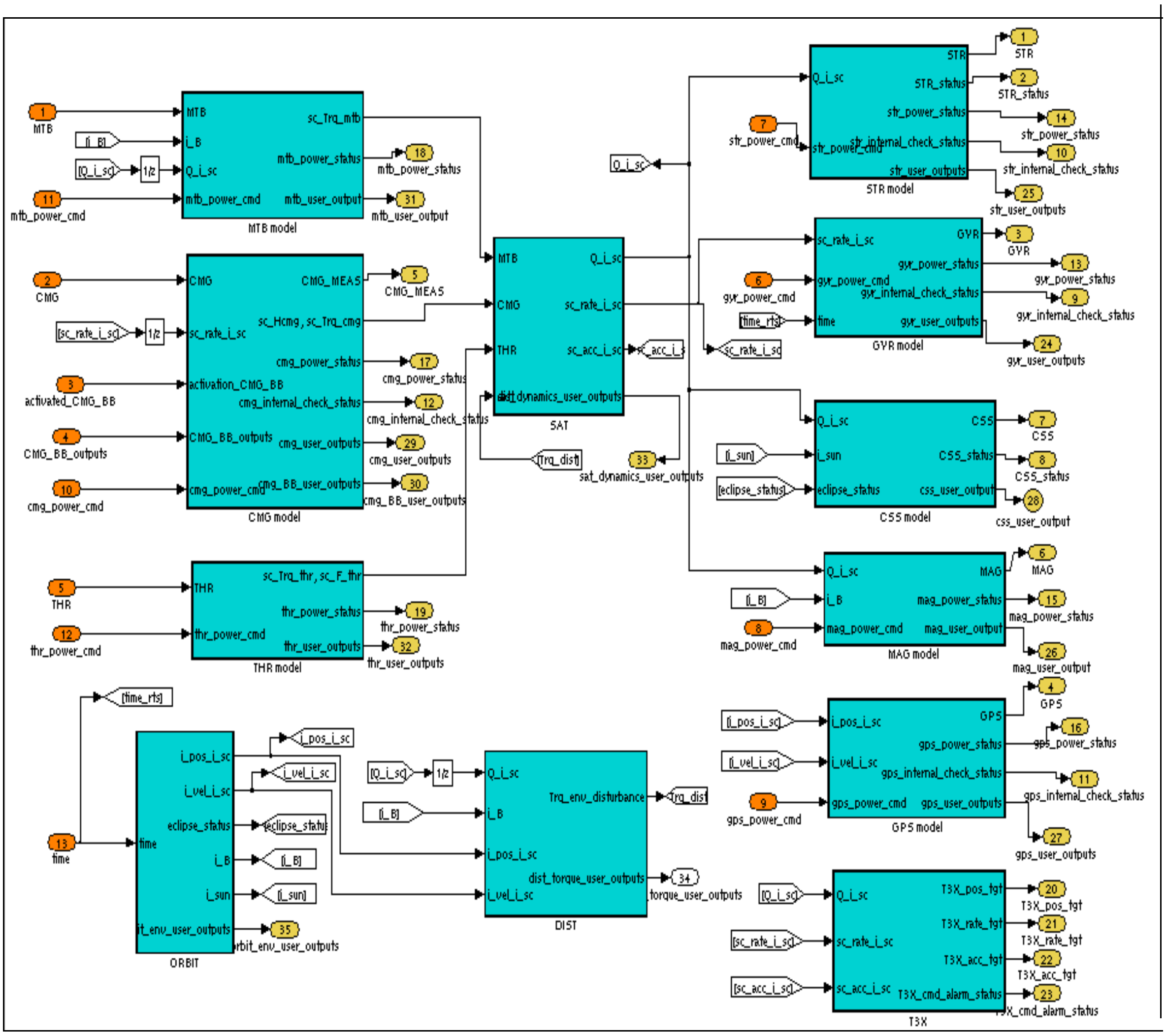

Fig. 4. Compound PACS simulation model in Simulink

The model is a multi-rate model: the highest simulation frequency is 96 Hz. The real-time version of the model is to run in the RT-TB under the EuroSim simulation environment. The EuroSim simulation environment has been chosen because it is a powerful real-time simulation environment and, most importantly, the MOSAIC tool can be used for automatic transfer of the Simulink models into the real-time EuroSim environment. As described above, MOSAIC facilitates easy automatic or semi-automatic integration of compound Simulink simulation models into EuroSim. Using MOSAIC it is possible to transfer a compound model as one (atomic) model as well as a set of sub-models. In the PACS project the compound multi-rate simulation model was transferred as an atomic model, i.e. the MATLAB RTW was made to generate one integrated C code model of the compound Simulink model. The RTW generated C code was subsequently converted into EuroSim compatible code using MOSAIC. The resulting model is scheduled in EuroSim at the highest simulation frequency of the compound model

(96 Hz). The internal logic of the model inherited from the Simulink compound model then takes care of the scheduling of the lower frequency parts of the model.

Lessons learned:

- The atomic model transfer of the compound model in Simulink via RTW and MOSAIC and the subsequent integration in EuroSim proved very simple (some mouse clicks), straight forward, fast (order of minutes), and error free. The resulting model was scheduled in EuroSim at the highest simulation frequency of the compound model (96 Hz). The internal logic of the model inherited from the Simulink compound model takes care of the scheduling of the lower frequency parts of the model. Hence, explicit scheduling of submodels in EuroSim is not required.
- Care should be taken when validating the real-time simulation under EuroSim against the MATLAB/Simulink original.
  - Firstly, the time points at which samples are taken (i.e. logging the output variables) in both simulations are not the same. The calculation steps and order by which Simulink performs a simulation step is: calculate model inputs (Input), calculate model outputs (Output), calculate next model states (Update State). To achieve that samples taken by MATLAB/Simulink can be compared by the samples taken by EuroSim, the EuroSim Action Manager, which performs the logging in EuroSim, should be scheduled explicitly in the EuroSim task scheduler, in the following sequence of tasks: Input, Output, Action manager, Update State.
  - Secondly, care should be taken when transferring a compound model as a set of submodels. Sometimes it may be desirable to transfer a compound model in Simulink as a set of submodels to EuroSim. This allows the separate scheduling of the submodels under the EuroSim scheduler. A library of solvers used by Simulink is available in EuroSim; hence the same solvers can be used in EuroSim as in Simulink. Fixed step solvers shall be used for models to be transferred to EuroSim. However, in Simulink a compound model is integrated as one big model, i.e. the intermediate integration steps used by multi-stage fixed step solvers are applied simultaneously over all submodels. In EuroSim, even when using the same multi-stage fixed step solver, the submodels are integrated separately, sub model by sub model, in the order in which they are scheduled. This causes differences between Simulink and EuroSim results. In these cases fixed step single stage rectangular integration (Euler 1) that uses no intermediate points over the integration time step should be used for validation, as this would yield the same results in Simulink and EuroSim. In the PACS project has chosen to transfer the compound Simulink model as one integrated model to EuroSim, as the Simulink model used a fixed step multi-stage solver for accuracy reasons.

5 Concluding remarks and Future plans

The NLR product MOSAIC has become an important ingredient of many space projects. New functionalities are added to MOSAIC based on user experience. In general developments of MOSAIC are driven by customer requests. Updates of COTS tools and model standard definitions usually result in an upgrade of the MOSAIC capabilities. In the near future MOSAIC will support version 2 of the SMP standard, and it will support of MATLAB TLC files for model transfer. The design of MOSAIC is modular. Because of this MOSAIC can be easily extended to satisfy new needs in simulation model interfaces. MOSAIC is available as a licensed NLR product [12].

6 References

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Appendix A List of abbreviations

ACMS	Attitude Control and Measurement System
ATV	Automated Transfer Vehicle
CDF	Concurrent Design Facility
CMG	Control Moment Gyros
COTS	Commercial Off-The-Shelf
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre
EuroSim	European Real-Time Operations Simulator
GPS	Global Positioning System
HW	Hardware
LEO	Low Earth Orbit
MOSAIC	Model-Oriented Software Automatic Interface Converter
NLR	National Aerospace Laboratory NLR
OBCS	On Board Computer Simulator
OBSW	On Board Software
OBASW	On Board Application Software
PACS	Precision Agile Control System
RT-TB	Real-Time Test Bench
RTS	Real-Time Simulation
RTW	Real Time Workshop
SCOS	Spacecraft Control and Operations System
SIMSAT	Software Infrastructure for the Modeling of SATellites
SMP	Simulation Model Portability
SPECTRA	Surface Processes and Ecosystem Changes Through Response Analysis
SW	Software
s/c	spacecraft
TLC	Target Language Compiler
TVE NG	Test and Verification Equipment Next Generation
VSRF	Virtual Spacecraft Reference Facility