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Simulation Data Management Approach for Developing Adaptronic Systems – The W-Model Methodology

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***Abstract*—**Existing proceeding-models for the development of mechatronic systems provide a largely parallel action in the detailed development. This parallel approach is to take place also largely independent of one another in the various disciplines involved.

An approach for a new proceeding-model provides a further development of existing models to use for the development of Adaptronic Systems. This approach is based on an intermediate integration and an abstract modeling of the adaptronic system. Based on this system-model a simulation of the global system behavior, due to external and internal factors or Forces is developed. For the intermediate integration a special data management system is used. According to the presented approach this data management system has a number of functions that are not part of the "normal" PDM functionality.

Therefore a concept for a new data management system for the development of Adaptive system is presented in this paper. This concept divides the functions into six layers. In the first layer a system model is created, which divides the adaptronic system based on its components and the various technical disciplines. Moreover, the parameters and properties of the system are modeled and linked together with the requirements and the system model. The modeled parameters and properties result in a network which is analyzed in the second layer. From this analysis necessary adjustments to individual components for specific manipulation of the system behavior can be determined. The third layer contains an automatic abstract simulation of the system behavior. This simulation is a precursor for network analysis and serves as a filter. By the network analysis and simulation changes to system components are examined and necessary adjustments to other components are calculated. The other layers of the concept treat the automatic calculation of system reliability, the "normal" PDM-functionality and the integration of discipline-specific data into the system model.

A prototypical implementation of an appropriate data management with the addition of an automatic system development is being implemented using the data management system ENOVIA SmarTeam V5 and the simulation system MATLAB.

***Keywords*—**Adaptronic, Data-Management, LOEWE-Centre AdRIA

I. Introduction

Due to the integration of mechanical and electronic components in mechatronic systems a close cooperation between the various disciplines becomes necessary. These disciplines use various models to describe the systems and component structures and functions.

In literature there are different approaches to coordinate and control the cooperation between the various disciplines, such as the V-Model in [1]. For an optimal development of mechatronic systems, the V-model provides a largely parallel, independent action in the detailed development by the various disciplines, because of the different description methods and models.

This contrasts with the results of studies in the automotive industry. These studies showed that there are a lot of problems during the integration of the discipline-specific solutions caused by a lack of communication of results and data during the parallel development [2]. To solve these, ProSTEP recommends the alignment of results between the different disciplines on given times during the detailed, parallel development of mechatronic system components [2].

Due to the higher degree of structural integration of electronic components there is a higher dependence between the specific disciplines in adaptronic systems. Therefore we can assume that the problems shown by ProSTEP become larger if the existing process models for the development of mechatronic system are used for the development of adaptronic systems without adaption or modification. For improving the development process of adaptronic systems it is therefore necessary to ensure a comparison of the discipline specific results during the detailed design.

Bellalouna uses the SOA-concepts for an integration of discipline-specific data [3] (SOA – Service Oriented Architecture [4]), to ensure a cross-discipline alignment of results. In this approach, Bellalouna uses adapters between the discipline specific tools and a mechatronic platform, using an interdisciplinary data-model.

Tabbert proposes the comparison of results and information through the use of parameters [5]. Therefore Tabbert recommends the use of a data-management-system with a data-model which is based on the “SimPDM”-concept. “SimPDM” is an approach for a simulation-data-management which includes parameters, properties and the relationship between them [6]. Following Tabbert, also a parametric requirements-management should be used [5], to detect changes in the output-values and their effects on the different disciplines.

Nattermann and Anderl propose the W-Model as a new approach for a proceeding model for the development of adaptronic systems [7]. The W-Model is based on the use of a dedicated data management system providing a set of functions which are not part of normal PDM-functionality.

In the present paper a proposal for such a data-management-system is made. The data-management-system uses a data-model that depends on "SimPDM", following Tabberts recommendations.

The data-management-system includes system modeling and an automated system-simulation. For the automated simulation a simulation-model of a whole active system using the mathematical software MATLAB Simulink is used. The simulation model was developed by Herold et al. In this model the system is divided into five parts, belonging to different technical disciplines. These parts are excitation, mechanical structure, sensor system, actuator system and signal processing [8].

For the automation of the system-simulation the model developed by Herold et al. was integrated into the change-management of the data-management described in this publication. By this automation changes on single components can be analyzed in terms of their system related impact.

Following Tabberts recommendation [5] the data-model of the data-management-system is based on the "SimPDM-Model" [6] for the inclusion of parameters and properties. For the modeling of the adaptronic system a partition analog to the simulation-model developed by Herold et al was used, due to the alignment of system-properties and simulation-parameters.

II. Adaptronics in AdRIA

The AdRIA-Center is a research center which was founded by the German federal state Hessen in 2008, as part of the LOEWE-project (LOEWE – federal initiative for the regarding of scientific excellence). Main target of the AdRIA-Center is research of adaptronics in scientific depths and width. The AdRIA-Center is a cooperation between the TU Darmstadt, the University of Applied Science Darmstadt and the Fraunhofer institute LBF [9], [10].

In the development of mechanics, the system is designed in a way that the behavior of a mechanic structure follows specific requirements. As an example of such a purely mechanical system at this point the Euler column should be used. This is in the development sized to a defined load to bear without breaking.

In mechatronics, electronic circuits, consisting of sensors, controllers and actuators, are added to mechanical structures to specifically affect the behavior of the mechanical structure [11]. Fig. 1 shows how this can be applied to the example of the Euler column. In Fig. 1 the electronic components were added in order to influence the buckling load and the bending behavior of the column.

Fig. 1 shows that the electronic components in mechatronic systems are additions to existing mechanical structures. That means the electronic components themselves are not part of the original system and can be switched off or removed as desired, if they are no longer needed.

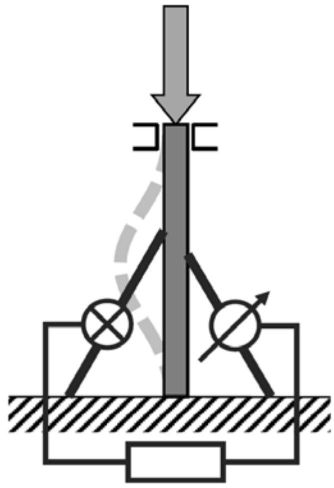

Fig. 1 Euler's column as a mechatronic system, cf. [12]

According to the interpretation of the adaptronic systems within the LOEWE-Center AdRIA this is no longer possible. According to this understanding, adaptronic systems are a further development in a direction in which the electronic components are fully integrated into the mechanical structure [9], [10], [13]. Because of this development also a clear separation between the mechanical structure and electronic components is no longer possible because the electronic circuit is itself part of the influenced structure. Therefore, there is no possibility to switch the electronic components on or off or removing the circuit without dissolving the mechanical structure.

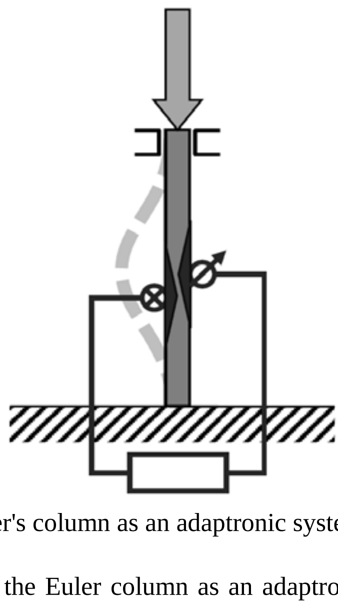

Fig. 2 Euler's column as an adaptronic system, cf. [12]

Fig. 2 shows the Euler column as an adaptronic system. It can be seen that the electronic components are fully integrated into the mechanical structure, or replace it partially.

III. Development of Adaptronic Systems

Because of the structural integration of electronic components and the associated interdependencies a close cooperation between the different disciplines during the development is necessary. Studies have shown that applications of existing proceeding models in practice can solve the associated problems only partially [2]. These studies show that a parallel and independent detailed development, of discipline-specific solutions, lead to problems in the integration of partial or complete systems. Such an application is recommended in the V-model for the development of mechatronic systems [1]. These integration problems lead to necessary iterations in the development and to longer development times in general.

Adaptronics have a higher degree of integration of components in comparison with mechatronic systems and associated greater interdependence between the technical disciplines. Because of this it is to be feared that an application of existing mechatronic proceeding models in the development of adaptronic systems would result in a greater number of issues.

To avoid this, an approach for a new process model for the development of adaptronic systems was developed by Nattermann and Anderl. This approach was developed as part of the LOEWE-Centre AdRIA and is a further development of the existing V-model to a W-model for the development of adaptronic systems. Following Nattermann and Anderl the W-model describes a five-step approach [7].

These steps are system-analyzing and distribution, first drawing up of discipline-specific solutions, integration and system-modeling, detailed development of components and at last system integration and analysis.

Looking at the contents of each step it is noticeable that the first step of the W-model is analogous to the V-model for the development of mechatronic systems [1], [14]. This step is primarily an analysis of the system to be developed and the demands on the system characteristics and system behavior. In addition the system space is divided into subsystems, components, and discipline-specific sections [7].

In the second step Nattermann and Anderl recommend a first draft in the individual disciplines. Also in the V-model a development in transdisciplinary level is recommended. The approach from Nattermann and Anderl differs from the V-Model, so that at this point no detailed solutions will be developed but only a first draft of the abstract discipline-specific solutions.

In a third step these abstract solutions are then integrated across disciplines. For this purpose, an abstract model of the system to be developed is created. The system-model consists of the models of the specific technical disciplines and the specific needs and influenced parameters and properties included. According to the W-model for the development of adaptronic systems this system-model is thereby stored in a central data-management-system. From the parameters and properties included in the system-model a parameter-network should be developed. This network should be used for the analysis of mutual dependencies and the balance of discipline-specific solutions in the following detailed development.

The integration and system modeling in step 3 is followed by the actual detailed development of individual system components. As in the V-model for the development of mechatronic systems, this development is parallel in the various disciplines. Unlike the V-Model, this development will not take place independently of each other. The established system-model and the data-management-system used for system modeling are used for discipline-specific developments in mutual dependence on one another. Following Nattermann and Anderl the established parameter-network is used for the cross-disciplinary alignment of results.

According to the W-model, development is completed by an integration of discipline-specific developments and a verification of the fulfillment of requirements of components and systems.

Following the W-model, the parameter network established in Step 3 should be used for the cross-disciplinary integration. For this purpose, a network analysis of the relationships and dependencies between the parameters and properties shall be developed. This will be used to assess the impact of changes to various system parameters and to initiate necessary adjustments.

According to the W-model and the concept of Nattermann and Anderl for a therefore used data management system, network analysis is integrated in the Change- and Release-Management and therefore automatically carried out at a change to a component or part of the system.

In practice, however, this would lead to an infinite number of adjustments, as any change in one component inevitably impacts on other components which have had to be changed also. Here, the majority of the changes probably would relate only small details of each component, which had no significant effect on the system behavior.

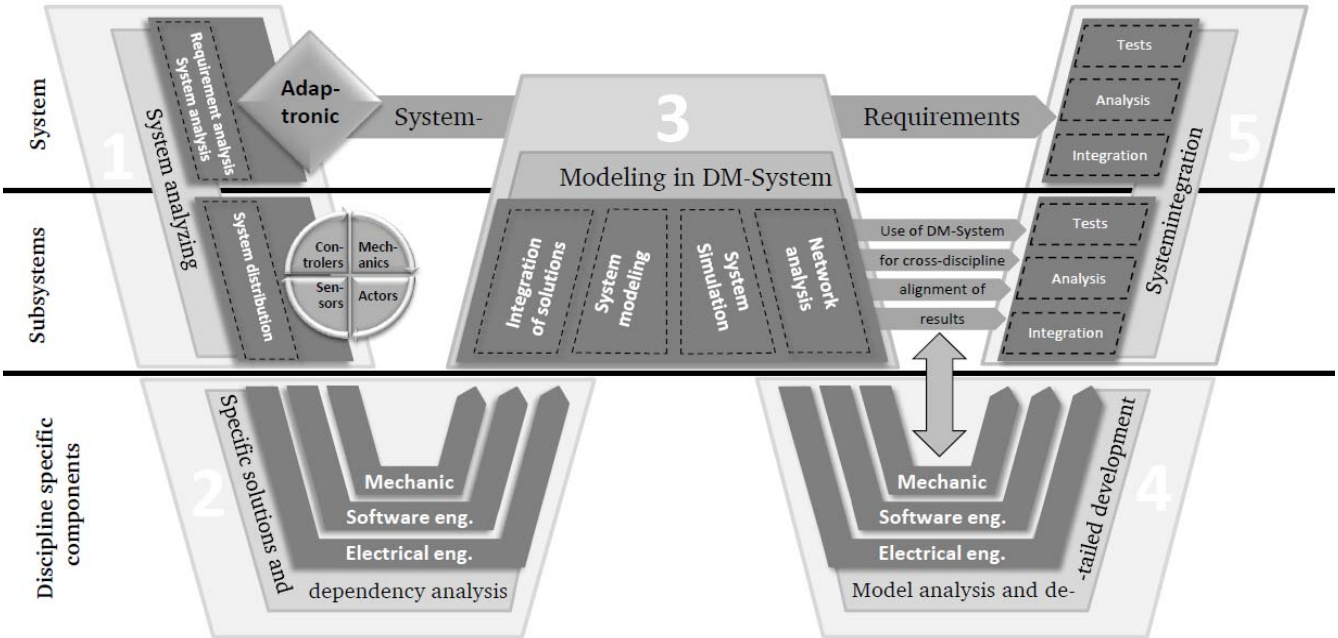

Fig. 3 W-Model for the development of adaptronic Systems with an included parameter analysis and system simulation, cf. [7]

Both from a business perspective and in terms of reducing the development time such a wide range of adjustment steps and simulations during the development would be not acceptable. To reduce the number of adjustments and confined to the really necessary changes, the expansion of the W-model for the development of adaptronic systems with an abstract simulation of the global system behavior is proposed at this point. This simulation is inserted in the third step of the W-model, the intermediate integration and system modeling.

In practical use the system-simulation is used to evaluate changes to individual components automatically for their influence on the global system behavior. Therefore the system-simulation is intended a first step, to be carried out prior to analysis of the network parameters. For the simulation a standardized abstract model of the overall adaptronic system to be developed is used. This simulation model is produced in the third step of the W-Model, together with the system model and the parameter network. For the input parameters, the critical system parameters of each component and the data on the changes are used. As results the simulation provides the abstract global behavior of the adaptronic system. This behavior is then compared with the defined system behavior according to the requirements.

If the simulation should show no change of general system behavior outside of set boundaries no network analysis should be carried out due to lack of relevance of the changes. Only when the system behavior was influenced in a way that it would no longer match in accordance with previously set limits or requirements on the system, an analysis of network parameters and a corresponding adjustment of other system components is required. A second criterion which makes an analysis of the network parameters and an adaptation of other components imperative are changes to interfaces between different components or disciplines.

Fig. 3 shows the W-model for the development of Adaptive Systems with system-simulation inserted in the central third step.

IV. Concept for a Data Management System for the Development of Adaptronic Systems

The approach for a data management system for the development of Adaptive Systems proposed in this paper is based on a concept which was developed by Nattermann and Anderl. This concept provides a data management, which organizes the functions for the integration of disciplines and the alignment of their results into different layers. The order of the layers is determined by the dependencies and relationships between these functions (Nattermann and Anderl 2010).

Because of the changes on the W-model by the addition of a system simulation in the central third step the approach for the data-management used in this step has to be adapted, too. These adjustments describe the concept of a data model which breaks down the functionality in 6 layers (see Fig. 4).

A. System-modeling

The top layer of the concept shown in Fig. 4 contains the system modeling. In this layer a number of functions are provided by an abstract system model. The model divides the adaptronic system in a number of components, subsystems and discipline-specific solutions. To ensure compatibility of the system models with the system simulation the system decomposition developed by Herold et al. was used for the creation of the simulation model. This breaks the adaptronic system in the areas of excitation, structure, signal processing, actuators and sensors [8].

In addition to the creation of the system structure within the system modeling the concepts offer the possibility of definition of parameters and properties and creation of links between them and with the system. In addition, the definition of system requirements and connection with the system properties is part of the system modeling.

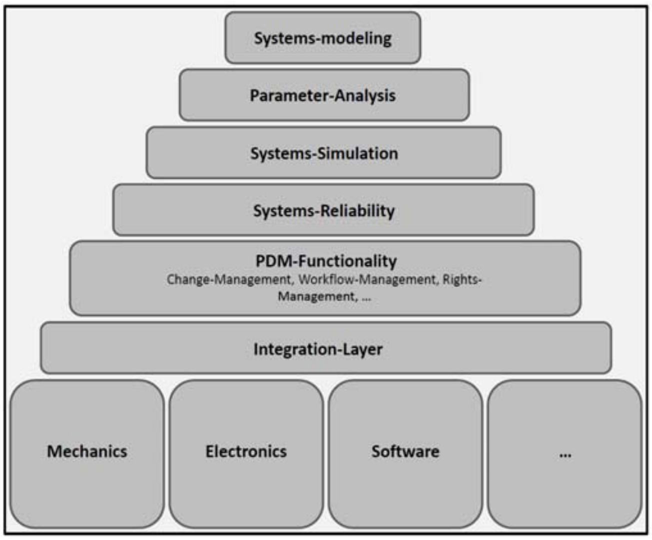

Fig. 4 Layer Concept for a data management system for the development of adaptronic systems

B. Parameter-Analysis

The second layer of the concept for a data management for the development of adaptronic systems contains the parameter analysis which is part of the original W-model.

In this layer, the parameters defined in the system model are analyzed and tested for the mutual dependencies. To quantify this dependence, the parameters can be viewed as a directed and weighted network. This network is used to determine a sensitivity analysis, using the requirements prescribing the system characteristics and behavior and any necessary adjustments to the system and component parameters. Here, the system requirements contained in the system model are used as the basis of the system characteristics and the system behavior investigations.

C. System-Simulation

The third layer is a simulation of the global system behavior due to external and internal excitations. This simulation is not a detailed simulation which uses a variety of detailed component properties. It is instead an abstract overall simulation that is feasible because of the reduced complexity using only a few critical system parameters.

The system simulation is based on the simulation model which was developed by Herold et al. (see Fig. 5)

This simulation model is modular, so that the different disciplines can be calculated by different modules. This allows a simple definition of the simulation. To this end, the functions required for the calculation of the simulation are defined through the definition of the respective components and selection of the modules. In addition, the modular construction allows the exchange and expansion of the simulation to change the degree of abstraction to detailed level in a later phase of development.

For the automation of the standardized simulation it is integrated into the change and release management of the data management system. Through this the simulation will undergo compulsory in the implementation of changes to existing components, or the insertion of new components. The system is thereby able to calculate the effects of the changes on the overall system and start an evaluation process.

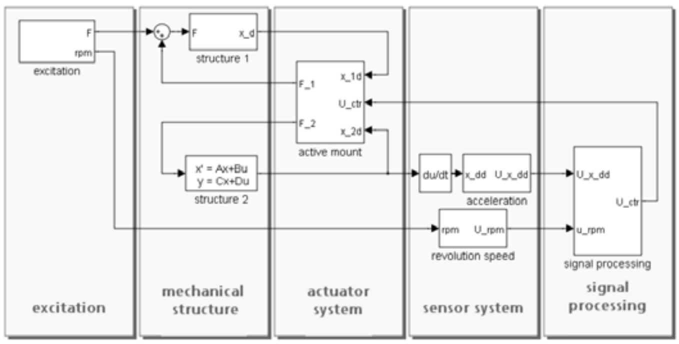

Fig. 5 Matlab-SIMULINK model for the development of active systems [8]

In the development of the individual disciplines, the simulation is thus playing a central role, as it summarizes the results and data of all involved disciplines. The central character of the simulation can be seen in Fig. 6, which shows the integration of data from the different disciplines in the simulation model.

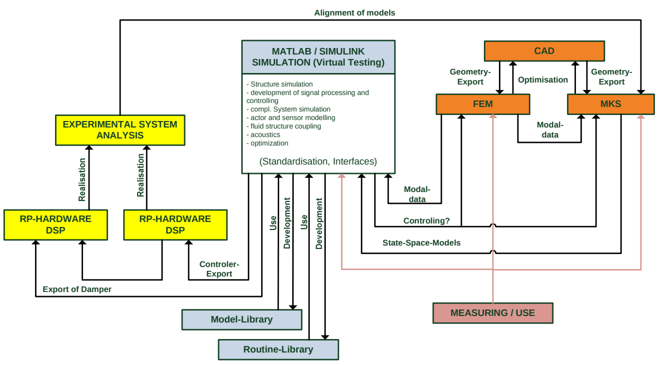

Fig. 6 Integration of the System-simulation in the development of active systems [8]

For the standardization of the simulation, which is a prerequisite for automation, first the input and output parameters have to be standardized. As input data for the simulation serve the system properties and parameters that were defined in the system model. For this, they are read from the data management system, the appropriate values are selected and written to the input desk of the simulation. To carry out the simulation, the individual modules of the selected simulation are loaded into the software tool used for the simulation. After this the simulation can be started.

When the simulation is completed the output Desk of the simulation, or already in the course of the simulation visualized results, are recorded and stored in the central data management together with the used simulation modules and the input parameters. The calculated system behavior is also automatically checked to see if it has changed beyond previously defined limits. If this is not the case, no further adjustment of other components is required.

If the changes to the system behavior exceed the defined limits the functions of the second layer of the concept are called and started automatically, using the parameter analysis to determine the necessary adjustments to other components.

D. Calculation of the Systems Reliability

Due to the high degree of structural integration in adaptronic systems a failure of single integrated components often leads to a failure in the global function of the overall system. Therefore the calculation of the life expectancy of the system and the components takes a special place in the development of Adaptive Systems.

Fig. 4 shows the inclusion of an automated calculation of the systems and component reliability in the concept for a data management system for the development of adaptronic systems. Following this concept the component reliabilities are modeled in the data management system, together with the respective calculation methods. By linking the individual components reliabilities and the definition of the calculation method the system reliability can be derived.

The component and system reliability is associated with the system structure, the properties, the managed data, and the requirements. Thus the individual reliabilities can automatically be calculated from the stored data and can be analyzed in relation to the requirements. This allows an automatic evaluation of changes in individual components in order to the reliability and requirements.

E. PDM-Functionality

The fifth layer of the concept is the standard PDM functionality for the storage and management of the data generated in the development. These functions include the Element-, Workflow-, User- and File-management.

F. Integration-Layer

The last layer of the concept shown in Fig. 4 is the so-called integration layer. This layer contains the functionalities for the integration of the data generated in each discipline and the linking of these data with the generated system model. The future implementation of this layer requires a large number of connectors in order to interpret and read the data that will be produced by the different software tools of the individual disciplines.

To master this variety of compounds, the concept provides the use of the SOA concept, which was also used by Bellalouna for the implementation of the integration platform [3].

According to the SOA-approach the connections of the data management system to the respective software tools of the different technical disciplines are realized as services. Due to this, service programs are used for the integration of the discipline specific data, which are not part of the original data management system.

V. Implementation

For the implementation of the concept an existing data management system was chosen. This has been adapted and expanded in its structure and functionality. By using an existing system a new implementation of PDM-functionality could be waived. For such a system the software ENOVIA SmarTeam V5 was chosen. SmarTeam is a data management system which has all general PDM-functionalities and also provides the opportunity to easily adapt and expand its functions and data models. For the implementation of the system simulation the software tool MATLAB was used. This has made it possible to use the existing simulation model of Herold et al. [8].

For the implementation of the specialized data management system, a corresponding data model has been developed to ensure the various features of the concept shown in Fig. 4. The data model sees a modeling of the adaptronic system by a partition in the five areas of excitation, actuators, sensors, signal processing and structure by Herold et al. The modeling also includes the definition and combination of parameters, properties and requirements. In addition, the definition of simulations by the use of individual, interdependent modules, and linking the simulation with system modeling is part of the data model.

For the automation of the simulation the model developed by Herold et al. was standardized and a coupling between ENOVIA SmarTeam V5 and MATLAB was generated. This makes it possible to load, adapt and run simulations in MATLAB with an automated workflow in SmarTeam.

Currently the implementation of the established data model takes place. For this, the classes, attributes and methods contained in the data model are transferred to SmarTeam. Upon completion of this work, the data model will be validated in SmarTeam. For this purpose, data, procedures and processes are used, which were developed within the

LOEWE-centre AdRIA during the development of real adaptronic systems.

VI. Conclusion

Adaptronic systems are characterized by an extreme degree of structural integration of electronic components. Therefore, the development of appropriate systems needs cooperation off all disciplines. This was in the past often complicated by the different models, methods and descriptions used in the participating disciplines. At the same time an adaptation of methods employed in the various disciplines is difficult for various reasons.

Therefore, an approach for a new process model for cross-discipline development of adaptronic systems is given in this paper. The proposed approach is a further development of the W-model for the development of adaptronic systems, which divides the development process in five steps [7]. As part of this paper, the W-model is extended using an integrated, automated system simulation, which is used to consider the impact of adjustments to individual components on the global system behavior, in the course of a component adaption.

Both the W-model as also the presented further development implies the use of a dedicated data management. This system exceeds the functionalities of a normal PDM-system. As part of this paper, therefore, a concept for such a data management system for the development of adaptronic systems is proposed which divides the functions into six layers. These layers contain a system modeling, a parameter analysis, a system simulation, the integrated consideration of the reliability, the standard PDM-functionality and an integration layer for the integration of discipline-specific data to the central data management system, using the SOA-approach.

For the proposed concept of a data management system an appropriate data model was developed, which is currently being implemented. For this purpose, the existing PDM system ENOVIA SmarTeam V5 is used. For the implementation of the system simulation contained in the concept this PDM system was coupled with the simulation software solution MATLAB. Also a standardized simulation model, based on existing solutions, was used.

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