KNOWLEDGE ENGINEERING BASED FLIGHT TEST TECHNOLOGY FOR CIVIL AIRCRAFT AIRWORTHINESS CONFORMITY

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Abstract

Through the study of the flight test process of aircraft compliance verification based on knowledge engineering, the flight test technology for compliance validation and airworthiness regulations are fused based on the knowledge bank. The knowledge engineering model of the airworthiness regulations is established to match the knowledge unit of airworthiness regulations with the attribute information of the compliance verification knowledge unit. The knowledge ontology model in a flight test field is constructed and applied to the flight test engineering. By establishing the knowledge bank based on the flight test process of airworthiness verification and an automatic knowledge-pushing platform, and using the knowledge management and a flight test engineering cooperation method, it is possible to make the flight test engineering for airworthiness verification knowledgeable, integrated and intelligent so as to optimize airworthiness verification flight test outline, flight test scheme and flight test method, improve the quality and efficiency of airworthiness verification flight test engineering and reduce flight test cost.

1 Introduction

In order to effectively implement the flight test of airworthiness compliance of civil transport category aircraft, it is necessary to rely on a variety of airworthiness regulations, norms, standards, airworthiness management procedures, instructions, etc., and in the process of making verification flight test methods, it is necessary to consult the advisory circulars and other documents. However, the airworthiness regulations are usually in principle, standard and general requirements, and there are no specific flight test techniques, methods, test data measured methods, data processing techniques, flight test guarantee conditions and auxiliary flight test facilities to meet the requirements of airworthiness compliance. So, in the implementation of the flight test of airworthiness compliance of civil aircraft, it is necessary to design, select and adopt specific flight test techniques and methods that meet the requirements of airworthiness, including data processing technology, flight test guarantee conditions and flight test auxiliary facilities. In formulating the airworthiness verification flight test outline, flight test content and method of flight test, what regulations and rules should be followed, what necessary verification flight test technologies should be adopted, which content should be verified, which design indexes should be verified, and all of these problems should be carefully considered and weighed in the design of flight test plan. This process presents a comprehensive application of interdisciplinary expertise in aircraft design, manufacture and test, as well as the complexity combing and integrity of application of the airworthiness system.

Modern civil transport category aircraft airworthiness verification flight test is not only a knowledge-intensive innovation process, but also an intensive sharing communication process between design, manufacture and test. It involves the professional knowledge, practical experience of many subjects and the creative work of flight test engineers collaborated with aircraft designers and manufacturing engineers. The traditional civil aircraft airworthiness verification flight test is basically executed at the concatenated flight test operation mode and advanced in accordance with the airworthiness regulations. This model is not suitable for the high efficiency, high quality and fine goal of modern civil aircraft design, development and test process. In this paper, we study the application of the technology and method of knowledge engineering into civil aircraft airworthiness certification flight test engineering. Based on the existing airworthiness system and artificial intelligence technology, the knowledge bank and knowledge automation push platform per airworthiness verification flight test flow are established. By cooperating the method of knowledge management with flight test engineering together make the airworthiness verification flight test engineering knowledgeable, integrated and intelligent. Through the integration of the airworthiness regulations knowledge repository and the compliance verification flight test knowledge repository, it is feasible to optimize the airworthiness verification flight test outline, flight test design scheme and flight test method, so as to improve the quality and efficiency of airworthiness verification flight test engineering, and reduce the cost of flight test.

The concept of the Knowledge Engineering (KE, Knowledge Engineering) was developed in the late 1970s from the technical development of building expert systems, knowledge-based systems and knowledge-intensive information systems. It took the knowledge repository as the resource for dealing with test objects, borrowed the engineering thought, and studied how to design, construct and maintain the knowledge system with the principle, method and technology of artificial intelligence, and achieved the goal of knowledge innovation and technological innovation. The acquisition of knowledge, the representation of knowledge and the reasoning of knowledge constitute the three main elements of knowledge engineering. The function of knowledge-based system is generally reflected in the aspects of recognition perception, prediction fitting, fault diagnosis, optimization design and machine learning. The research contents of knowledge engineering in the flight test engineering for civil aircraft airworthiness compliance verification include basic theory research, practical technology development, knowledge system tool research. Through the knowledge engineering, the airworthiness management procedure, airworthiness compliance verification technology and method are integrated into the flight test engineering process, and the intelligent flight test management software platform for civil aircraft airworthiness compliance verification is constructed[1].

2 Construction of the flight test flow of airworthiness compliance verification based on knowledge engineering

The flight test of compliance verification refers to the application of various verification flight test techniques and methods according to airworthiness regulations to verify whether the function and performance indexes of the verified aircraft meet the requirements of the airworthiness regulations of civil aircraft, and confirm the degree of conformity between the design indexes of the verified aircraft and the requirements of airworthiness regulations. In the process of verification flight test, the relevant knowledge should be considered and weighed, including airworthiness regulation and terms, airworthiness verification flight test technology, aircraft design concept and design technical requirements, technical requirements for flight tests in aircraft design, and requirements for aircraft flight test modification in aircraft design, etc. Therefore, the organization and implementation of the compliance verification flight test program is a complex system project, which requires the overall planning of the flight test from the viewpoint of the system. In terms of the full life cycle of civil aircraft, airworthiness certification test flight needs to be planned and implemented from the design, manufacture, test, use, maintenance and management. From a professional point of view, aircraft airworthiness certification flight test technology system consists of general performance, structural strength, flight control system, power plant, hydraulic system, environmental control system, avionics system, electrical system and general basic specialities. From flight test process point of view, the compliance verification flight test needs to comb the aircraft configuration, flight test flow management, and build standard flying action repository, flight test measuring modification design knowledge repository, flight test data processing method repository, flight test data processing software repository, flight test measuring driver program and measuring program repository, aircraft maintenance/airport service knowledge repository, standard flight test job sheet repository, etc., by these knowledge banks and their subordinate professional auxiliary repositorys to support the operating and running of the flight test engineering, as shown in figure 1. According to the Fig. 1, the compliance validation flight test process based on knowledge engineering could be divided into the flight test outline layer, flight test programs, flight test task assurance layer, flight test process security layer, flight test data processing layer and emergency disposal layer.

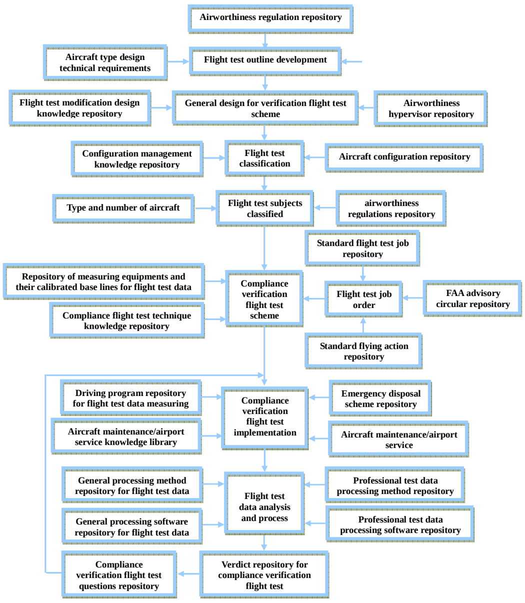

Fig.1 Knowledge engineering based aircraft compliance verification flight test flow

3 Fusion between airworthiness regulations and compliance verification flight test technology

The compliance verification flight test is by use of flight test technology and means, to prove whether the verified aircraft meet the requirements of civil aircraft airworthiness regulations, verify the flight test results and airworthiness regulations in accordance with degree. During the verification flight test, the application of airworthiness verification flight test technical knowledge and airworthiness regulation knowledge is the key knowledge to support the whole verification flight test process. At the beginning of the compliance verification flight test engineering, the relevant airworthiness knowledge is triggered according to the content of the obtained verification plan, including the interpretation and transformation of the airworthiness regulations and terms, and integrating the contents of the interpretation and transformation into the compliance verification flight test technology, so as to realize the good constraints of the flight test activities by means of the airworthiness regulation knowledge and verification flight test technical knowledge, and promote the high efficient implementation of the airworthiness verification flight test activities. The integration and application of the knowledge of airworthiness regulations and airworthiness verification flight test technology is an important inheritance and prospect link in ensuring civil aircraft airworthiness verification flight test. Fig.2 describes the recombination and integration of the compliance verification flight test technology and airworthiness regulations based on knowledge engineering[2].

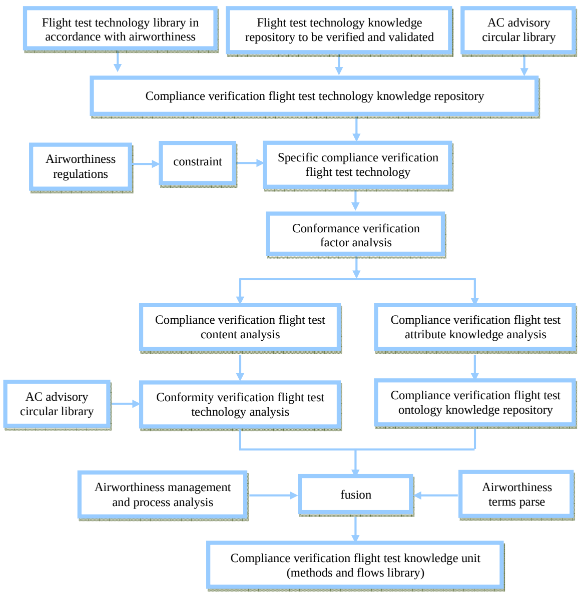

Fig. 2 Fusion of the knowledge repository based compliance verification flight test technology and airworthiness regulations

Based on this principle of recombination and integration, we can define the conformance verification flight test knowledge unit as follows:

Definition 1: Compliance verification flight test knowledge unit is the extracted specific validation flight test activities constraint knowledge collection based on airworthiness regulation analysis, and the knowledge unit is a blend of key attribute information about airworthiness regulations and airworthiness verification flight test technical knowledge.

The compliance verification flight test technology knowledge repository is derived from the successful implementation rules of verification flight tests, flight test experience, the flight test methods recommended by AC advisory circular library, and the flight test techniques and methods to be verified and confirmed. The specific verification flight test techniques designed for compliance verification projects need to be constrained by airworthiness regulations. Factors of compliance verification knowledge unit include the certification support class knowledge, certification process knowledge and certification management knowledge. Through the analysis of the three kinds of knowledge unit, comb compliance verification flight test content, compliance verification flight test technology, compliance verification flight test attributes and compliance verification flight test ontology knowledge library. For the technical analysis of the compliance verification flight test, it is necessary to consult the AC advisory circular. Finally, the compliance verification flight test knowledge unit (methods and process library) adapted to the project is formed by fusing the airworthiness management process and airworthiness regulations[3].

The analytical method for the airworthiness regulations of FAR25 for civil transport aircraft is to refer to the compliance verification checklist of civil aircraft, to extract the knowledge factor of the regulations, to establish the knowledge-based analytical model of the airworthiness regulations, and to make the verification purpose and verification method of the regulations more specific and knowledge-based. The knowledge factor extraction includes ATA (applicable positions), MOC (compliance methods), compliance documents, etc.

The compliance documents can be further subdivided into several compliance documents according to the characteristics of the subject being reviewed. After a complete compliance verification workflow, the analyzed regulations will form a series of verification experiences and verification rules. The knowledge engineering analytical model of the airworthiness regulations is shown in Fig. 3. The steps corresponding example 1 are as follows:

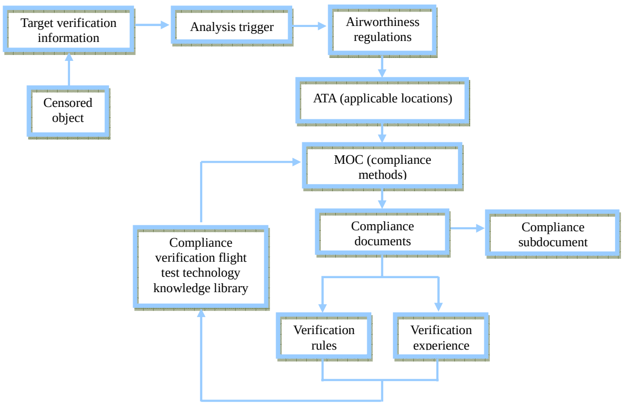

Fig. 3 Knowledge engineering model of airworthiness regulation

The control system fault compliance verification flight test about the ARJ21-700 aircraft (as shown in Fig.4) is for instance analysis:

Fig.4 ARJ21-700 aircraft

1) FAR25.671(c) article : The airplane must be shown by analysis, tests, or both, to be capable of continued safe flight and landing after any of the following failures or jamming in the flight control system and surfaces (including trim, lift, drag, and feel systems), within the normal flight envelope, without requiring exceptional piloting skill or strength.

2) Compliance verification content: elevator jam, the resistance to the rudder, aileron jam location, spoiler roll jam location.

3) applicable ATA code: 2700 (flight control system).

4) Compliance methods (MOC) : the descriptive documents (MC1), analysis/calculation (MC2), laboratory test (MC4), ground test method (MC5), flight test (MC6).

5) Knowledge library: AC 25.671- x, the policy PS-ANM100-1995-00020, issued by the FAA.

6) Compliance documents: the compliance report on the control system response to the pilot's operation force.

7) Verification rules are as follows:

The test status of unilateral elevator jam test is shown in table 1.

8) Verification experience: omited.

Table 1 Single side elevator jam test status

No.	Altitude (km)	Airspeed (kn)	Weight	Gravity center	Landing gear	Flaps/ slats	engine	note
1	3.0	1.23VSR	normal	Former	down	Take off	As needed	right elevator is jammed -9°
2	3.0	1.23VSR	normal	Former	down	approach	As needed	right elevator is jammed 7°

The compliance verification flight test method for single side elevator jam is as follows:

a) Flight altitude 3000m, flight speed 1.23 VSR, landing gear down state, flap/slat wing "2" jammed, trimming plane, keeping steady flat flight;

b) Fault signal settings, the right side elevator jammed -9°;

c) The left step elevator, the overload is 0.8g/1.3 g;

d) Flight altitude 3000m, flight speed 1.23 VSR, landing gear down state, flap/slat wing "3" jammed, trimming plane, keeping steady flat flight;

e) Fault signal settings, the right side elevator jammed 7°;

f) The left pilot completes the following jobs: the step elevator, the overload requirement 0.8g/1.3 g, and simulates approach landing.

4 The reconstruction of knowledge unit of airworthiness regulations and verification technical knowledge unit

While in the traditional airworthiness compliance verification activities compliance verification test regulation numbers, the general code table ATA number for civil aircraft systems/components, compliance method (MOC), experiment number, serial number, test name, completion date, duty department, test leader, test inspector, head of the people, the state of test progress and other relevant information have been provided, the compliance methods could not determine the specific airworthiness verification ways and technical verification details, not achieve the whole control and constraint to the process of airworthiness verification activities with airworthiness regulations knowledge. Through on the interpretation of airworthiness regulations for the airworthiness compliance verification technique knowledge, it is the key to the selection of the airworthiness compliance verification strategy and the constraint of compliance verification activities, and it is the link between the static airworthiness information and the concrete verification behavior. Therefore, the knowledge attribute information of the two is reconstructed to form a fused of airworthiness compliance verification knowledge library to realize the compliance verification under airworthiness regulations.

The reconstruction steps for the verification technique unit and the regulations knowledge unit are as follows:

Step 1: comb out the knowledge attribute unit of airworthiness regulations for the compliance verification project;

Step 2: comb out the compliance verification technique knowledge attribute unit for the compliance verification project;

Step 3: arrange the knowledge attributes related to step 1, step 2, and determine the information of the compliance verification technique knowledge attribute unit corresponding to the airworthiness regulations;

Step 4: map the knowledge attribute information of the airworthiness regulations to the verification knowledge unit directly.

Step 5: by analyzing the airworthiness regulations and matching the attribute information, the attribute information of the compliance verification technique knowledge inconsistent with the regulations attribute information is modified and mapped to the compliance verification technique knowledge unit.

Step 6: obtain the technical knowledge of compliance verification by referring to non-legal documents such as AC advisory circulars;

Step 7: through the verification rules and the verification experience confirmed by the airworthiness management organization to enrich the compliance verification technology knowledge library.

Through the above steps, the knowledge attribute of airworthiness regulations and compliance verification technique knowledge attribute are reconstructed, and the compliance verification knowledge library is formed to integrate the airworthiness compliance verification technology, airworthiness regulation requirements and special compliance verification behaviors, as shown in Fig.5.

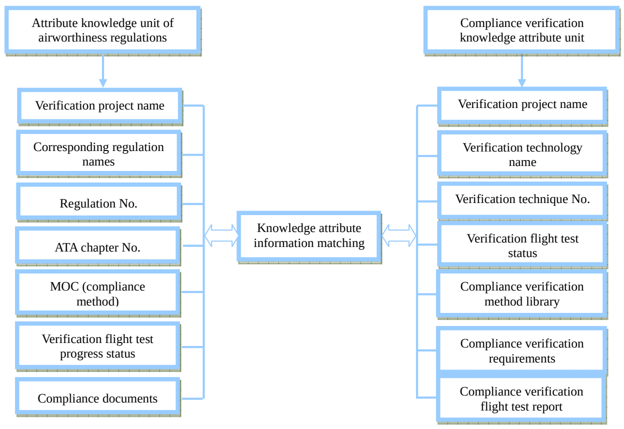

Fig.5 The attribute information matching about airworthiness regulations knowledge unit and compliance verification knowledge unit

The type certification flight test of the ARJ21-700 aircraft flutter/aeroservoelasticity was analyzed as an example, and its corresponding airworthiness regulation was FAR25.629(a,b, e). The regulation requirements refer to FAR25.

As shown in Fig.2, for flutter/ASE verification flight test, based on the constraints of the airworthiness regulations, to develop specific compliance verification flight test techniques, list the compliance verification elements to be analyzed, and analyze the flight test content and technology of compliance verification flight tests; The compliance verification flight test knowledge unit (including method and process library) is obtained by fusion with the attribute knowledge of the compliance verification flight test and the ontology knowledge library about the compliance verification flight test.

According to Fig.3, follow the airworthiness regulations to determine the applicable position ATA code, 5101 (aircraft structure), and then determine the test link and flight test status points. The compliance method MOC is a method of using an illustrative file (MCL), an analysis/calculation (MC2), a laboratory test (MC4), a ground test (MC5), a flight test (MC5) and a compliance verification flight test report. The reason for the flight test (MC6) is that the verification test of the large Mach number flutter and ASE validation test cannot be carried out in the ground laboratory, nor can it be solved completely by the CFD and other aerodynamic calculation software.

According to Fig.5, the aircraft configuration status of the flight test is determined and the manufacture compliance inspection is finished before the flight test through the innuendo and matching of the airworthiness regulation knowledge unit and the compliance verification knowledge unit. The flight tests of the large Mach number flutter and the ASE validation were completed by using the flight test method, such as a large angle subduction at the zigzag climbing speeding up for a long time. The compliance verification flight test knowledge unit formed by the complete compliance verification workflow includes:

1) Flutter test point: 4 altitudes, 37 test points;

2) ASE test point: 5 altitudes, 27 test points;

3) 19 interested modes of the whole airplane.

4) Excitation technology: atmospheric turbulence excitation, FES control surface frequency sweep excitation, FES (pilot) pulse rudder surface excitation;

5) Test technology: the whole airplane is equipped with 51 vibration acceleration sensors, equipped with FES excitation system, and equipped with real-time telemetering system.

Through the reconstruction of the knowledge unit of airworthiness regulation and compliance verification technical knowledge unit, the flight test operation flow of flutter /ASE verification is illustrated in figure 6.

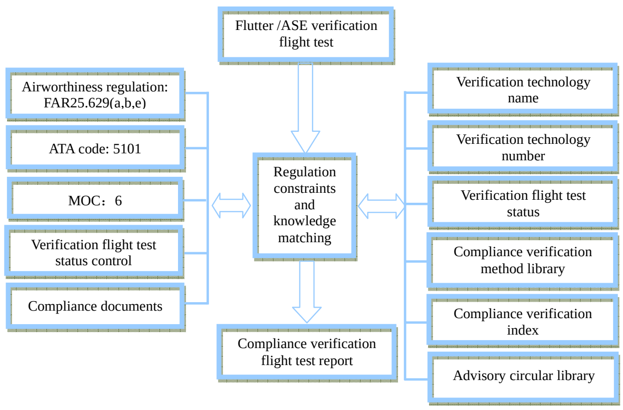

Fig.6 Flutter /ASE verification flight test process reconfiguration

5 The push of compliance verification knowledge based on ontology in flight test field

5.1 Ontology concept

The ontology is a knowledge model that expresses information in semantics and logic, and it can provide a clear description of the relationship between concepts and concepts in a specific domain, providing a shared understanding of the field knowledge, as well as a formalized representation of the semantic interoperability between the human and the computer, the interaction and conversation between computers and computers[4].

Ontology construction methods mainly include domain ontology construction method, domain ontology construction method based on thesaurus, and domain ontology construction method based on top-level ontology.

Ontology representation language is a formalized language for writing clear, formalized conceptual model, mainly divided into two categories, based on AI and based on the Web. Currently, the most widely used ontology description standard language, OWL （Ontology-Web-Language）, is developed by the W3C.

In order to build the ontology library, it is necessary to first identify the important conceptual library of civil aircraft flight test field, then connect the concepts, and use the attribute to connect two different concepts organically, and establish the relationship between concept and concept. The basic relationships in the civil aircraft flight test ontology are as follows:

1) is-of， a class hierarchy. One of the most important relationships in the field ontology of flight test program, it connects classes to subclasses, forming a structure.

2) attribute-of, attribute relation. Indicate that a concept is an attribute of another concept, such as that concept "parameter name" is an attribute of the concept "test parameter", and the "program name" is an attribute of "flight test program".

3) instance-of, instance relationship. The relationship between the instance of the concept and the concept, such as "stall flight test ", is an example of the concept "flight test program", and "flight altitude= 6 km" is an example of the concept of altitude.

4) kind-of, inherited relationship. For example, "airworthiness regulation" is a kind of "reference"; The flight test risk assessment report is a flight test report.

5) part-of, whole and part relationship. For example, "airspace" is part of the "experimental resources".

5.2 Ontology model for compliance verification flight test domain knowledge

The construction matrix VE= (VG, VR, VS, VT, VF, VC, VL, VN) represents the domain knowledge ontology model of compliance verification flight test. Where VG represents the concept set of airworthiness management field; VR represents the set of association relations; VS represents the concept set of legal regulations; VT denotes the concept set of compliance verification methods; VF represents the concept set of manufacturing compliance;

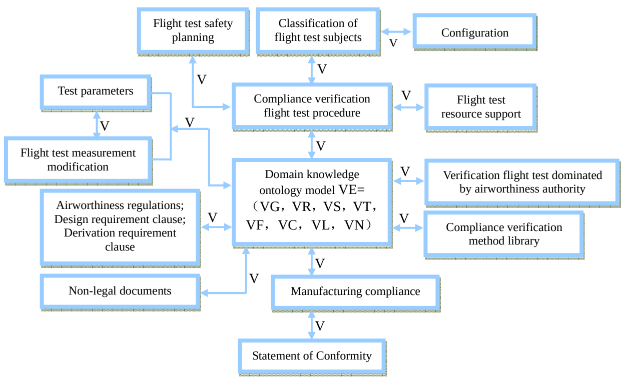

Fig.7 The framework of the knowledge ontology model in flight test field

VC represents measuring and measurement modification concept set; VL represents the concept set of a compliance verification flight test process; VN represents a set of non-legal document concepts. By analyzing the class hierarchy relation, attribute relation, instance relation, inheritance relation, integral and partial relation of the concept set in the compliance verification flight test field knowledge, the knowledge ontology framework of the flight test field is constructed as shown in Fig.7.

5.3 Application of the knowledge ontology model in the compliance verification flight test

Select EXPO (ontology of science experiment, established on scientific experiment by Wales university), as the upper body of a civil aircraft flight test knowledge ontology. The knowledge Ontology in flight test of civil aircraft and SUMO (Suggested Upper Merged Ontology, international common standard upper knowledge Ontology) are grafted through EXPO to support semantic share, mutual operation and extended application of knowledge in the civil aircraft flight test.

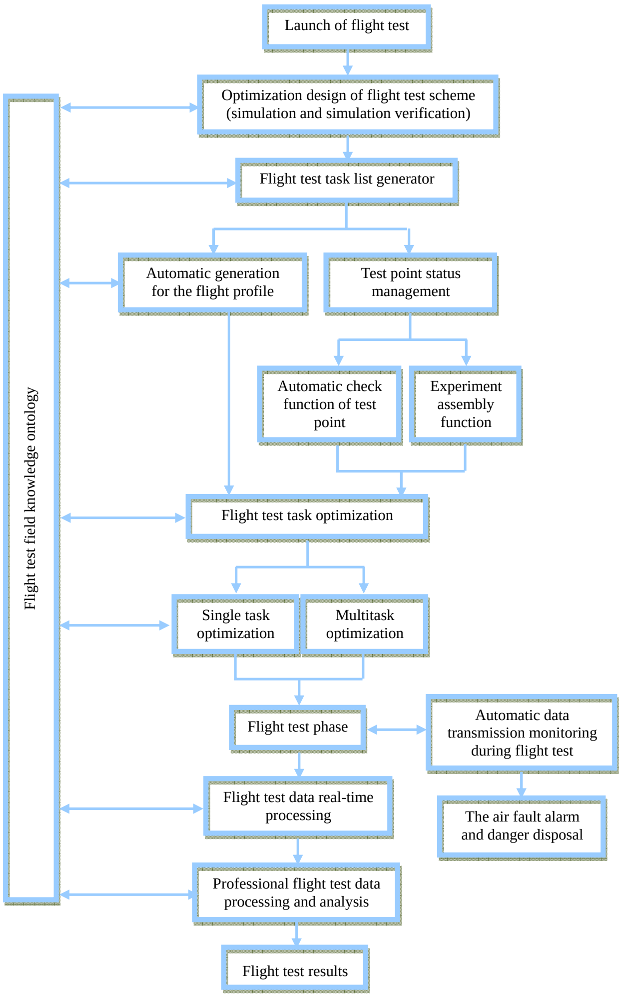

Fig.8 Application of the knowledge ontology model in flight test field

On the basis of the knowledge ontology model established in the flight test field, the ontology editing software Protégé of Stanford university is selected to implement the knowledge ontology in the civil aircraft flight test field, and to convert the knowledge ontology of civil aircraft flight test field into an OWL format file by use of the coding transformation tool from Protégé, which is convenient for understanding, use and modification of the computer. Fig.8 shows the specific application of the knowledge ontology model of the compliance verification flight test field in the flight test business management for the TC type approval[5].

6 Conclusions

By studying the construction of airworthiness compliance flight test process based on knowledge engineering, it has explored the way and method of the fusion on airworthiness regulations and compliance verification flight test technology. Through the reconstruction of the knowledge unit of airworthiness regulations and the knowledge unit of verification technology, the knowledge ontology model of the flight test field was constructed, and the flight test field knowledge ontology model was applied to the flight test engineering, and the knowledge engineering was integrated into the civil aircraft airworthiness verification flight test project. Based on the existing airworthiness system and artificial intelligence technology, we build a knowledge library and knowledge automatic push platform based on airworthiness verification flight test process. By adopting the method of knowledge management and flight test engineering together make the airworthiness verification flight test engineering knowledge, integration and intelligence.

To optimize airworthiness verification flight test outlines, flight test plans and flight test methods, so as to improve the quality and efficiency of airworthiness verification flight test engineering, and reduce test flight cost.

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