Practice of Project Management Methodology for Commercial Aero-engines Based on Integrative Project Architectures

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Abstract: To collect and share information of projects or products and make it consistent and correct so that the quality and costs of projects can be effectively controlled, an integrative project architecture integrating different types of breakdown structures is necessary. In this paper, the international research status on work breakdown structure (WBS) was analyzed, and an integrative project architecture for commercial aero-engines was designed, where product breakdown structure (PBS), WBS, organization breakdown structure (OBS) and cost breakdown structure (CBS) were integrated and built. And the architecture was applied in information systems. A transfer from technological views of complex products through their lifecycles to management views has been realized with this standardized architecture, thus development tasks and costs can be controlled.

Key words: integrative project architecture; commercial aero-engines; work breakdown structure (WBS); product breakdown structure (PBS); organization breakdown structure (OBS); cost breakdown structure (CBS)

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0 Introduction

The development of commercial aero-engines is an extremely complicated system engineering. With the progress of technology and management instruments, the traditional management technology has met unprecedented challenges. Aiming at the project management problems encountered in the development of aircraft engines, it is necessary to adopt modern information technology to integrate the products, work, organization and cost management of the project, and establish the integration project structure. In order to ensure that projects can be controlled, the projetct integration plan has to be strictly enforced.

In this paper, a multi-type breakdown structure integrative application was established through the integration of product technical information, cost information and planning information, in order to form a multi-business unit identity in the commercial aero-engine development project. It would facilitate information sharing and coordinated project management across multiple business fields.

1 Related Work

Work breakdown structure (WBS) is a work hierarchical breakdown oriented by deliverables. The breakdown object is carried out by the project team to achieve the project objectives and submit the required deliverables. WBS organizes and defines the entire scope of the project[1]. The release of MIL-HDBK-881A, an acquisition manual of the U.S. Department of Defense, started the WBS application of the national defense and military projects[2]. WBS is used as a tool to define the scope of projects by international aviation manufacturers,

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which has also been actively explored in domestic aircraft development projects[3-5].

A comprehensive project-product life cycle management model is established by combining the model based system engineering method and the best practices of project management. Sharon et al. developed an object-process methodology based on this model as an approach for planning project-product management ensembles[6-9].

Wang et al. studied the standards and guidelines of WBS from ESA or NASA space project, analyzed the development of Chinese aerospace products, and indicated that such satellite projects provide guidance for the preparation of WBS[10]. But it cannot be denied that WBS is usually arbitrarily used. Zheng and He et al. indicated that it is difficult to build the most effective WBS, because of the dependance on subjective experience of managers and the lack of uniform standards and methods in preparation of WBS[11-12]. This leads to uncontrollable results in preparation of WBS, and significantly affects development of project plans, cost calculation, effectiveness of the organization and control of the project.

In the aviation field, there are mainly two modes of WBS based on different concepts[5]. The projects represented by Airbus focus on the development process of products. The engineering development activities are breakdown based on the process and task division firstly, and then the hierarchical decomposition is carried out according to the product structure. Based on these two steps, WBS of large aircraft projects is established. The projects represented by Boeing focus on the delivery and integration of products. Hierarchical breakdown is set up according to the product structure, followed by breaking down according to the development work, to form a hierarchical system composed of the final aircraft products, development system, verification results and other auxiliary products. WBS based on development process is more suitable for the early stage of large aircraft development. It is closely combined with the task division of entity units, and clearly defines the work interface of design, test, manufacturing, final assembly and customer service. The functional management is relatively strong, but the characteristics of complex product system engineering management are insufficient. WBS based on the product delivery integration puts more emphasis on the overall integration of products, highlights the project management of strong matrix, and easily presents the structure and hierarchy of products. The final products and auxiliary products are distinct, and the implementation path of products is relatively clear.

The above findings raised a number of WBS construction methods in different areas. But for a highly complex system such as commercial aero-engines, the uniform standards of WBS have not yet formed. As a result, the maturity level of domestic commercial aviation engine WBS is low, and the project plan and budget control are difficult. Moreover, WBS of international benchmark enterprises is also closely combined with enterprise product development strategy. Therefore it is not a strong guidance for domestic commercial aero-engine products in the early stage.

At the same time, both Airbus and Boeing take their own focus on the product development process as an important reference for WBS, providing a useful reference for WBS establishment of commercial aero-engines.

2 Architecture Design of Commercial Aero-engine Integrative Project

2.1 Challenges of commercial aero-engine integrative project architecture

(1) Product breakdown structure (PBS): PBS is the breakdown from the whole engine into components that cannot be further divided, which is the breakdown of project entity objects.

(2) WBS: WBS breaks down deliverable project and work into smaller and more manageable components. The main purpose is to provide a struc-

tured view of what is being delivered.

(3) Organization breakdown structure (OBS): OBS is to solve who will be responsible for specific work packages, assign team units to various project levels and define responsibilities.

(4) Cost breakdown structure (CBS): CBS is to decompose costs into different types suitable for meeting project control requirements and establish a connection with WBS.

Each functional department involved in a project usually uses its own breakdown structure. For example, the project management department adopts WBS and OBS, the engineering design department uses PBS, the finance department adopts CBS, and the human resources department uses OBS.

Under the current integrated product development (IPD) mode, an IPD team needs to meet the requirements for product delivery, project management, cost control and personnel responsibility distribution.

It is one of the major challenges in current commercial aero-engine development process to meet the requirements of project management, design, finance and other aspects. For this purpose, we have to establish link and integrated relationship between project plan and control strategy in the absence of a unified method for grouping and organizing project and product information.

Therefore, it is necessary to carry out an integrative management method in the development of aero-engines for associating and integrating multiple breakdown structures, which can be understood and approved by all functional departments. With this architecture, the collection and sharing of business and technical information related to projects and products can be achieved, so that information can be correlated and coordinated, and project plan, quality and cost can be effectively controlled.

2.2 Architecture design idea of commercial aero-engine integrative project

WBS of aero-engine product development is divided into general WBS and specific WBS. The general WBS mainly breaks down the work according to categories which need to be performed in the processes of design, development, production, test, forensics and maintenance of aviation product development. Many of these activities should be carried out in accordance with the engine, not assigned to specific components, such as the design and principle of certification, technical pre-study, performance, noise control, airworthiness, four-performance designs, structure test and flight test, ground support, and technical publications, etc. The general WBS is not for a specific product, but a summary of product development work. It is the experience and practice formed in the development process of the enterprise. The work of the general WBS is relatively fixed, which is not closely related to the specific project management work and is not the focus of project management.

Project management focus is usually not a general WBS. The used WBS is needed to consider PBS, functional breakdown structure (FBS), etc., which is called the specific WBS. Integrative architecture also refers to such WBS[13].

WBS is represented as work packages at each level[2]. Work packages are project management tools which are necessary for setting, monitor, and project control. The key to integrate PBS with WBS is the way that WBS work packages are associated with PBS parts.

The core of the enterprise is the products. So the integrative architecture inevitably takes PBS as the core. WBS, CBS should be the assistant work of the PBS.

PBS is a hierarchical breakdown structure of products, such as hardware items, software items, and information items, used in the breakdown process of product logic and function. PBS is closely related to WBS, which inevitably includes PBS. Associating WBS with PBS through WBS work packages is to associate project management objects with product design objects for achieving the purpose of product integrative architecture.

According to the actual situation of commercial

aero-engine development, the design of project integrative architecture should meet the following requirements, as shown in Fig.1.

(1) Realize the integration of PBS and WBS, and project managers can refer to or call PBS information during WBS of project.

(2) Realize the integration of WBS and OBS, and project managers can directly refer to or call appropriate matrix integrated product team (IPT) members when allocating human resources for WBS nodes.

(3) Realize the integration of WBS and CBS, and financial managers can directly build CBS on the basis of WBS.

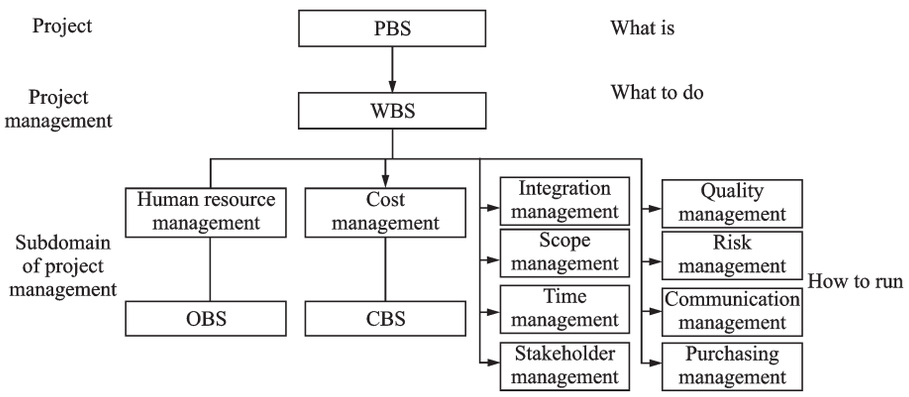

Fig.1 Integrative project structure of aero-engine

2.3 Relationships among PBS, WBS, OBS and CBS

2.3.1 Relationship between PBS and WBS

PBS is a hierarchical decomposition structure of products, such as hardware items, software items, and information items (files, data sets, etc.), used in the product logical and functional decomposition process.

PBS is closely related to WBS, so it can be considered that PBS is a part of WBS, or that WBS contains all elements of PBS, as shown in Fig. 2. Through WBS work packages, WBS is associated with product structure. Precisely, project management (PM) object is associated with product design object, which constitutes the architecture of enterprise product information integration and builds a bridge between configuration management and project management.

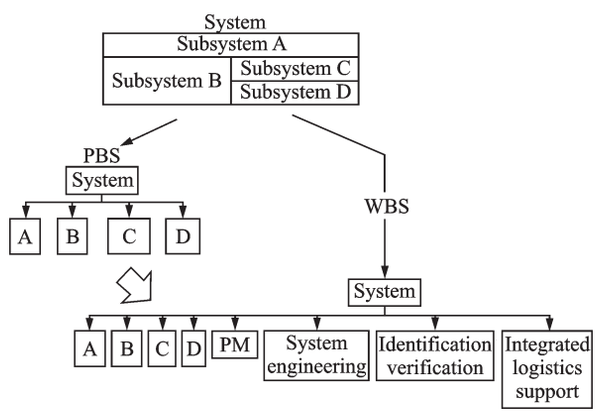

Fig.2 Relationship between PBS and WBS

2.3.2 Relationship between WBS and OBS

OBS is an organizational breakdown structure, which is human resource based on project requirements identification. It is designed hierarchically according to work division (management and implementation) and category (design, trial production, experiment, etc.). As shown in Fig. 3, OBS will eventually show the person in charge of the different levels of work packages, and the project members from the relevant departments or units will be hierarchically and systematically linked to the work packages.

IPT organization is a matrix project management structure, that is, through the interdependent and collaborative system of the project and functional management systems, it is implemented step by step to everyone involved in the project. The project management is responsible for decomposing the work and requirements layer by layer according to

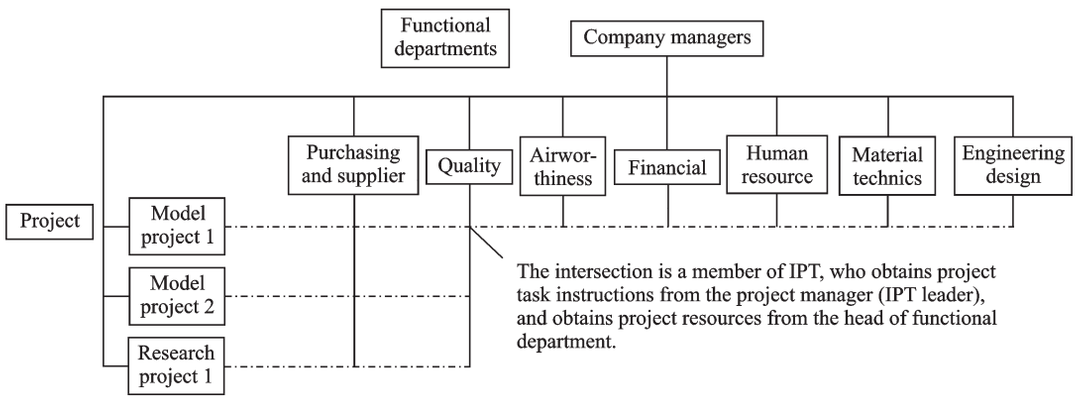

Fig.3 Relationship between project and department

the project objectives, and constructing the WBS of project. The functional management is responsible for formulating general standards, norms, procedures, work instructions and other work requirements, and coordinating and managing the human, financial, material, infrastructure and other resources required for the specific work according to the profession and category, as shown in Fig.4.

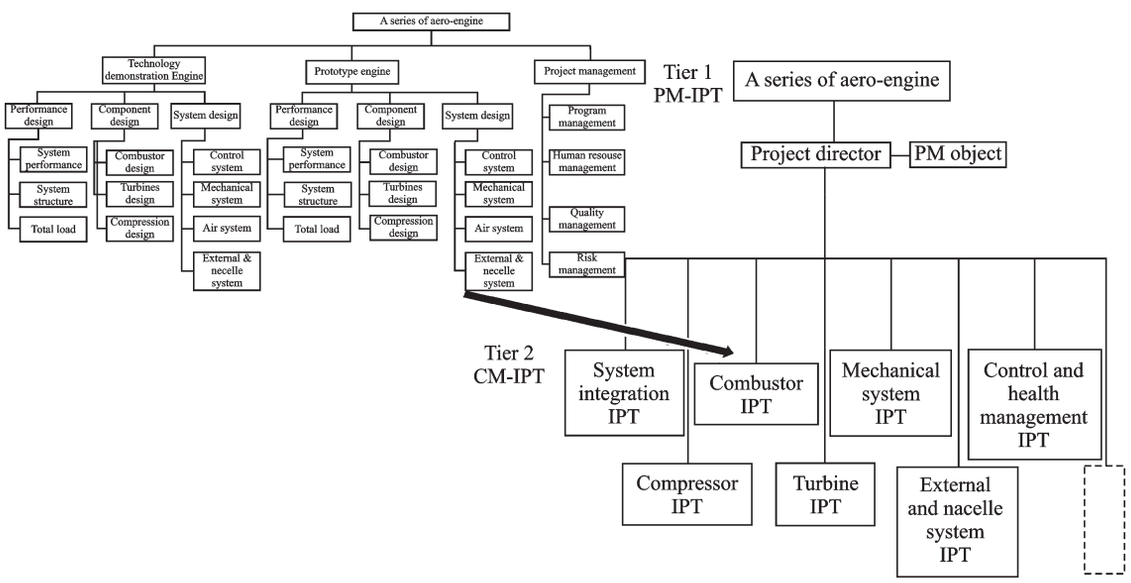

Fig.4 Relationship between WBS and OBS

2.3.3 Relationship of WBS and CBS

The CBS fund management and control model based on the WBS task arrangement is based on the project proposal and implementation plan. Between the project budget and the project annual budget, a CBS funding decomposition matrix covering the WBS task arrangements at each stage of the project development is established. This is used as a project funding management baseline during project implementation to ensure that the development funding is generally controllable, as shown in Fig.5.

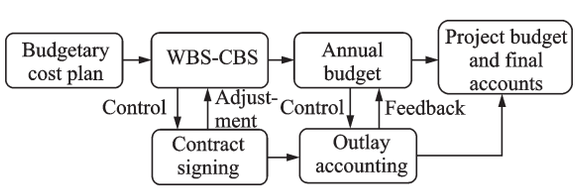

Fig.5 WBS-CBS fund management mode

3 Application of Integrated Framework for Commercial Aero-engine Projects

Firstly, PBS of commercial aero-engine product can be programmed according to the actual prod-

uct structure through the integrated project framework of the product, or PBS standard template can be tailored to generate PBS of the specific project model. Secondly, through the analysis of the development process, a series of general steps or standard activities are established according to the actual development process of the product to form a WBS standard template. Then, based on PBS, according to the general steps or standard activities, the mapping relationship between PBS and WBS standard templates is analyzed, and WBS of the specific product model is constructed through PBS. Among them, PBS is the embodiment of the delivery results, common steps or standard activities are the embodiment of the development process, and WBS is the result of their joint actions. Finally, according to the project WBS task arrangement, each task is equipped with cost and resource information, such as labor, equipment, and external contract, and combined with the company's project matrix management mode. And then press the unit, such as gas machine, combustion chamber and turbine, to be equipped with project management. The OBS team allocates full-time project accounting for each level of project IPT team, participates in the whole process of project management, implements deep integration of business and finance, and integrates the concept of fund management and control into all levels of project management team, as shown in Fig.6.

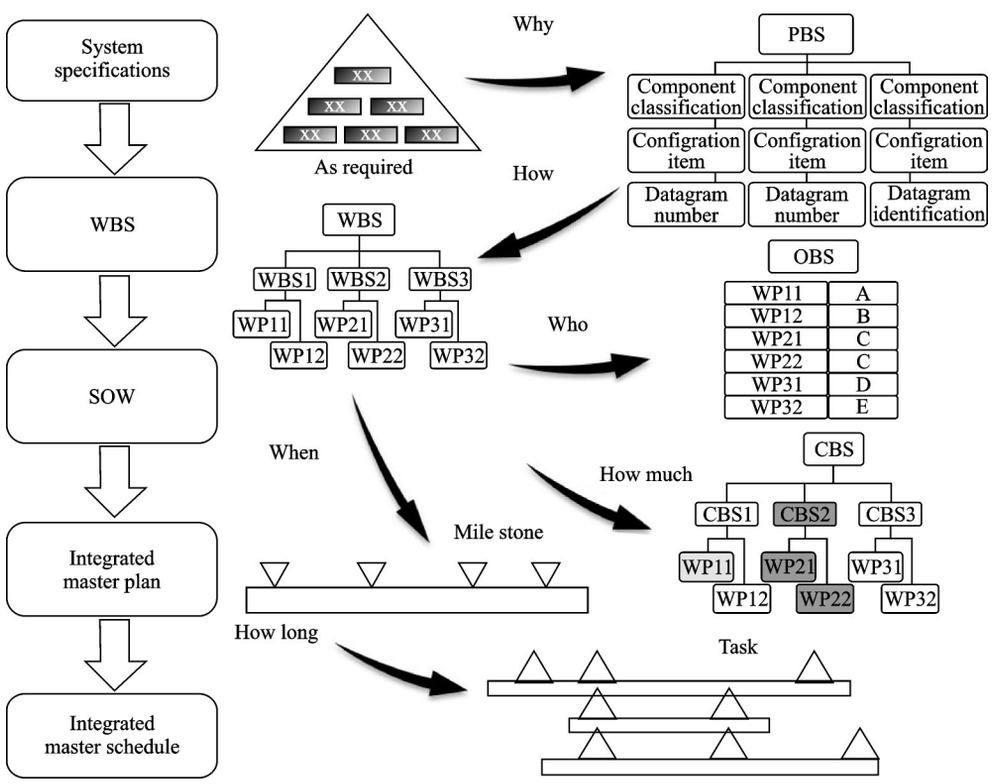

Fig.6 Integrative project architecture and project management elements

3.1 PBS construction

The establishment of PBS embodies the specific understanding of project objects. The main source is the understanding of stakeholder needs. The result is a systematic decomposition of complex products, which is decomposed into subsystems by complex systems until decomposed into system elements. Specific to aero-engine products, JASC-Code ATA 100 defines the prevailing rules for this decomposition[14]. Commercial aero-engine products follow the same principles and build their own PBS, as shown in Fig.7.

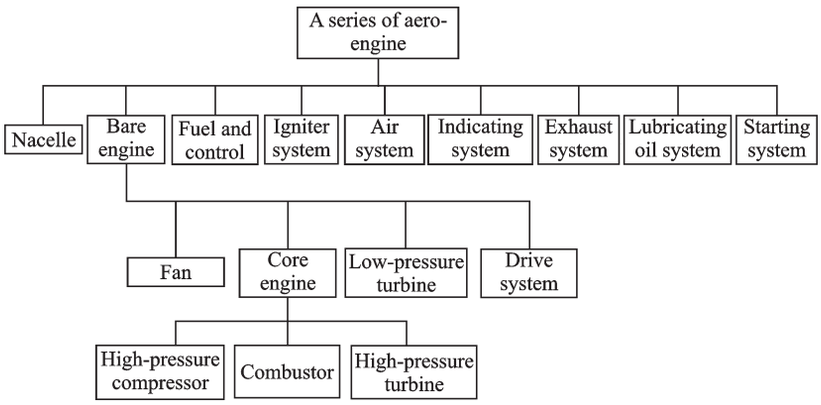

Fig.7 PBS sample of aero-engine

3.2 WBS construction

After building PBS, the project object has been structurally decomposed according to the understanding of the stakeholder's needs, and can be independently implemented and integrated with the verification element. The next step is to solve the problem of how to do it, that is, the construction of WBS.

The WBS construction of the commercial aero-engine product is aimed at achieving the project and is deliverable-oriented. The main decomposition principles are as follows: The decomposition process divides the project work into layers that are more detailed and more manageable. The process is deeper and progressive, and finally reaches the level of the work package where the granularity is not suitable for further subdivision. The working components of each level divided in the decomposition are treated as WBS units with independent attributes.

As the project work component at the bottom of each branch of WBS, a WBS unit that usually has the following characteristics can be called a work package: (1) From the perspective of task assignment and implementation, it cannot be further decomposed; (2) it can effectively estimate the cost, task time and deliverables of the task; (3) it has ability to specify clear heads of responsibility and responsible persons; (4) it can clear ending signs that can be completed relatively independently; (5) it can be outsourced or dispatched as a whole.

Each WBS unit is used to describe each level of WBS containing at least the following elements: (1) WBS coding; (2) work objectives; (3) responsibility subject; (4) job description; (5) iconic deliverables.

The hierarchical decomposition principles of WBS are: (1) Business types and business implementation processes involved in project implementation; (2) product decomposition structure involved in project development; (3) product function realization or professional division of labor involved in project development.

The 100% decomposition principle is that WBS shall include all business activities involved in the aero-engine project as applicable scope and shall ensure that no work is left out and no additional work is added to the work breakdown activities. The next level of decomposition of each work task must represent 100% content of the previous work task.

Uncrossing principle is that WBS should ensure tasks are not repeated and do not overlap with each other.

According to the characteristics of the development of commercial aero-engine, WBS should not only reflect the branches related to product structure, but also include branches related to technical researching and project management. A WBS structure example of a commercial aero-engine is shown in Fig.8.

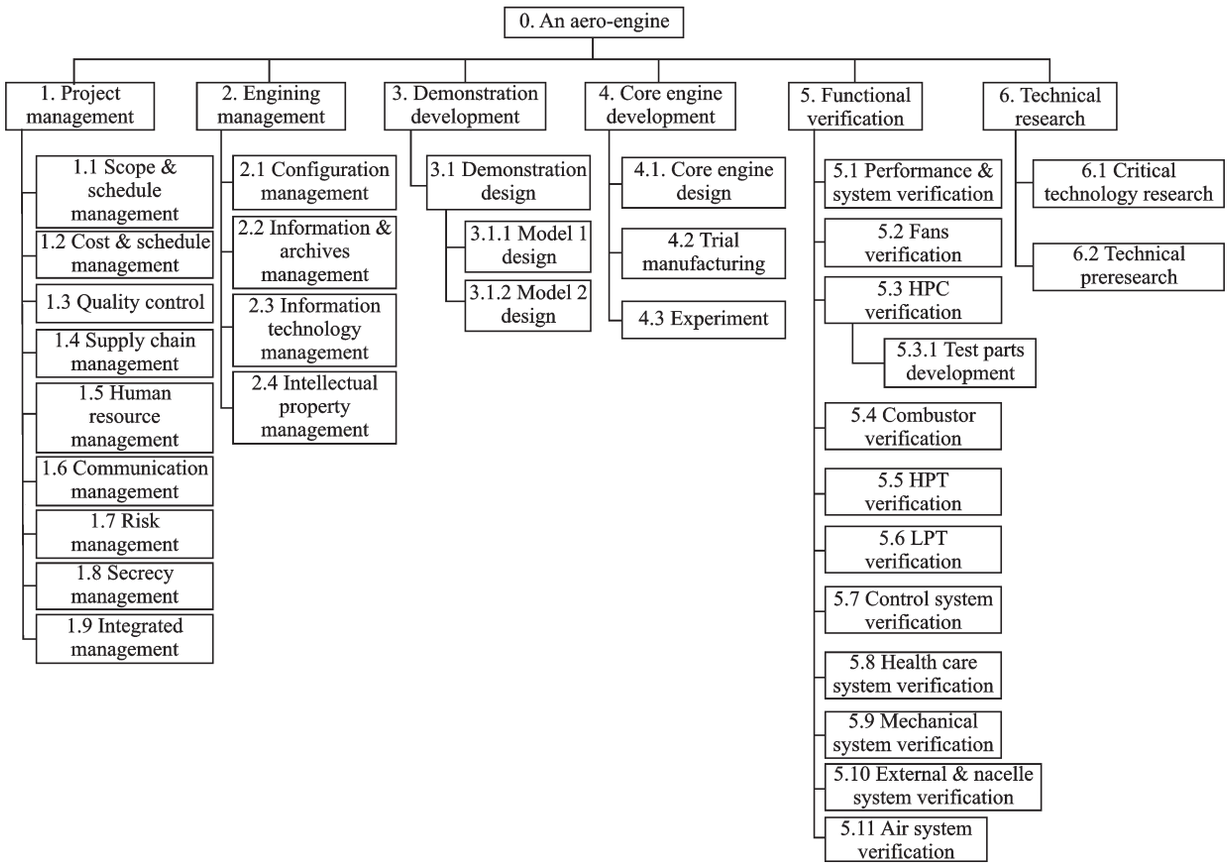

Fig.8 WBS sample of aero-engine

3.3 OBS construction

OBS is built to solve the problem of human resource allocation after the establishment of WBS. Through the establishment of OBS, the logical relationship among human resources, responsibilities, tasks, powers, performance appraisal and other matters of complex product development can be clearly organized in the form of integrated product development team in matrix management organizations.

OBS of commercial aero-engine development is constructed according to the organization principle of integration project team. IPT refers to a working team composed of professionals and managers from cross-unit, cross-department, multinational, internal and external suppliers, who complete the activities and tasks of integrated product development projects or specific interrelated project activities and tasks within prescribed time and cost. In accordance with the principles of "five-management" (human, money, affair, demand, result) and "four-focus" (demand, change, node, result), "six-clearness" (task, target, plan, security, responsibility, acceptance) and "six-integration" (idea, personnel, element, method, information, product) are achieved to realize "reinforcement", which commands the overall project work, coordinates each system and interface of the work package, effectively controls changes, quickly solves problems, and strengthens overall state and control.

According to the differences of management level, project development stage and product object, the IPT team is divided into administrative management integrated IPT (AM-IPT), program management integrated IPT (PM-IPT), component management integrated IPT (CM-IPT), and component design builds and test integrated IPT (CDBT-IPT), and encodes levels 0, 1, 2, and 3 in accordance with management and product implementation logic and integration relationships, as shown in Fig.9.

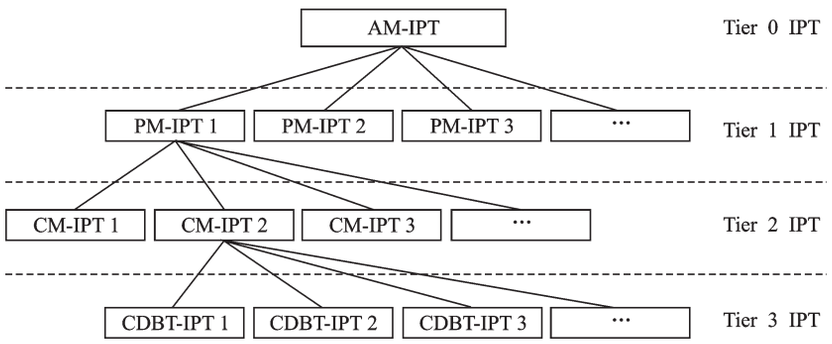

Fig.9 Sample of OBS

3.4 CBS construction

In the design process of commercial aircraft products, cost control is an important means to ensure commercial success while achieving technical and product success. And cost-oriented design and cost-based design are two accepted methodologies. In addition, value engineering is a relatively successful cost control method at present. In recent years, the innovative problem solving theory (Teoriya Resheniya Izobreatatelskikh Zadatch, TRIZ), which develops well, can also be used as an effective method to control costs.

In practical application, different cost control theories must break down costs and expenses in a similar way from the source, so as to achieve cost control. When collecting cost data, the main method to determine the basic data composition is the combination of WBS and CBS. CBS breaks down product costs horizontally, that is, breaking down cost items into sub-items that are easy to trace. In this way, WBS and CBS are unified in the same data table, and the cost size and detailed composition on each node of WBS can be clearly represented by CBS. CBS usually has a close relationship with the causes of various costs and expenses. Only when the division of various costs and expenses is detailed enough, the real cost control approach can be found through cost analysis, functional analysis or root cause analysis. At the same time, cost data collection must cover the whole life cycle of the development, production, use and service guarantee of commercial aircraft engine products, including all direct, indirect, labor and non-labor costs related to products.

The CBS decomposition example of commercial aircraft engine is shown in Fig.10. According to the hierarchical system of WBS, the principle of "near thin and far thick" is used to collect development funds of different levels of the project and complete CBS budget decomposition based on WBS task arrangement.

WBS				Financial information			
Tier	Number	Task	···	Man-hour	Test length	Contract amount	···
3	W010205	HPC design		26	18	2.6	
4	W01020501	Stator components design		17	11	1.6	
5	W0102050101	All levels stator components design		12	3	1.3	
5	W0102050102	HPC casing design		5	8	0.3	
4	W01020502	Rotator design		9	7	1.0	
5	W0102050201	Blisk-bladed disk design	···	9	7	1.0	···
3	W010206	Combustor design		21	5	1.5	
4	W01020601	Nozzle design		5	2	1.0	
4	W01020602	Combustor liner design		16	3	0.5	
5	W0102060201	Tile design		16	3	0.5	

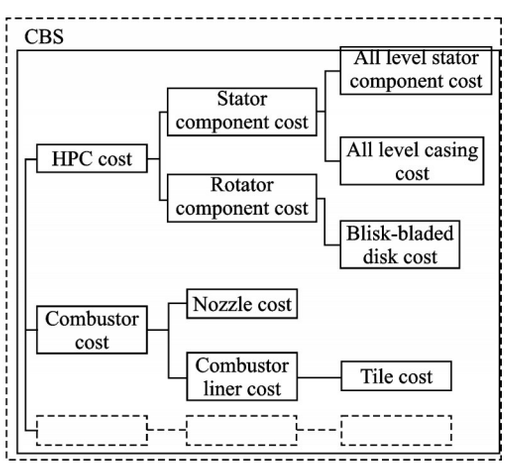

Fig.10 CBS example of aero-engine

3.5 Information technology support

In order to ensure that the completed project integration architecture can operate normally in the business of commercial aero-engine development, it is necessary to ensure the scientific and reasonable development of the project and the overall controllable development funds. Based on the existing information system, taking the product data management system and the comprehensive plan management system as the core, AECC CAE develops the corresponding functions so as to ensure the efficient and accurate transformation from the technical view to the management view of the whole life cycle of complex products in a unified and standardized way. Corresponding functions are shown in Fig.11.

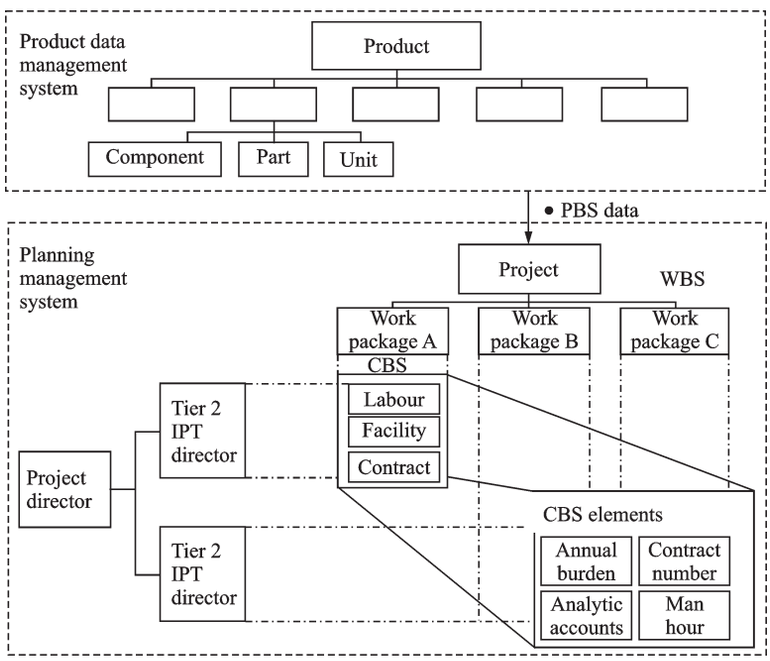

Fig.11 Sample of integrative project structure system

4 Conclusions

The experience of project management proves that structured breakdown structure provides strong support for project management. Through the integrated implementation of PBS, WBS, OBS and CBS, the rapid construction of WBS and CBS of commercial aero-engine is realized. It ensures the scientific and reasonable development task of the project and the overall controllable development budget.

Through the integration framework of PBS, WBS, CBS and OBS, different functions and technical departments can carry out engine product development efficiently and orderly in the way of project integration team with a coordinated mechanism and principle. However, the current commercial aero-engine project has not yet completed the development of a type of product, and the accuracy of work and cost breakdown related to project management planned in WBS still needs to be verified and optimized in the follow-up work. At the same time, the breakdown of delivery and service work after the development stage of commercial aero-engine products in the whole life cycle has not been planned, which can be used as one of the key points in the follow-up work of the integrated project framework to carry out corresponding research work.

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Author contributions Dr. **ZHANG Yujin** designed the study, complied the aero engine project architectures, improved the architecture in practice, and wrote the manuscript. Prof. **LIAO Wenhe** guided the study and gave key opinions on some of the core issues.

Competing interests The authors declare no competing interests.

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基于集成项目框架的商用航空发动机项目管理方法与实践

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摘要:为实现项目和产品有关信息的收集和共享,使得项目信息关联、协调一致,从而保证项目计划、质量和成本得到有效管控,需要建立汇聚多种项目分解信息的集成项目框架。本文分析了国内外工作分解结构的研究现状,设计了集成产品分解结构、工作分解结构、组织分解结构、成本分解结构的商用航空发动机集成项目框架,完成了相应分解结构的构建与集成,并在信息化技术的支撑下进行了实施。从而以统一规范的方法保证了复杂产品全生命周期技术视图向管理视图高效且准确的转换,确保项目研制任务科学合理、研制经费总体可控。

关键词:集成项目框架;商用航空发动机;工作分解结构;产品分解结构;组织分解结构;成本分解结构