Data Exchange of Digital Twins Based on AML in Space Science Experiment Equipment

Peng Guqi, Zhong Hongen
Technology and Engineering Center for Space Utilization, Chinese Academy of Sciences Beijing, China

E-mail: Pengguqi17@csu.ac.cn

Abstract. With the development of Computer Aided Design (CAD) and manufacturing technology, various industries are transforming to digitalization, and the realization of the digital model of aerospace products is an important part of “digital aerospace”. Based on the theory of system engineering, this paper proposes a three-dimensional conceptual model of analysis of payload in the life-cycle of physical device design, as well as the concept of digital twin five-dimensional model in the design stage. Combined with the actual application requirements, this paper explores the content and standards of digital twin model construction of payloads, by using the model mapped to the AutomationML (AML) to realize the data exchange and fusion.

1. Introduction
With the advent of the Cyber Physical Systems, the improvement of network technology, information physics systems, digital technologies, and intelligent technologies promote the digitalization and intelligent transformation of aerospace products. Grieves (2014) proposed the Digital Twin concept to manage product information at product item level along its life-cycle. A Digital Twin appears as a virtual representation of the physical product, a digital shadow that reflects the structural, maintenance, performance, and operational health characteristics of the physical system. Its early application [4–7] is applied in the military and aerospace fields. NASA and Air Force Research Laboratories apply digital twin technology to aircraft health control [1, 2]. In 2012, the US Air Force Research Office proposed the concept of “vital digital twins” to emphasize the idea of a single source of real data. To date, in China there are many aerospace institutes have researched the digital twin model and more specifically, the model-based systems engineering (MBSE). Three Department has put forward MBSE-based aerospace product design solutions, and the 805 institution has proposed the application research of MBSE in the manned space field. In addition Advanced Space Academy proposed digital prototype engineering for the launch vehicle, etc [3].

Although digital technology has been widely applied in the development of products in the aerospace field, a few issues remain in the digital model research:

(i) Space Scientific Experimental Rack covers a wide range of fields (e.g. light, machine, electricity, heat, etc.), while the industry data exchange standards are not yet well defined, achieving inter-operability between fields is a significant challenge for digital twin development.

(ii) The development of Space Scientific Experimental Rack involves co-ordination between multiple research institutes based on the corresponding design management software for interdisciplinary fields. The above software is very mature but the interface compatibility between different software cannot be ignored.
(iii) The existing product data management only focuses on the technical state management. Such a way is dependent on the development and design documents, instead of realizing the digital model management. Given the above situation, this paper has the aim to present a model architecture that offers services for different fields. We want to present a data exchange protocol using AutomationML for exchange data between the Digital Twin and other systems, and a methodology for communication for the data exchange.

2. Theoretical research on the construction of digital twin model

The digital twin model conforms to the basic characteristics: virtuality, uniqueness, multi-physical, multi-scale, hierarchical, integrated, dynamic, super-realistic, computable, multi-disciplinary[3]. For each physical entity, we can create a digital twin model of it using a modeling tool. The American engineer Hall[8] has proposed the three-dimensional analysis model[9] of system engineering. We further propose a three-dimensional analytical conceptual model in the design stage, as shown in Figure 1 below.

![Figure 1. Three-dimensional analytical conceptual model.](image)

In practice, the digital twin model is constructed based on time and knowledge slices. The life cycle of the model can be divided into six stages. Each level realizes further refinement of model attributes on the basis of the previous model. The preliminary design level mainly aims at the decomposition of data indicators and the unit level includes the subject domain model and uni-disciplinary model. The stand-alone level includes simulation model and realize part of data exchange work. The higher-level different model phases can meet different levels of usage requirements: load level should meet the basic test requirements, system level can realize information interaction with external system. Complete level includes data knowledge during the design phase test data and real-world operational data, which can be used for simulation prediction of its future operation, as well as support for design and simulation of new models. Therefore, the digital twin model is a dynamic digital representation of a physical world in its life-cycle.

According to the above modeling approach, the user has the possibility of creating a high level model of physical object. Different types of product models will be created during the different phases of product life-cycle, while creating a composite digital twin that integrates numerous parts from different fields is complicated, as shown in Fig.2.

![Figure 2. The composition of payload model object](image)
To reflect the operational context of the physical twin, a digital twin model requires a physical twin for data acquisition and context-driven interaction. Furthermore, such models sometimes are inter-operable among each other. Having this in consideration, this paper proposes the concept of five-dimensional model of digital twin: $M_{DT} = (PE, VE, Ss, DD, CN)$. The most relevant topics for the creation of the digital twin can be summarized as follows[11]:

$PE$ represents the physical entity. For example, a Space Scientific Experimental Rack payload is a simple system-level $PE$, including components, resource sets, and information collection, which enables resource co-ordination and information transmission between subsystems.

$VE$ stands for virtual entity, $VE = (P_v, B_v, R_v, M_v)$, $P_v$ is a physical model. $B_v$ is a behavioral property model, describing the physical model behavior at different time and scale. $R_v$ is mainly based on the accumulation of historical data, which continually updated with the latter’s performance, maintenance, and health status data throughout the physical system’s life-cycle. $M_v$ mainly contains management information of virtual models, which can organize the storage model data along every stages.

$Ss$ is a service model, which provides services to the physical device and services to the virtual model.

$DD$ is a twin data model, which is the driver of each virtual device and service operation.

$CN$ is the connection model, which is the key to constructing the digital twin system. It needs to ensure the connection between the physical entity and the virtual model, and the data transmission between the virtual models.

In summary, data associated with the physical system are supplied to the virtual environment to update the virtual model in the digital twin. Besides it is necessary to have a way of communication between the virtual models. To aggregate all the models, it needs to enable the exchange of each model[9, 10].

### 3. Data exchange of digital twin model

The existing modeling method is usually based on the corresponding interface of commercial software for interdisciplinary fields, such as ANSYS, ADAMS, MATLAB/Simulink. Therefore, the digital twin model involves the exchange and transfer of data between multiple model tools. To achieve the data exchange requirements of the above digital twin model, there are several ways to provide information to other systems. Through comparing various available open formats for model data exchange, as shown in Table 1[14, 15], this paper proposes an AML-based data exchange approach, As shown in Fig. 3.

AML can be used to store and exchange engineering data in different engineering fields. It makes use of CAEX as a meta model for the storage and exchange of engineering models. By definition, CAEX supports object-oriented modeling for all aspects, which includes four concepts: role class, interface class, system unit class and instance level[12].

| Feature                     | Data Format |
|-----------------------------|-------------|
| Mechanical Data             | AML         |
| Electric Data               | STEP        |
| Process Control Data        | JT          |
| Topological Information     | XPDL        |
| Establishing Concept Relationships | XML    |
| Tracing Concept Dependencies|             |
| Mechanical Data             |             |

In order to organize an intermediate data transfer file format, it is necessary to define the organization form of the data, data type, data length, etc., and for each model object, the mapping relationship between the model data should be clarified[13]. The following is an example of a thermal simulation model under comsol (as shown in Fig. 4), which realizes the expression of model information by AML.
and the data transfer interaction with the mechanical structure model. Different levels of digital twin model has inconsistent data exchange content, and the emphasis of model attributes is different. For a digital unit model at the overall unit level, the model under comsol contains the definition of global parameters, component information of the model, such as model geometry, model material, model physics Information, and simulation results of the model.

Figure 3. Data transfer in AML intermediate format.  

Figure 4. Thermal simulation model under comsol.

According to the above modeling framework, the electrical box is modeled. The model instance information and data element were mapped in AML format, and the relationship is shown in Table 3. Different model data are mapped into four categories of AML, where the role class, interface class and system unit class are data category definitions in the model, and can be reused as the abstract part of the model. Instantiate the abstract attribute in the instance class to implement an instance of the electrical box heat transfer model.

The AML unit class is composed of management model, physical model and structural model data. The specific model data is represented by the attributes in the class. Each attribute has its content, format and other descriptions. System unit class mainly contains the cold plate of electrical box, heat transfer structure, heat source of the electrical box, box body, etc. In addition to the basic roles, the role class also has user-defined role classes such as components, structural parts, etc. The interface class also has basic interface class and user-defined interface classes, such as three different heat transfer interfaces. The heat simulation of model instantiation can be realized by applying the different attributes of the model, as shown in Fig. 5. To better understand and view model attribute, the model can be extracted, and some parts are shown in Figure 6.

Table 2. Mapping relationships between model data in AML

| Data element                | Example                                      | Mapping to AML                        |
|-----------------------------|----------------------------------------------|---------------------------------------|
| Hierachy level, Object      | Heat transfer model module,                  | Internal Element                      |
|                             | Heat transfer system                         |                                       |
| Property                    | Structural attribute,                       | Attribute                             |
|                             | Physical property                            |                                       |
| Classification              | Cooling device, Components,                 | RoleClass                             |
|                             | Structure                                    |                                       |
| Simple Relation             | Heat transfer                                | ExternalInterface with External      |
|                             |                                              | Element for relation data             |
| Directed Relation           | Contact heat transfer                        | ExternalInterface with Internal       |
|                             |                                              | Element for relation data             |
| Groups                      | Heat source,cold plate, box body, electrical box | SystemUnitClass                      |
Through the above modeling method, the mechanical structure model of the typical electrical box model is created. For the mechanical structure, the data model lays particular emphasis on the related attribute information of the structural model. To ensure the understanding of the data content, the same attribute representation of the different domain models should be consistent. The AML-based model is shown in Figure 7.

Figure 5. Data transfer in AML intermediate format.

Figure 6. Thermal simulation model under comsol.

Figure 7. Three-dimensional analytical conceptual model.

It can be seen that creating AML-based models can simplify the data exchange. The user has the possibility of representing physical components via a high-level model without having the professional knowledge in systems or programming languages and this model is used for the exchange of information, so that groups of proficiency in various fields and modeling tools can work together.

4. Future Works
This paper we proposed a methodology to create models using the AutomationML and an approach to exchange data between systems that making use of the Digital Twin. Through communication mechanism of these collaborative models, we can efficiently map the domain model to the specific AML-based models and they are shared to increase the consistency and collective knowledge around domain areas, so as to solve the compatibility problem of models and data exchange between the inter-systems and multi-systems.

At the same time, more and more industrial manufacturers are beginning to provide support for AML models, which stores engineering information and allows the modeling of physical and logical components in different aspects. Through the establishment of digital product profile, we can make it possible to track the performance and maintenance history of each physical twin over time, continuous research and development even after the sale of the physical twin. Specifically, these models can be exploited in upfront engineering, testing, system maintenance, and smart manufacturing.

5. Conclusion
In this work, we presented the main challenges of current Digital Twin technique and a approach to exchange data between fields using high level models. Through the theoretical research on the creation of digital twin model at the overall level, we propose a three-dimensional digital twin model in the design stage. The model structure of the payload is created according to the relevant field, and
explained the model data connotation of the digital twin model of the payload under the five-dimensional model structure. To validate our proposal, we take thermal simulation as a case to study. From this model, we make use of the AutomationML models to exchange data between systems. The use of models allows that a user model a Digital Twin of the physical objects more efficiently. For future work, we intend to use the Digital Twin exchange model for other purposes.

6. References

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