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# Digital Integration of Data and Information into System Model of Aerospace Equipment

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We have investigated how to integrate data and information and system modeling for the effective management of aerospace equipment. The method of such integration can be developed through the in-depth study of relevant data and information and the characteristics of system models. Solutions and methods are proposed to design and develop efficient aerospace equipment management. The proposed method is important for the technological advancement and development of the aerospace industry and provides a reference for further development of system models in other engineering applications.

## 1. Introduction

The global demand for space exploration, autonomous aircraft, and unmanned vehicles is on the rise owing to the continuous advancements in science and technology. Data analysis, AI, and other cutting-edge technologies have facilitated the automation of aerospace equipment through digital integration. The design, manufacturing, and application of aerospace equipment require a multidisciplinary understanding of design, structure, materials, dynamics, thermodynamics, and other spacecraft-related technologies. Aerospace systems consist of multiple subsystems and interconnected components, often requiring state-of-the-art technologies. Consequently, research and development in this field represents the pinnacle of technological advancement.

Aerospace equipment must endure extreme environments, necessitating the use of appropriate materials, components, systems, and processes to ensure safety and reliability. Therefore, emerging technologies and materials along with advanced materials, 3D printing

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technology, new propulsion systems, high-performance computing devices, and advanced sensors are increasingly applied to aerospace equipment.

System models abstract the complexity and details of a system (equipment) using a mathematical model. Key characteristics and operations of the system are examined to simplify and integrate the components and their interrelationships in the system. The mathematical model is established to determine the parameters of the system to help understand and/or predict the operation and performance of the system.[1,2] System models are constructed on different scales, from micro- to macroscale, to enable engineers to analyze the characteristics of a system and predict its malfunctions. The extension of a system model is necessary to increase its flexibility and applicability to diverse operating conditions.

The system modeling (SysML) language is based on the unified modeling language and used in system engineering.[3] The SysML language is used to build a system model of a spacecraft to analyze and predict the performance and operation of the components. By integrating existing data, the SysML language is used for the abstraction and simplification of multiscale system models owing to its scalability and practicality. It is also used for analyzing, designing, and optimizing complex systems in aerospace equipment.[4]

Research on system modeling has been conducted by space agencies, enterprises, and academia to improve the design, development, and operation of aerospace equipment and related technology.[5] Aerospace companies and research institutions have carried out various research studies on the modeling and simulation of devices used in aerospace equipment and their integration and verification. Digital transformation and digital twins have been introduced in the aerospace industry to improve the efficiency and reliability of the equipment. Academicians have also conducted research on system modeling for aerospace equipment. Using model-driven methods, a series of functional, operational, and structural models have been established to describe and analyze the safety and performance of aerospace equipment from diverse aspects. Interdisciplinary collaborations have enabled experts in various fields to integrate their knowledge to develop aerospace equipment.

NASA has extensive experience in applying system engineering and modeling based on which it has developed aerospace components, propulsion systems, and navigation control devices. Recently, AI and machine learning technology have been extensively used to analyze and process a huge amount of data for decision-making and the optimization of equipment design. The European Space Agency has been committed to the research on system modeling for the design and operation of space missions. The aerospace industry has been involved in research for the development of related technologies.

In such research, integrating existing data and information into system models is inevitable in aerospace equipment. However, challenges remain in the acquisition, representation, and verification of data and information for models. Therefore, research is mandatory to develop an accurate, efficient, and reliable method of integrating data and information into system models for the continuous innovation and development of aerospace equipment. In this study, we used the SysML language to investigate how to integrate data into system models effectively to maintain aerospace equipment effectively and efficiently.

## 2. Methods

In integrating data and information into system models, their digital expression is critical. The data and information include demands, functions, metrics, logical and physical architectures, parameters, and sensor data of aerospace equipment. The system model is constructed on the basis of a scenario, a standardized model library, and the digital expression of data (Fig. 1).

To build a metamodel, ontology technology is used to define and sort the components of aerospace equipment and their complex relationships. Mapping and describing the components are conducted for the metamodel. Then, the standard view from the perspective of each component is defined to model aerospace equipment. By integrating aerospace equipment ontology and standard views into the metamodel, a scenario is created for digital modeling based on the model library. The defined scenario is used to determine the demands of the aerospace equipment in mapping, comparing, and iterating the model library for multilevel engineering. The scenario is described in hierarchical and item-based terms for the in-depth digital integration of data into the model.

In this study, a system model of an aircraft landing gear was constructed for the analysis of the model and its library. The general demands of the landing gear were considered to verify the model design's rationality.

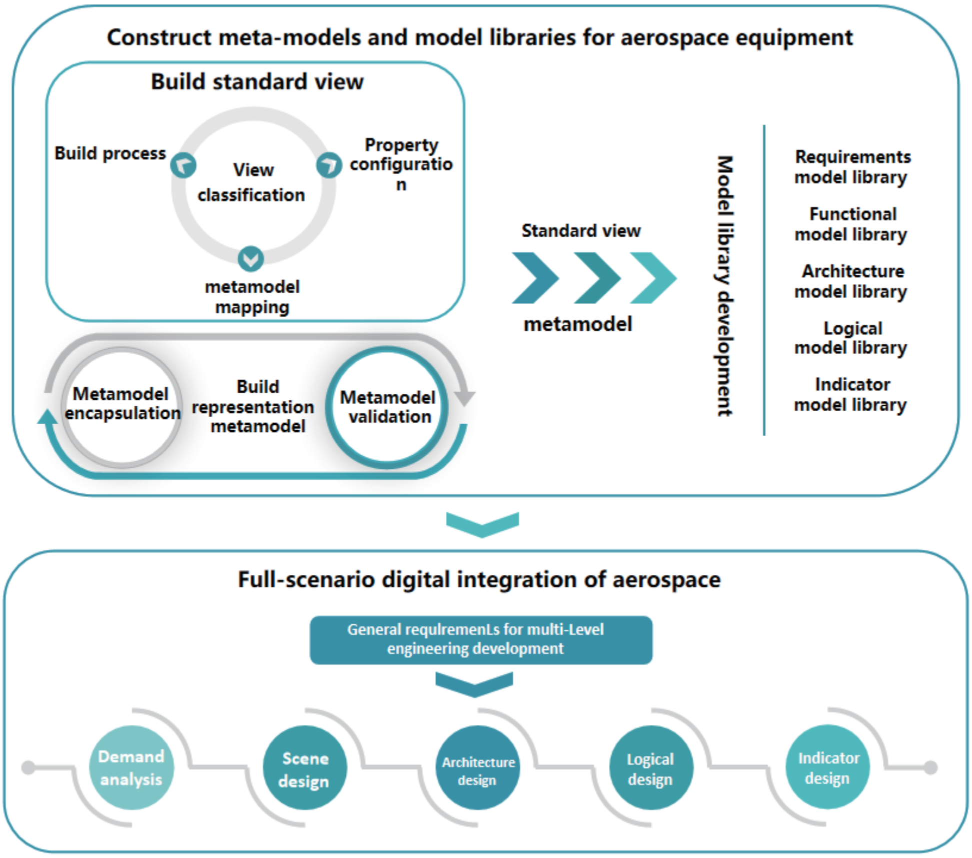


Fig. 1. (Color online) Construction of system model and digital integration into system model.

## 3. Model and Library

In the digital modeling of aerospace equipment, multiple tasks for users and their demands are considered along with system boundaries in operating scenarios, including altitudes, signal attenuation and interference, and the movement and characteristics of targets. Interaction with other equipment and the status, operations, and constraints of operating resources are included in the scenarios.(6,7) As shown in Fig. 2, the model library includes various standard views, the ontology, the metamodel, and the model interacting with each other based on model-based system engineering (MBSE).(8,9)

### 3.1 Metamodel

Data and information on aerospace equipment need to be constantly collected and updated as the system model keeps changing and new materials, technologies, and design concepts are continually applied to the equipment, especially MBSE is applied to CubeSat.(10,11) For the digitization of the data and information, a language system for the model must be constructed to integrate them and ensure that the prediction of the model is consistent with the real measurement values and to ensure cybersecurity. To build the language system using digital engineering,(12) metamodels are necessary to determine the necessary data and information, attributes, and explicit associations between the components of aerospace equipment. The construction of a metamodel using the terminology related to rockets is shown in Fig. 3.

### 3.2 Model library

On the basis of the database for constructing a system model, a model library is established. In this study, we established a model library of an aircraft landing gear. To establish the model library, the corresponding model and database were constructed on the basis of the characteristics of the landing gear and the demands for its maintenance.(13) At the same time, the reliability and integrity of the data were assessed for the design, development, and operation of its system model. The model library comprised sublibraries of functions, operations, architecture, and parameters (metric library) as shown in Fig. 4.

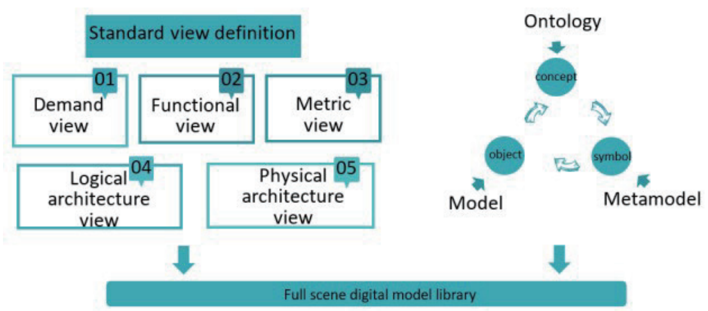


Fig. 2. (Color online) Standard views and interaction of ontology, metamodel, and model in digital model library.

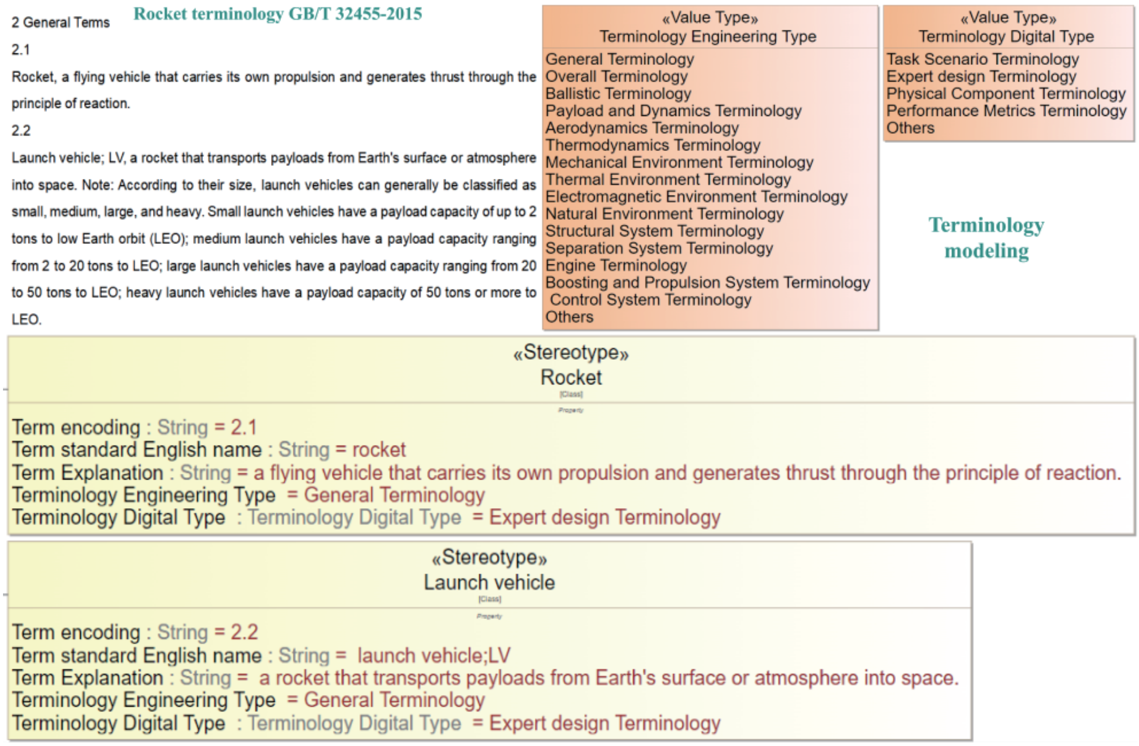


Fig. 3. (Color online) Metamodel construction using rocket terminology.

## 4. System Model of Aerospace Landing Gear

It is necessary to analyze the missions, architecture, and demands of equipment in the development of the system model. The consistency of the architecture and parameters of the model must be ensured to meet the system demands and ensure the comprehensiveness and reliability of equipment operation at the task, system, hierarchy, and architecture levels. A subsystem model of each component such as a task model or an architecture model needs to be constructed for digital mapping to enhance the accuracy of the model (Fig. 5). Tasks, functions, concepts, and architectures of aerospace equipment need to be determined in various scenarios at multiple levels and from diverse perspectives to define or construct modeling semantics and syntaxes. The functional logic and relationships between internal and external interfaces must be understood through quantitative and qualitative demand analysis. In this study, we conducted the digital mapping of the landing gear using SysML.[14,15]

### 4.1 Task model

The task model of the landing gear was designed to evaluate how well it met the requirements of the standard views presented in Fig. 2. For the assessment, the rules of digital mapping were established considering the necessary criteria and demands. Tasks in diverse situations were defined in the modeling as shown in Fig. 6.

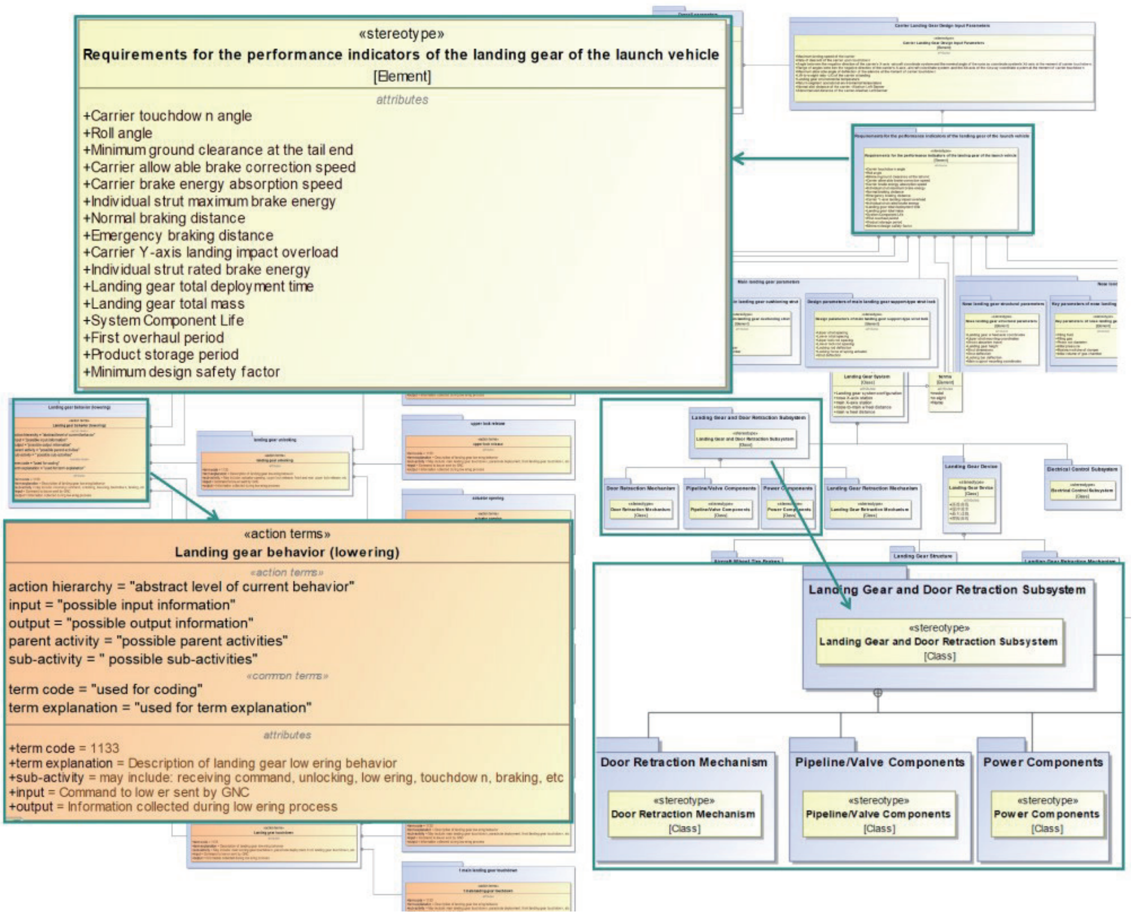


Fig. 4. (Color online) Model library and its sublibraries for system model of aerospace landing gear.

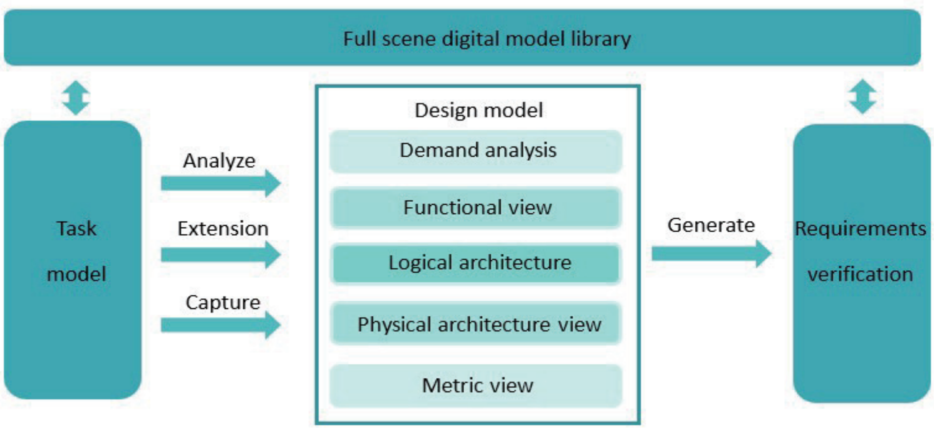


Fig. 5. (Color online) Digital mapping for system modeling aerospace equipment.

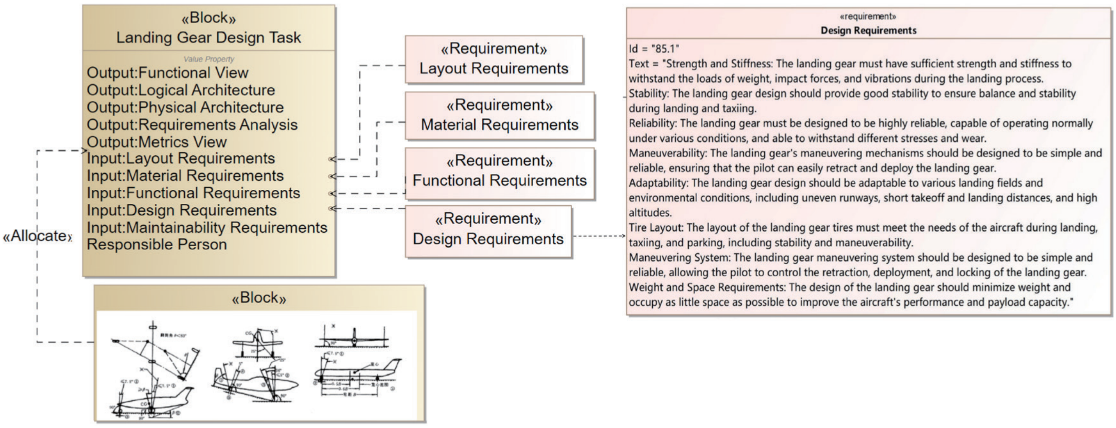


Fig. 6. (Color online) Task model of landing gear.

### 4.2 Demand view

In the demand view, necessary tasks are constantly iterated through digital mapping. The main task of demand analysis is to establish a complete library of demands. The demands in written documents are sorted and listed in a hierarchical library on the basis of their characteristics and difficulties at engineering, system, subsystem, and equipment levels. Items for each demand are mapped in the system model using the modeling language. As shown in Fig. 7, the structural demands of the landing gear were refined in this study, including the retracting mechanism, lower and upper lock design demands, and others. After establishing the demand library, completeness analysis and change tracking are carried out to refine the demands for the digital mapping in the system model. For numerous tasks, complex demands, and frequent changes of demands, MBSE is used.

### 4.3 Functional view

On the basis of the tasks in the demand view, a scenario is created to understand the operation of aerospace equipment in various situations and discover potential problems or possible improvements. In various scenarios, the functional view is determined to describe the functions of the equipment from the user's perspective. The system of aerospace equipment consists of multiple functional modules, so the functions of the modules and the relationship between them are described. From the functional view, the functional components of the equipment and their relationship can be understood for the design and development of the system model. The functional view helps to understand the structure of the equipment and to effectively analyze system demands and define necessary modules.

As shown in Fig. 8, the aircraft has a landing process involving "opening the door" and "generating thrust for descent" in landing. To open the door, "door unlocking" and "door actuating" must be carried out. To generate thrust for descent, three landing gear operations must be conducted: "landing gear unlocking," "landing gear actuation," and "landing gear in place." After analyzing this operation, we can analyze the landing gear operations.

| | |
|---|---|
| R 86 structure design requirement | |
| R 86.3 Design Requirements for Master Locks | |
| R 86.3.8 Deformation Compensation Requirements | The position of the upper lock or locking pin should be adjustable appropriately to serve as a compensation for design, manufacturing, and usage def ormations. |
| R 86.3.7 Failure avoidance requirement | The upper lock should avoid failure due to corrosion, icing, dust accumulation and lack of lubrication |
| R 86.3.6 Emergency unlocking device | The upper lock should be equipped with an emergency unlocking device to ensure that the lock can still be unlocked when the normal unlocking syste m fails |
| R 86.2 Lower lock design requirements | |
| R 86.2.6 Safety device requirements | When stopping, the lower lock should be equipped with a safety device |
| R 86.2.5 No unlocking requirement | After the lock is locked, it should be able to remain unlocked under ground vibration and hydraulic fluctuations in general aircraft operation |
| R 86.1 Landing gear retraction mechanism design requirements | |
| R 86.1.9 Environmental impact | The effects of high temperature, low temperature, and icy conditions on unlocking and locking should be considered |
| R 86.1.8 fail-proof | Lock mechanisms should be designed in such a way that broken spring or small part fragments will not affect the function of lock mechanisms or landi ng gear structures and equipment in the event of their failure |
| R 86.1.7 Reliable device | All retractable landing gear shall have a reliable locking mechanism/device to hold the landing gear in the retractable or retractable position when in th e retractable or retractable position |

Fig. 7. (Color online) Listed demands for landing gear tasks.

## 4.4 Logical architecture view

We determined the logical relationship between the modules of aerospace equipment to understand its structure and the relationships between its components. The dependencies, data flows, and information interactions between the components were analyzed for simulation and optimization for effective management and troubleshooting and for ensuring consistent interactions between the components.

Figure 9 shows the transition condition and the actions of each component of the aerospace landing gear. When the "landing gear retraction and retraction actuator" receives the signal of "landing gear unlocking", the "standby" state of the landing gear is switched to the "decentralized" state, and the landing gear is retracted. When the "action start" signal is sent to the operation system, the "landing gear action" is executed to open the strut.

## 4.5 Physical architecture view

The physical architecture view is defined to describe the components of the equipment. The functions of the components are listed in a library to understand their operations, effectively assign tasks, and identify possible problems and risks. By understanding the structure and functions, system deployment and maintenance can be conducted effectively. Figure 10 shows that a landing gear is composed of the landing gear strut, the anti-sway mechanism, and the main gear. The retraction and deployment subsystem consists of the landing gear uplock, landing gear retraction actuator, downlock, power supply unit, hydraulic lines, valves, and gear door retraction actuator.

## 4.6 Metric view

Aerospace equipment faces a wide range of operational demands. To optimize performance and minimize the risk of malfunctions, these demands are categorized by subsystem. Figure 11

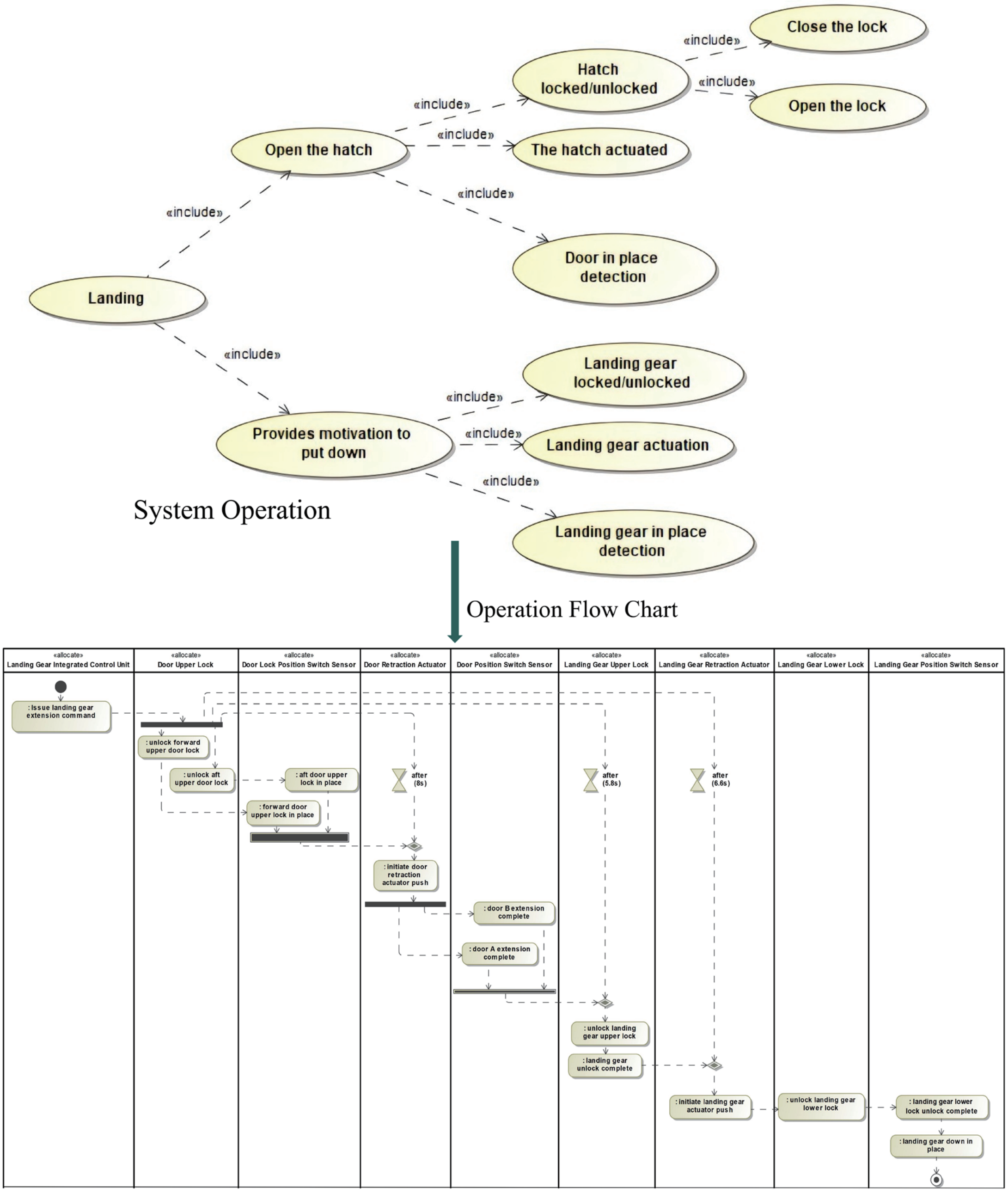


Fig. 8. (Color online) Landing gear operation analysis in landing.

shows the operational analysis of landing gear shutdown, which is conducted through balanced landing gear load distribution. Figure 12 provides the parameters for the metric view of subsystem operation.

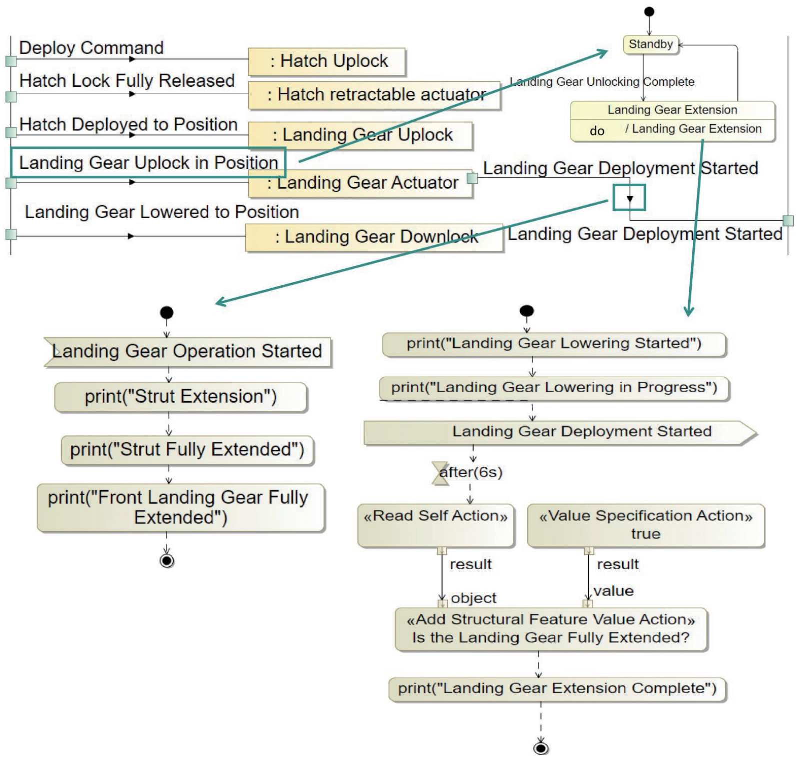


Fig. 9. (Color online) Components and their operations in aerospace landing gear.

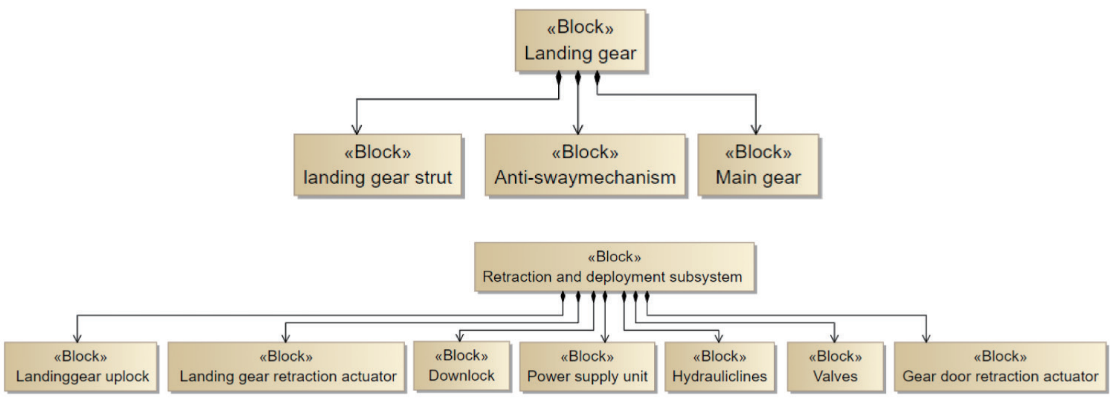


Fig. 10. (Color online) Physical architecture of aerospace landing gear.

## 4.7 Requirement verification

Demands are determined through verification and confirmation to ensure the correctness, completeness, and consistency of aerospace equipment operation. For aerospace system modeling, the demand view is vital as tasks and operations must be correctly defined to ensure

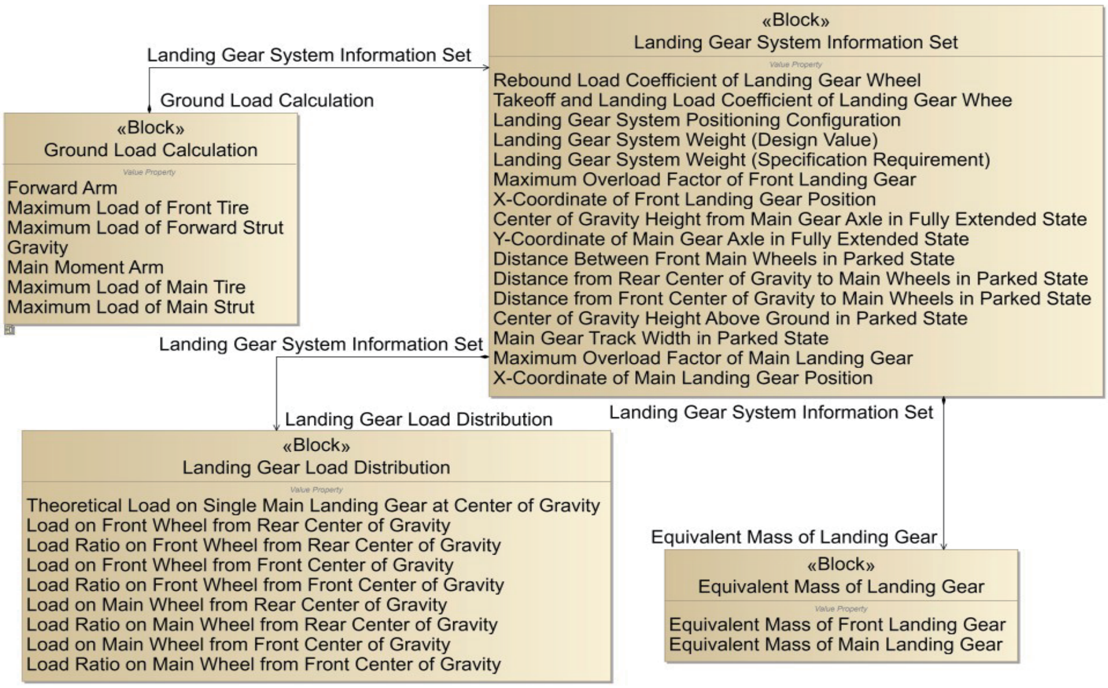


Fig. 11. (Color online) Operations of landing gear shutdown.

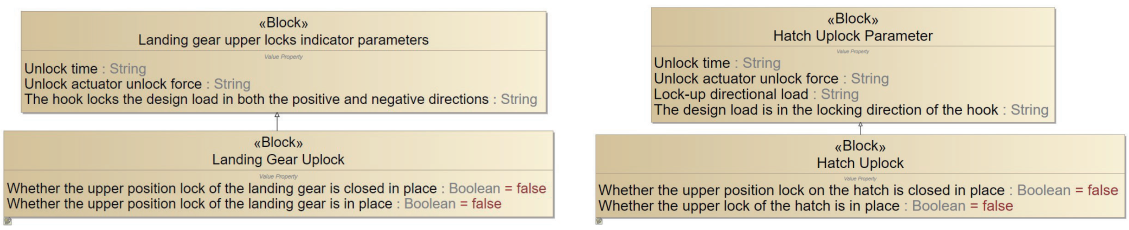


Fig. 12. (Color online) Parameters for metric view of subsystem operation.

the appropriate operation and prevent problems. As shown in Fig. 13, the demands of the subsystems are listed from the function library of the system model. Through the verification of the demands, the equipment can operate reliably, safely, and efficiently, and the equipment can be maintained effectively to prevent potential malfunctions.

Figure 14 shows the parameters in the demand view. The demands are defined at multiple levels of the operations of the equipment and its subsystems and components. Each subsystem's and component's demands must be defined correctly to monitor their operations efficiently using various sensors. Through digital mapping and integration with functional, metric, logical architecture, and physical architecture views, the system model can be verified. Then, signal transmission, signal conversion, and the optimization of the equipment operation can be ensured. To avoid data redundancy and inconsistency, a relationship matrix including demands and

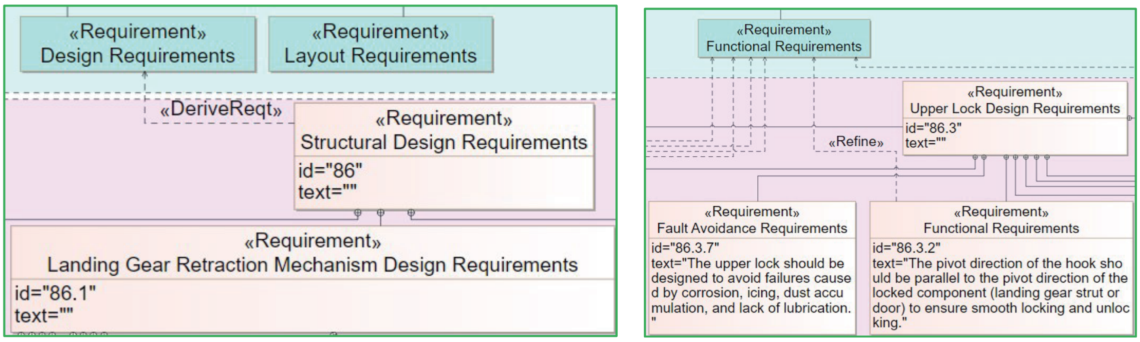


Fig. 13. (Color online) Demand analysis and results.

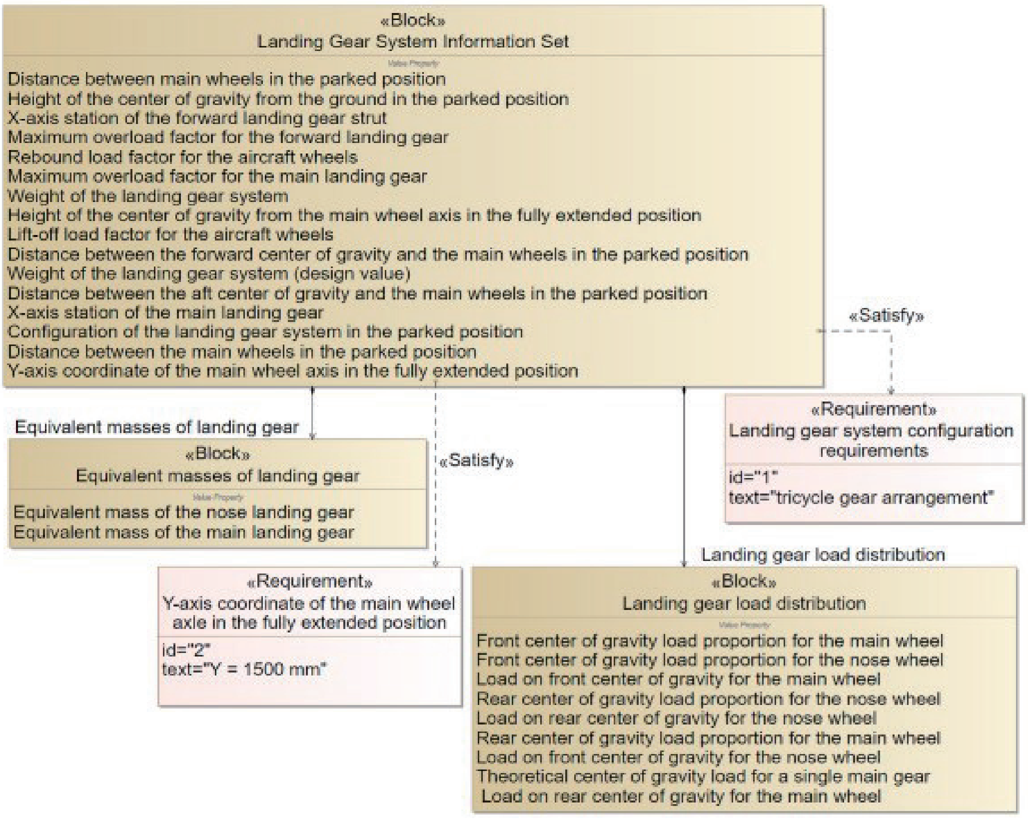


Fig. 14. (Color online) Parameters in demand view of system model of aerospace equipment.

parameters is constructed (Fig. 15). Digital mapping is of great significance in improving the efficiency and quality of system engineering and management and contributes to collaborative work among experts from different fields.

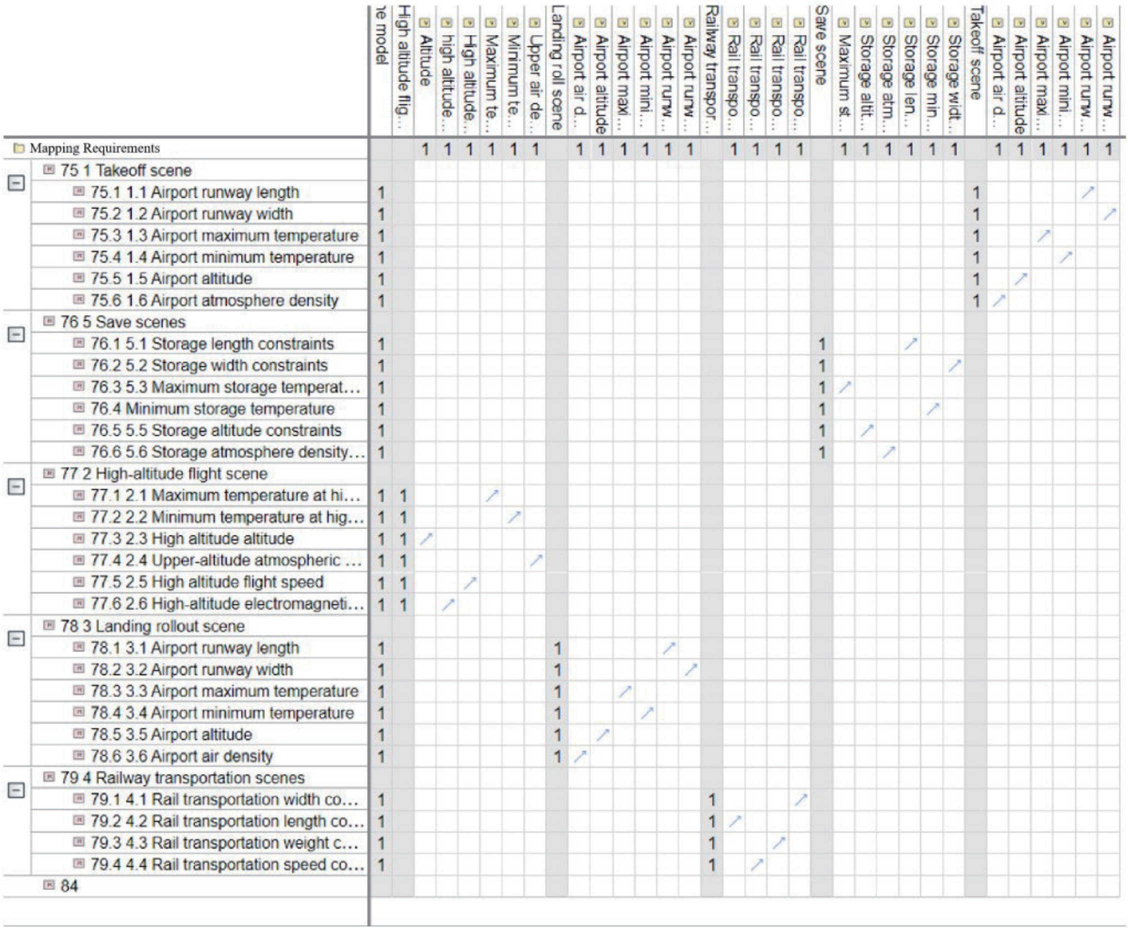


Fig. 15. (Color online) Demand and parameter matrix of system model.

## 5. Integration of Sensor Data

As a series of mature products, sensors have a very complete data structure. However, when applied in a system model, the metrics will be abstracted and simplified. This leads to the use of inappropriate data analysis methods by the system model when processing sensor data and analyzing the correlations among metrics. In addition, sensor data is highly specialized, and only professionals in specific fields can deeply understand its meaning and potential value, which also increases the difficulty of establishing correlations among metrics.

To integrate sensor data into the system model, sensor models that meet the requirements are selected from the model library (Fig. 16). The model data in the model library is extensive and comprehensive. In fact, during the construction of the system model, the selection is carried out on the basis of the data in the standard model library. The selected models will be abstracted by designers according to the system model. The system model integrates sensor data through "value Property," and the sensor models constrain the data range of the system model through "constraint Property," so as to achieve the integration and correlation of data.

Figure 17 shows the integration method for the position sensor and the landing gear system model. The calculation results of the ground loads of each component in the landing gear that need to be restricted by the position sensor are stored in the ground load calculation module. The load conversion module within the position sensor module transforms the overall load of the landing gear into the sensor load. The load range module constrains the range of the sensor. During the design of the landing gear, if the ground load of any component exceeds the load range permitted by the sensor, the design metrics need to be modified. The design is considered reasonable only when the ground load is within a reasonable range.

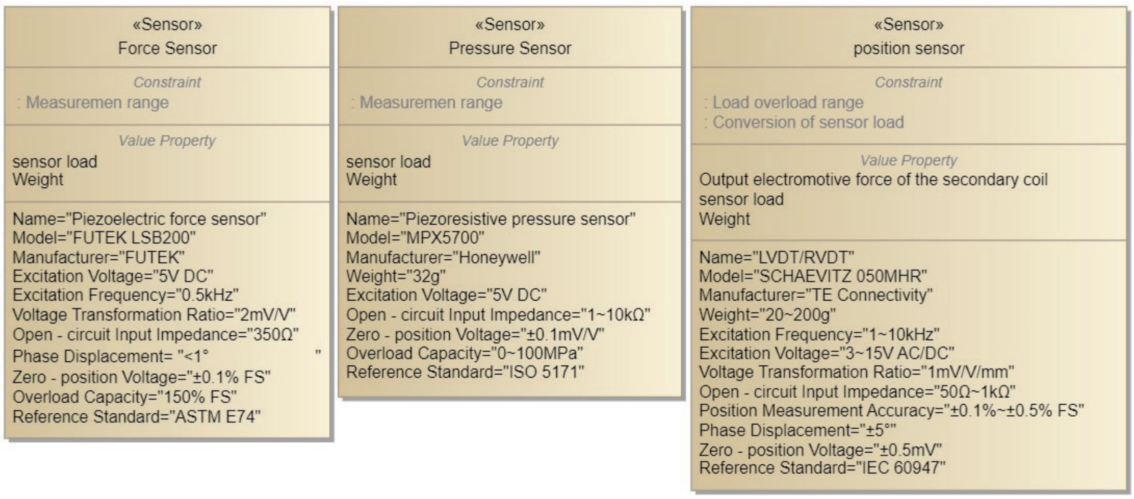


Fig. 16. (Color online) Sensor data set in the model library.

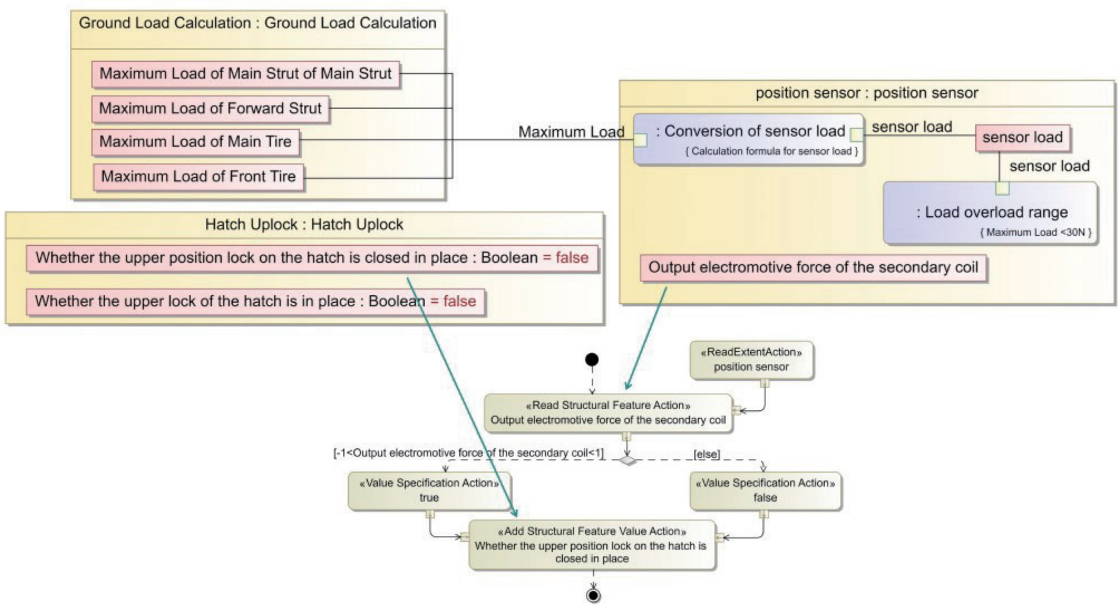


Fig. 17. (Color online) Integration of sensor data and system model.

System modeling methods exist to address the design of complex systems. Metrics possess very obvious emergent properties. However, the determination of component metrics precedes the design of system metrics. Therefore, system design metrics must be restricted by component metrics. Nevertheless, the design of component metrics usually involves multiple fields or manufacturers, which leads to a rapid increase in communication costs. Hence, when integrating component metrics into the system model, restricting all metrics through a constraint module can effectively ensure the rationality and applicability of the design metrics.

## 6. Conclusions

Integrating data and information into the system model of aerospace equipment enhances its design, development, and reliable management. Given the multidisciplinary nature of aerospace equipment and the extensive data collected from various sensors and past operations, it is crucial to incorporate data and information from aerospace, mechanical, electronic engineering, and other fields. Design guidelines, technical specifications, and engineers' experiences also need to be included in the system model. By establishing a system model that comprises architectural, mathematical, verification, and simulation components, the structure, function, performance, and elements of aerospace equipment can be analyzed, monitored, and maintained. This model enables the analysis of component correlations and interactions, identifies performance-affecting factors, and supports optimal design and decision-making. It facilitates parameter optimization and performance analysis. Additionally, the system model provides essential data for resource allocation, risk assessment, diagnosis, and identifying potential issues, ultimately improving the quality, reliability, and safety of aerospace equipment.

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