Research on Knowledge Network Modelling for Aero-craft System Design

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Abstract: A great amount of existing knowledge is required during the development of aero-craft system. At present, the existing knowledge organization model construct different knowledge model for different stages is difficult to adapt to the complicated product life cycle application. This study proposes a product development oriented knowledge network model focusing on expressing the knowledge demands and connecting the computer-aided system. Under the overall knowledge network model, this study describes the ontology description method of spacecraft product model, development tasks and aerospace terminology. Recommending missile aerodynamic knowledge within the design stage is presented as a case study, and the framework and the method is proved to be effective.

1 INTRODUCTION

A great amount of existing knowledge is required during the development of aero-craft system. The current knowledge modelling methods are only focus on single discipline, as they are highly specified which are impossible to describe the Multi-disciplinary knowledge related to aero-craft design. This study analyses the concepts related to digital prototyping of aero-craft system, and proposes a knowledge organizing framework for aero-craft design. Based on ontology language and unified prototyping system, the quest of aero-craft development and aerospace engineering knowledge are constructed and described in an organized knowledge framework. This study focuses on expressing the knowledge demands in modelling and connecting the computer-aided system. Pushing aero-craft aerodynamic knowledge within the framework is presented as a case study, and the framework and the method is proved to be effective.

The demand of knowledge in aero-craft system development can be categorized into the following aspects (Feng, 2015):

(1) Aero-craft development involves many practitioners and disciplines. Multi-disciplinary knowledge support is highly required, and product design phrase is required for consistent communication and collaboration of experts from design, manufacture and support.

(2) The application of knowledge content is restricted, and the specialization rate is high. Designers need to obtain specified knowledge in individual requests. Thus, there is a need to match the knowledge and the specified design activities.

(3) Knowledge such as existing design cases is of high value. Based on previous experiences, the design period can be shortened, and similar failures can be avoided.

(4) The contents of knowledge are expressed in different forms. A single knowledge note in product design can have many forms, including technical reports, models, algorithms and figures. The description of knowledge is highly diversified which requires for a knowledge system can express, store and connect different forms of knowledge vectors

(5) The requirements of new aero-craft system are changing, with an increasing flow of data and

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knowledge. The newly added knowledge should be properly recorded and managed for avoiding unnecessary loss and keeping

With development of information technology, the development of aero-craft system is changing towards a driving mode based on data, information, knowledge and wisdom. The knowledge module and product developing automation have becoming key measures for improving development efficiency. Thus, it requires unified depiction and organization of knowledge storage, description, transmit, share and reuse for covering corresponding aero-craft development phrases. The method is supposed to support the knowledge sharing, organizing and automatic application during aero-craft development procedure.

In this work, a novel knowledge network model for aero-craft development is proposed for integrating knowledge engineering and product design. The main contributions include follows:

(1) Discussing the knowledge framework for product development. Based on design of "product-task-discipline", the internal structure and connectivity of knowledge were discussed from application and case study perspectives. The framework covers all knowledge involving sectors in product development.

(2) Constructing aerospace term base, and using ontology language to express the standardized terms and their interrelationships.

(3) Analysing product data model system and combining multi-view requests. The relationships between physical structure model, data result model, case studies were discussed. Through connecting product structure and development tasks, the reuse of knowledge is improved. On the other hand, the multi-disciplinary knowledge is automatically matched to the product structure and development tasks via using standardized terms in knowledge expression, as a semantic support for knowledge automation.

(4) Pushing knowledge based on application scenarios within the knowledge network framework. Taking aero-craft knowledge as a case study, modelling it using ontology and using SPARQL ontology reasoning query technology for knowledge pushing and searching.

The merits of the proposed method: (1) Combining knowledge network model and product development mode, the knowledge generated during the whole aero-craft development is organized and modified to fit the requirements of practitioners with the purpose of improving knowledge utilization efficiency while lowering the management cost. (2) Organizing knowledge according to the work flow, which facilitates the automatic application of knowledge in aero-craft development. (3) Fully expressing the logic reasoning based on ontology terms of knowledge, and knowledge pushing based on scenarios is realized.

2 THE RELATED WORK

For knowledge organization and modelling the current methods are only focus on single discipline or function, as they are highly specified which are impossible to satisfy the need of digital prototype based developing mode. No report on life cycle knowledge management and application. Some researchers established knowledge models based on product structure and specified disciplinary domain. Yongdang proposed the implementing framework of knowledge organization model for aircraft engine design based on ontology (Yongdang et al., 2007). Changjie et al. put forward ontology based knowledge expressing method for tooling design knowledge, which included four sub-ontology models: design object, designer, design flow and design knowledge (Changjie et al., 2014). Bock established a product-based descriptive model to depict products from environmental, behavioural, and performance perspectives (Bock et al., 2010). The existing methods have some values in various applications, but they have certain limitations in current product design activities. Physical prototyping is now gradually replaced by digital prototyping. The knowledge generated in the process requires for proper management. Knowledge organization model should be robust and adaptive during the mode transformation, due to co-existence of knowledge within new and old prototype development modes (Abdullah et al., 2002). For development of complicated product such as aero-craft system, multi-disciplinary knowledge is desirable, hence knowledge organization should. Instead of single knowledge note, knowledge cluster is required. Current knowledge models are developed for certain phrase, which cannot handle the life cycle (Teswanich et al., 2002). During the establishing ontology, the relationships between tasks, products and knowledge have always been neglected. In the proposed knowledge model, digital prototyping and expression of technical terms during product development are discussed, with a focus on modelling knowledge demand and application of CAD system.

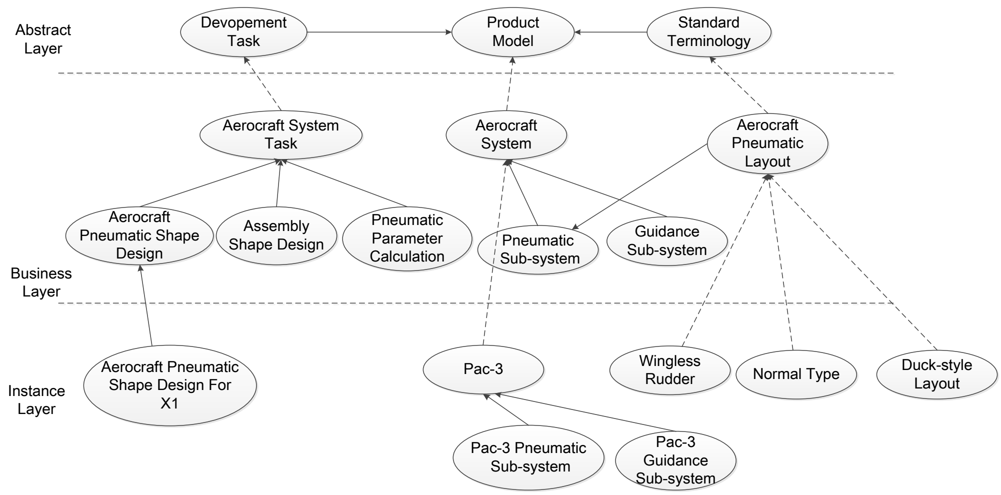

Figure 1: Knowledge modelling architecture for aero-craft design.

3 KNOWLEDGE MODELING ARCHITECTURE

Knowledge modeling architecture for aero-craft design is divided into three layers as shown in Figure 1. In abstraction layer defines the contents of top-level knowledge, in business layer divides the complex product manufacturing system into details, and in instance layer realizes concrete expression and organization of knowledge oriented to the specific product models. In knowledge modeling architecture the dotted lines represent the subclass inheritance relationship in various knowledge resources, while the solid lines describe the relationship between related objects.

The abstraction layer of knowledge modelling architecture mainly includes: (1) Product-model class, which mainly characterizes the general product structure, including detailed product structure and some parameters related to product life cycle (Panetto et al.,2012), such as physical model, data model, core function, performance parameters and etc. These parameters can be specifically expressed as researching products, mature models or product structure and key indicators' parameters for other historical products. From the physical structure, the class contains systems, subsystems, equipment and their hierarchical relationships, key parameters and functional description. (2) R&D class: is the main scene for R&D and an important carrier of knowledge demand. In this paper, the class is playing a more important role in organizationally expressing knowledge from time and scene dimension. (3) Terminology class: is unified knowledge of professional standard vocabulary and the relationship between them, mainly used for illustrating product model examples and description constraints for developing task instances. Additionally, the knowledge resources with the terms or the keywords can also be organized into knowledge modeling architecture of professional domain dimensions.

The business layer defines subclasses of three abstract classes, R&D tasks, aero-craft subsystems and space terms, combining with specific business process division, product structure division and involved professional areas in R&D of aero-craft system. Among them, aero-craft-subsystem class is refined into detailed subsystem and related architecture of the aero-craft. R&D class is refined into a series of specific R&D tasks connected with each specific sub-system. Space-term class includes the professional area, environmental requirements, technical approaches and other contents in the field of aero-craft's R&D.

The instance layer puts forward the specific task examples, product model examples, standard terminology examples and etc. for classes defined in the business layer. In the layer, the product models, composed of composition and parameters, are divided into the product subsystems and corresponding parameter file reports in accordance with aero-craft overall category templates in aero-craft system. The tasks are refined into specific models in work nodes of collaborative design system. The standard terminology examples are specifically illustrated as terminology entries, standard definitions and professional relationship.

After the completion of knowledge modeling architecture, this paper will discuss about the product model, R&D task and storage and expression of standard terminology. As the mainstream knowledge representation method in the field of knowledge engineering, ontology, implementing the knowledge model, can guarantee the uniqueness of knowledge comprehension, express various types of semantic-complex knowledge and establish the interrelations among amount of knowledge.

4 ONTOLOGY DESCRIPTION FOR PRODUCT-MODEL CLASS

In the R&D of aero-craft system, the product model of product structure, data and function, has multi-view application requirements (Lu et al., 2010). It is necessary to organize, analyse and elaborate the product model by comparing R&D goals and current modes in different views. In the process of R&D, the system can be divided into structure view, function view and performance view according to different uses. Figure 2 shows the interaction between various modes of view application.

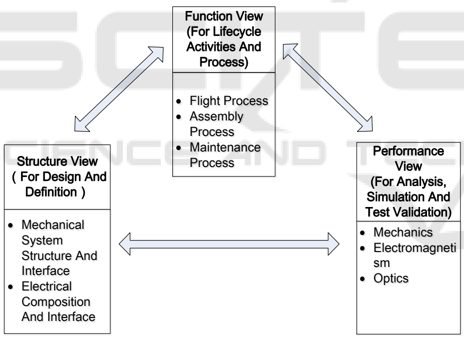

Figure 2: Various modes of view application.

The background of multi-view application puts forward new requirements for constructing, describing and storing aerospace product models and information by using ontology description method. The requirements are mainly reflected in the following aspects:

(1) Dynamicity. The storage and display of the ontology model should be dynamic, especially when describing the functional view, which is able to satisfy the need for illustration and application of space knowledge from time to time.

(2) Flexibility. Storage of the ontology model can be instantly switched referring to different needs for various views. It cannot be occurred that the application needs are not be quickly satisfied due to complexity of the structure.

(3) Comprehensiveness. The storage and display of ontology model should be able to cover the different needs of various view application.

(4) Intuitiveness. Visualization of the ontology model should be intuitive for being presented directly in front of the applicators through by graphical structure.

(5) Extendibility. New product model and R&D task may cause optimization and complement to the ontology model due to uncertainty during R&D procedure. As a consequent, storage and display of ontology model should be of extendibility from ontology class structure to the related instance.

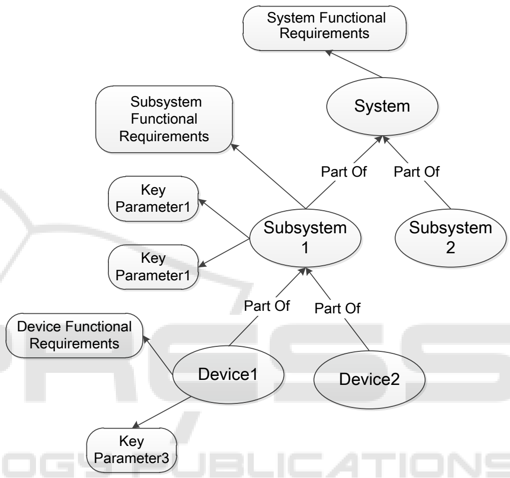

Figure 3: Aero-craft product model.

Figure 3 shows a description example of an aero-craft product model. According to the definition of aero-craft's digital prototype, the device components are established as the ontology class referring to the product hierarchical division method of "system, subsystem, single-device", and the hierarchical relationship is constructed based on existing method of modelling digital prototype.

For system, subsystem or device, each level of the ontology class has many related instances, covering different functional requirements, key parameters and key models. The associated models are mainly represented as the following categories:

(1) System functional requirements: consist of task requirements, combat process, maintenance process and other items. Functional requirements must be marked with environmental constraints, such as the influence of environment, like the atmosphere and electromagnetic, and non-system entities, for instance the target's characteristics faced by weapon system.

(2) Key parameters: key information in R&D process of the aero-craft product digital prototype in accordance with requirements for parametric development.

(3) Key models: are the structure, the electronic CAD files and CAE three-dimensional models for a cured device.This type of information can also be treated as a structural content associated in the ontology framework.

Figure 4 shows a model view of aero-craft pneumatic subsystem. For the case of mature aero-crafts, the view involves the relationship between product-model class and parameters, the relationship between product-model class and files, and the relationship between product-model class and models.

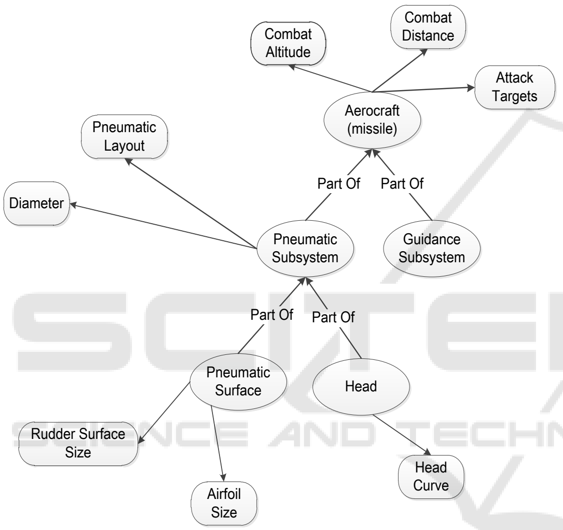

Figure 4: A model view of product structure.

The instance, describing the components and related parameters of aero-craft subsystem by the ontology language, is shown as follows:

```
<MISSLE RDF: ID = "XX MISSILE">
<MACH NUMBER RDF: DATATYPE =
"HTTP://WWW.W3.ORG/2001/XMLSCHEMA#FLOAT
"> 5 </ MACH NUMBER>
<MANEUVERABILITY RDF: DATATYPE =
"HTTP://WWW.W3.ORG/2001/XMLSCHEMA#FLOAT
"> 2.0 </ MANEUVERABILITY>
<TARGET AND AIRSPACE> <OWL:
NAMEDINDIVIDUAL RDF: ID = "XX - CRUISE
MISSILE AIRSPACE">
<COMBAT HEIGHT RDF: DATATYPE =
"HTTP://WWW.W3.ORG/2001/XMLSCHEMA#FLOAT
"> 12KM </ COMBAT HEIGHT>
<DEVELOPED COUNTRY RDF: DATATYPE =
"HTTP://WWW.W3.ORG/2001/XMLSCHEMA#STRIN
G"> US </ DEVELOPED COUNTRY>
<RUDDER SIZE RDF: DATATYPE =
"HTTP://WWW.W3.ORG/2001/XMLSCHEMA#FLOAT
"> 332.0 </ RUDDER SIZE>
<AIRFOIL SIZE RDF: DATATYPE =
"HTTP://WWW.W3.ORG/2001/XMLSCHEMA#FLOAT
"> 1056.0 </ WING SIZE>
 </MISSILE CLASS RDF: ID = "XX
MISSILE">
```

5 THE ONTOLOGY OF DESIGN TASK

Design task mainly shows the scene and environment of products' development, as well as an important concrete scene of knowledge reuse (Xuwei et al., 2009). In the actual description, using IDEF0 model expression method, combined with ICOM (Input, Control, Output, Mechanism) structure to achieve the model description for products' design task. One advantage of the IDEF modeling approach is that graphical representations can clearly describe model order, constraints, and resources. Also in ICOM, supplementary task activity description D and Mechanism M which is decomposed into personnel organization H and knowledge resource K, constitute a task node model ICO-DHK model that describes knowledge integration applications. The design task's ontology description model can be expressed as shown in the figure.

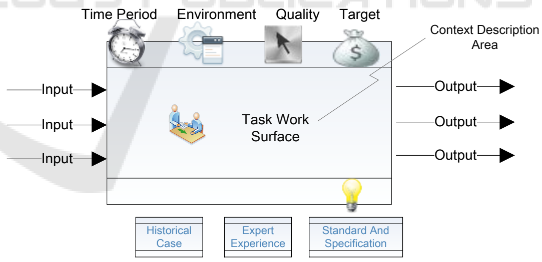

Figure 5: Ontology description of design task.

The task ontology model can be described as a group of six-tuple model ICO-DHK (I, C, O, D, H, K).

I represents the data input of the task node, describes the source, format, unit and quantity of the data entry;

C represents the task node control, which is actually composed of various constraints of the task process, including time period, environment, quality, target, cost, task flow, cycle judgment condition;

O represents the data output of the task node, describing the destination, format, unit and quantity of the data output;

D describes the professional and working content of the task node;

—H describes the personnel organization of the task node;

K describes the task tool resource and task knowledge resource of the task node

The data input of the task node I, the task node control C, the data output of the task node D, the personnel organization H constitute the task ontology description. In addition, inheriting from the IDEF0 structure description, it still has the task of decomposition of the lower level, as shown in Figure 3.

An example of using the ontology language to describe the design task is as follows:

```
<TASK NODE RDF: ID = "BALLISTIC VERIFICATION">
<TASK NAME RDF: DATATYPE = "HTTP://WWW.W3.ORG/2001/XMLSCHEMA#STRING"> BALLISTIC VALIDATION </ TASK NAME>
<DOWNSTREAM TASK RDF: RESOURCE = "# TASK END" /><CONSTRAINT>
<CONSTRAINT CLASS RDF: ID = "FULL WEIGHT VERIFICATION">
<CONSTRAINT NAME RDF: DATATYPE = "HTTP://WWW.W3.ORG/2001/XMLSCHEMA#STRING"> FULL WEIGHT VERIFICATION QUALIFIED </ CONSTRAINT NAME>
<CONSTRAINT VALUE RDF: DATATYPE = "HTTP://WWW.W3.ORG/2001/XMLSCHEMA#STRING"> 235KG </ CONSTRAINT VALUE>
<CONSTRAINT TYPE RDF: DATATYPE = "HTTP://WWW.W3.ORG/2001/XMLSCHEMA#STRING"> FULL WEIGHT </ CONSTRAINT TYPE>
</ CONSTRAINT>
</ CONSTRAINT>
<TASK DESCRIPTION RDF: DATATYPE = "HTTP://WWW.W3.ORG/2001/XMLSCHEMA#STRING"> BALLISTIC VALIDATION </ TASK DESCRIPTION>
</TASK NODE>
```

6 THE ONTOLOGY DESCRIPTION OF SPACE TERMINOLOGY

The use of standard terminology in the field of expertise can clearly regulate the relationship between terminology and jargon, and ensure the normalization and consistency of semantic representations in the knowledge network model (Feng, 2015). At the same time, the use of the association relationship between terminologies can achieve the knowledge networking of product and development task example.

This article draws on the "space science and technology descriptors" as the lexicon of descriptors. It is an industry vocabulary in the field of aerospace industry with System integrity, which sets the terminology of the various disciplines and expertise as a whole. It contains 21 first-class categories and 221 secondary categories (Ying, 1995). Each of the terminology includes Chinese name, pinyin, English name, and category. The association relationships between terminologies include the use, substitution, belonging, dividing and so on. An example of using the ontology language to describe the terminology is as follows:

```
<Terminology rdf: about = "http://www.owl-ontologies.com/unnamed.owl# satellite spray logo">
<Pinyin rdf: datatype = "http://www.w3.org/2001/XMLSchema#string"> Wei xing pen tu biao zhi </ Pinyin>
<English word rdf: datatype = "http://www.w3.org/2001/XMLSchema#string"> Satellite marking </ english words>
<Category>
<Category rdf: about = "http://www.owl-ontologies.com/unnamed.owl# general concept of aerospace technology">
<Category number rdf: datatype = "http://www.w3.org/2001/XMLSchema#string"> 0201 </ category>
<Category name rdf: datatype = "http://www.w3.org/2001/XMLSchema#string"> general concept of aerospace technology </ category name>
</ Category>
</ Category>
<Chinese word rdf: datatype = "http://www.w3.org/2001/XMLSchema#string"> satellite spray logo </ Chinese words>
</ Terminology>
```

It is important to emphasize that the above professional standard terminology will be construed as a described constraint for product design task or product structure. In other words, such as attack target, combat height, combat distance and other key parameters of aero-craft overall system development task, and pneumatic layout, track diameter, head curve, rudder dimensions , air foil dimensions and other key parameters of pneumatic related product structure need to be expressed in professional standard terminology.

7 KNOWLEDGE RECOMMODATION

The ultimate goal of establishing a knowledge network model for business scenarios is to realize the knowledge networking and efficient reuse of the product development process, and to open up the knowledge flow in the business scene .In order to verify the validity of the discussion model, the text uses the OWL language to compile a set of knowledge network model for the pneumatic selection design task with the model development background. The model example uses the model pneumatic subsystem as the product, and the Pneumatic shape design tasks for the examples of development tasks, associated with pneumatic design-related standard terminology. Examples of knowledge in the model include the Aero-craft pneumatic design scheme the empirical and knowledge related to the pneumatic design selection in the World Aero-craft Cluster. Through the description of the knowledge network model to realize the close relation in product models, development tasks and professional terms, and design system to support specific model tasks for knowledge push associated with the enterprise system. The specific process is as follows:

(1) First of all, the existing aero-craft case should be localized. Its structured description can be achieved through expressed in Standard Terminology. The main products covered the key aero-craft models in the United States, Russia and other countries of the "Aero-craft Daquan (third edition)", as well as some parameters, reports and models related with products pneumatic designs in a research institute. The application software obtains the product description files and automatically.

(2) The application software cooperates with the enterprise collaborative design platform and the product development task example to obtain the basic attribute and the key core index requirement of the task, and obtains the situation information of the task by using the interface provided by the collaborative design system. It mainly includes: (1) Basic attributes of the task, including the task name, the project name, the task template of the source, etc. (2)Task subscription and published data, including Input parameter name, parameter value, parameter type, and output description name, parameter requirements, and parameter type. The specific task requires designing a model of ground-to-air aero-craft pneumatic layout design. The development of the task type package in knowledge network is the specific development task example. Table 1 shows the main pneumatic parameters.

Table 1: Main parameter for task.

Project Name Missile Design	Xxx Missile Design
Task Name	Pneumatic Layout Design
Product System	Pneumatic Subsystem
Input Parameter	
Target	High Speed Fixed Wing Aircraft, Cruise Missiles
Mach	5
Combat Distance	1.5KM-10KM
Combat Height	0km-12km
Output Parameter	
Pneumatic Layout	
Diameter	
Rudder Size	
Wing Size	

(3) The software system utilizes the SPARQL query method to obtain the existing design experience or scheme which meets the task requirements by using the ontology description reasoning of the specific product development in the knowledge network model .In this case, we carry out knowledge search for "aero-craft case" knowledge, and then use the input parameters of the task to match the reasoning .For example, the attack target in this paper is a aero-craft case in the associated knowledge base similar to a counterpart with a high-speed fixed-wing aircraft, and the input parameter constraint of the Mach 5. The SPARQL query is as follows:

```
PREFIX rdf:
<Http://www.w3.org/1999/02/22-rdf-
syntax-ns#>
PREFIX rdfs:
<http://www.w3.org/2000/01/rdf-schema#>
PREFIX owl:
 <http://www.w3.org/2002/07/owl#>
PREFIX     base:     <http://www.owl-
ontologies.com/unnamed.owl#>
SELECT  distinct?  Missile?  Layout?
ControlSurfaceSize? WingSurfaceSize
WHERE {
Missile rdf: type base: missile class.
Missile base: aeronautical subsystems.
? Missile base: Pneumatic layout.
? Missile base: rudder size?
ControlSurfaceSize
? Missile base: wing size?
WingSurfaceSize
Missile base: aeronautical subsystems.
? Missile base: target and airspace? T.
?  T  base:  target.  Targets  .Filter
(targets = 'high speed fixed wing
aircraft'
```

```
 || targets = cruise missiles').
? Missile base: Mach number? MachNumber
.Filter (? MachNumber> = 5).
Missile  base:  operational  distance.
OperationalRange .Filter
 (operationalRange>     =     1.5     ||
operationalRange> = 10).
?  Missile  base:  combat  altitude?
CombatAltitude .Filter
 (? CombatAltitude <= 12).
};
```

After the ontology description push, product development staff can get the product examples which meet the requirements of the product development and their associated product design, model and other knowledge resources in the pneumatic design task work surface. Figure 6 is the interface of knowledge display pushed by application software.

Figure 6: Case knowledge display.

8 CONCLUSION

This paper focuses on the framework of knowledge network model for aero-craft design. And based on the framework, this paper conducts knowledge networking and push application validation for pneumatic layout design tasks of aero-craft product pneumatic subsystem. This framework realizes the fusion of the simulation of knowledge network and task scene, which can quickly build a knowledge networking and application sharing platform. Subsequent work will improve the overall framework to make it suitable for applications such as automatic knowledge discovery.

REFERENCES

Feng, D., 2015. Research on Knowledge Network Theory and Integration Application for Complex Product R & D Process. Doctoral dissertation. Zhejiang University.

Yongdang, C., Haicheng, Y., 2007. Construction and analysis of aero-engine design knowledge organization model based on ontology. *Journal of Aeronautics and Astronautics*, 22(1), pp.90-95.

Changjie, L., Xinguo, M., 2014. Ontology-based aircraft tooling design knowledge representation method. *China Mechanical Engineering*, 25(19), pp.2614-2619.

Bock, C., Zha, X., Suh, H.W. and Lee, J.H., 2010. Ontological product modeling for collaborative design. *Advanced Engineering Informatics*, 24(4), pp.510-524.

Abdullah, M.S., Benest, I., Evans, A. and Kimble, C., 2002, September. Knowledge modelling techniques for developing knowledge management systems. In *Third European Conference on Knowledge Management: Trinity College Dublin*, Ireland, p.17.

Teswanich, W., Anutariya, C. and Wuwongse, V., 2002. Unified representation for e-government knowledge management. In *Proceedings of the 3rd International Workshop on Knowledge Management in e-Government*, pp.199-209.

Panetto, H., Dassisti, M. and Tursi, A., 2012. ONTO-PDM: Product-driven ONTOlogy for Product Data Management interoperability within manufacturing process environment. *Advanced Engineering Informatics*, 26(2), pp.334-348.

Lu, Y., Panetto, H. and Gu, X., 2010. Ontology approach for the interoperability of networked enterprises in supply chain environment. In *OTM Confederated International Conferences" On the Move to Meaningful Internet Systems"*, pp.229-238.

Xuwei, P., 2009. Adaptive Personalized Information Service: Context-Aware and Ontology Based Approach. *Journal of Library Science in China*, 35(6), pp.41-48.

Ying, L., 1995. Space science and technology descriptors, China Aerospace Publishing House, second edition.