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BASED ON SYSTEMS ENGINEERING PROCESS THE CIVIL AIRCRAFT PROJECT PRODUCT BREAKDOWN STRUCTURE DEVELOPMENT RESEARCH

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Abstract

Project management tools are basic tools of the project organization in civil aircraft projects. Product breakdown structure (PBS) is the base of work breakdown structure (WBS), organization breakdown structure (OBS) and cost breakdown structure (CBS), and also is the basic structure of the whole project. The reason for the success of so many projects is doing right thing by right way. The product breakdown structure indicates the subject matter that an aircraft project needs to develop. Using the method of system engineering to do the design-forward, analyze and compile the product breakdown structure is the characteristic and key to the success of civil aircraft projects.

Keywords: Product Breakdown Structure, Work Breakdown Structure, Systems Engineering, Civil Aircraft Project

1. Introduction

The development of civil aircraft is a complex system. Based on the systematic analysis of the structure of the project, it is necessary to construct the product breakdown structure (PBS) and work breakdown structure (WBS) of the project, and then to carry out the systematic design of the management system for the project, so as the project, a large complex development system, can be effectively operated.

Of all the project management tools, it is necessary to set up a work breakdown structure of the project. This is the first important task of the project. On this basis, plans, funds and teams are analyzed. In order to better construct a work breakdown structure that conforms to the actual situation of the project, the first job to be done is to analyze and construct a good product breakdown structure. If the output of the project can be analyzed out, the system of the project work package can be set up smoothly. This is the task source of the product breakdown structure of the project.

In the early stage of the civil aircraft project, such as the conceptual design phase, preliminary design phase and the early stage of detailed design phase, the systems engineering process method is mainly used to assist in the analysis and construction of the product breakdown structure of the project gradually detailed. The systems engineering process is taken as the main method to analyze the product breakdown structure, which ensures the integrity and correctness of the product breakdown structure and the originality of the aircraft design project. In the several late stages of the project, the product breakdown structure of the project will be evaluated at the beginning of each year, and the analysis and structure construction of the project will be maintained.

2. Discussion on Relevant Concepts

2.1 Products and Product Breakdown Structure

The development of civil aircraft is a large and complicated product research and development project. Tens of thousands of people need several to more than ten years of sustained efforts to develop successful civil aircraft products. For the development of civil aircraft similar to such a

project named DR, the project is large in scale and complex in structure. Large-scale product projects should be decomposed according to the requirements of systems engineering through product decomposition. Decompose the product breakdown structure and analyze and work out the basic structure of work breakdown structure, organization breakdown structure (OBS), and cost breakdown structure (CBS).

Through decomposing the aircraft into a structured product system, the product items in this system are single in function, simple in structure and easy to develop, according to the levels of "aircraft", "group", "system", "subsystem", "sub-subsystem" and "equipment", concerning technical documents such as functions, requirements, and product descriptions. This significantly reduced the complexity of the whole project and effectively improved the success rate of the civil aircraft project.

The concept of the product is one of the core concepts in the development of civil aircraft. The product is software and hardware or equipment, which needs to be delivered to the main manufacturer through concept development, development, test verification and production, and operated and maintained in the aircraft operation environment as part of the aircraft product.

Various software and hardware products are finally integrated into aircraft products through layer-by-layer integration and assembly. The structure describing such an integration relationship is the product decomposition structure. The product breakdown structure is a tree structure, which can clearly explain the integration relationship of aircraft products.

Using the technology of product decomposition structure, the complexity of aircraft products is effectively reduced. Aircraft products that are coupled with the specialties of aircraft design, structure, electronics and flight control are degraded into concepts of airframe, propulsion system, mechanical system, avionics system, electrical system, flight control system, environmental control system, and commercial carrier system, which are easier to implement, and further subdivision is continued. Large civil aircraft projects are decomposed step by step to form a product structure system, which is decomposed into a group of sub-projects that are easier to implement and control.

2.2 Product Design and Requirement-based Product Development

Chinese civil aircraft now have entered the track of product design of aircraft. To emphasize product design is essential to emphasize requirement-based development of civil aircraft products. Starting from the requirement, we can gradually determine the original product breakdown structure.

The whole process is that the systems engineering process is used repeatedly, starting from capturing the needs of stakeholders, deriving the product breakdown structure[2] through functional analysis, requirements analysis, and design synthesis, and then confirming the construction of the product breakdown structure through the product requirement validation process. This systems engineering process can well determine the product breakdown structure.

Such a systems engineering process gradually iterates in the stages of conceptual design, preliminary design, and detailed design. The system-level PBS is determined in the conceptual design stage, the subsystem-level PBS is determined in the preliminary design stage, and the lower-level PBS is determined in the detailed design stage. In this way, the whole organization gradually identified and confirmed the product breakdown structure during the product development process with the development progress.

2.3 Systems Engineering Process and Product Breakdown Structure

Through the systems engineering theory, the process is at the core of the methodology. This systems engineering process is the core process of aircraft product development, including the complete NFRP process of capturing stakeholder needs, functional analysis, requirements analysis, design synthesis.[2]

Using the systems engineering process, the product breakdown structure of aircraft products can be well-iterated step by step.[1] This product breakdown structure is suitable for the unique management requirements of each aircraft product project. The work breakdown structure [3], organization breakdown structure and cost breakdown structure developed based on the unique product breakdown structure of each project can serve the project well. It has fundamentally solved

the problem that management personnel and technical personnel cannot coordinate and unify the technology and management of a product project.

The systems engineering process is a technology research and development tool, but also a management tool. Based on using the tool of the systems engineering process, the product breakdown structure developed can meet both technical and management requirements. Technical management such as configuration management, requirement management, and specification management can be carried out on the product breakdown structure. At the same time, the product breakdown structure can also be used as the basis for compiling the work breakdown structure, organization breakdown structure, and cost breakdown structure to carry out pure research and development management work [3].

3. Explore the Specific Historical Process of the PBS Compilation Method

The management basis for aircraft projects is the work breakdown structure of aircraft projects. On this basis, analysis and compilation of schedule plans, project funds and team organization can be carried out. The typical working process is to compile the product breakdown structure before compiling the work breakdown structure.

3.1 Preliminary Exploration of Project SJ and Early Stage of Project DR

China has several newly developed civil aircraft. In SJ, PBS was not specially compiled before WBS was compiled. Only in the unit list of WBS, the sections of the airframe and the systems of airborne systems were listed. On this basis, the WBS specified what work the project should carry out and regulated the work of the whole project at the beginning of the project. The early work breakdown structure of DR was also compiled according to this idea.

3.2 Exploration of Mid-term Reform of Project DR

Several years before, one of the companies in China's aerospace industry carried out a change in project organization to introduce IPT into the project organization. In order to introduce IPT, the WBS of DR was re-compiled, and the PBS of project DR was planned before the WBS was compiled. In this way, there is clear PBS analysis and construction work as the basis for WBS.

When compiling the first edition PBS of the DR project, the DR project has completed the preliminary design stage and entered the early stage of detailed design. In the design stage of preliminary design, the overall design scheme of aircraft and the joint definition of aircraft systems have been completed. The design status of the whole aircraft is clear. At the level of aircraft systems, further decomposition of aircraft subsystems could be based on aircraft design documents which developed by using systems engineering methods.

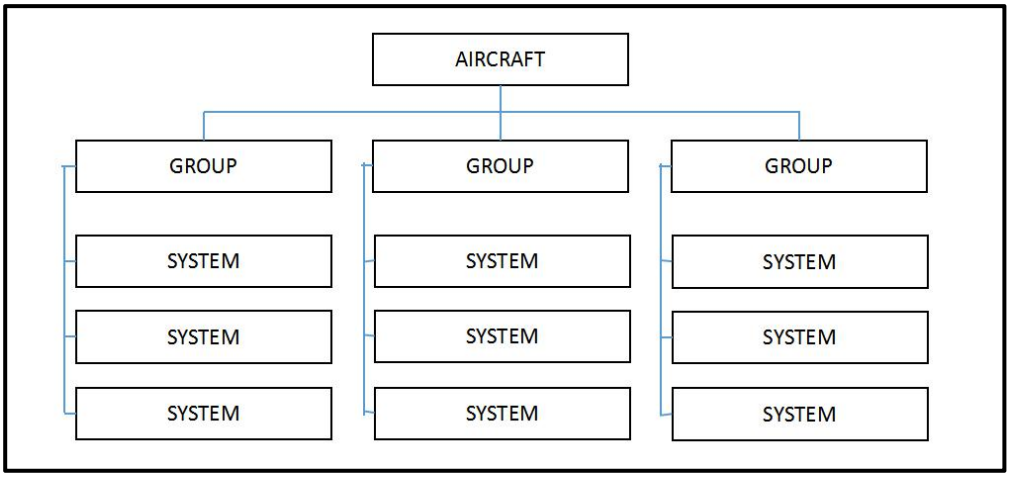

Figure 1 - Product Breakdown Structure (PBS) of Civil Aircraft Project (Level 1-3).

At this project stage, the project management organization of DR aircraft gave instructions to the project team to compile PBS of aircraft, and compiled product breakdown structure at four levels: "aircraft", "group", "system" and "subsystem". In the preparation of PBS for DR, ATA 2200 <Information Standards for Aviation Maintenance> [4] was adopted to split the "aircraft" into several product "groups" such as airframe, flight control and machinery, avionics and electrical,

propulsion and environmental control. On this basis, the "aircraft" was further split into "system" and "subsystem".

ATA Spec 2200 is changed from ATA100. By adopting the coding and definition of the ATA system, on the one hand, it can well meet the requirements of aircraft product decomposition and highlight the concepts of "system" and "subsystem". On the other hand, by adopting the system definition of ATA2200, the problem of information definition and communication between aircraft and various systems, between the main manufacturer and various departments and system suppliers, and between various specialties and teams within the main manufacturer can be well solved.

On the basis of adopting the ATA standard product numbering system in PBS, the product design scheme and PBS collected and summarized by the project management organization were checked to verify the PBS of the aircraft. At that time, DR has entered the detailed design stage, and the design scheme of the aircraft was relatively complete. According to the overall technical proposal of the aircraft and the definition of the aircraft, the PBS was checked and revised from top to bottom in these two aircraft-level technical documents. At the same time, referring to the description documents of each system scheme formed in the preliminary design stage, the decomposition of PBS was further confirmed from the level of each system and subsystem.

At the same time of confirming the design schemes of aircraft level and system level, the document defining the functional definition and requirement definition of the aircraft in the preliminary design stage was introduced, and the functions and requirements of the aircraft were decomposed and distributed in the form of "group" and "system". And in the PBS the three top-level structure is "aircraft", "group" and "system". Ensure that each PBS's three-level unit has function content and requirement content.

In order to thoroughly decompose and distribute the functions, the plane's functions are decomposed and distributed layer by layer, and the functions are decomposed and distributed to the fourth level of PBS of "subsystem". In this way, the decomposition and distribution of aircraft functions extend to the fourth level of PBS - "subsystem". On this basis, after checking and revising PBS again, the first edition of PBS of DR was finally finalized.

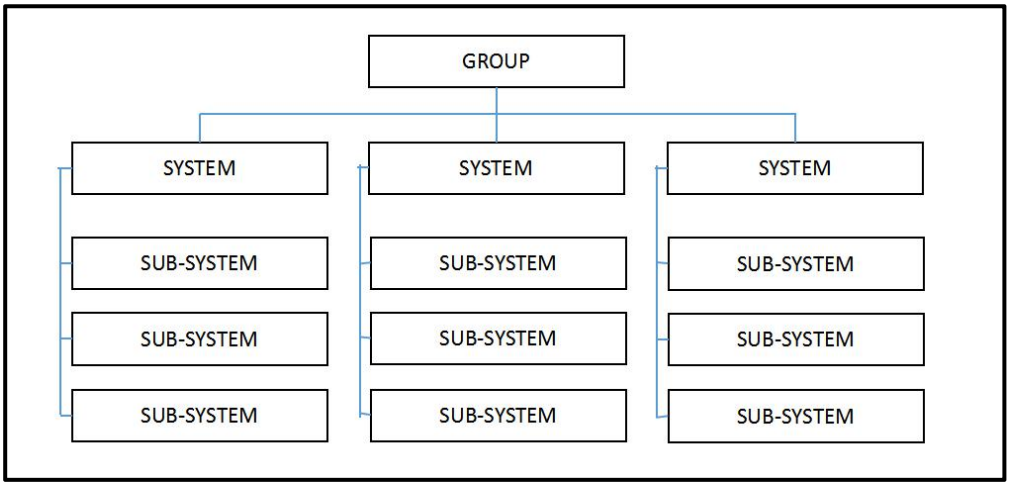

Figure 2 - Product Breakdown Structure (PBS) of Civil Aircraft Project (Level 2-4).

Before the PBS was released, the functional baseline and allocated baseline of the product had been decomposed and distributed according to the PBS structure. To every PBS unit, there were product specification requirements, so the PBS tree at the same time became a project specification tree. The WBS compiled on this basis is relatively complete and correct, and can guide the development of aircraft projects.

3.3 Recent Development of PBS

At the later stage of DR project progress to airworthiness certification, the second edition of PBS detailed to "sub-subsystem" and "equipment" was planned and being compiled. After the DR project entered the comprehensive trial production, the KT project started. According to the requirements of each stage, the KT project also compiled PBS of the project. For the KT project, at the end of the preliminary design and before the detailed design, the PBS draft detailed to the

equipment was prepared slightly earlier than the standard practice, but the official version of PBS has not yet been formed.

3.4 Current Recommended Normative Practices

After the development of the KT project started, relevant documentation standards were established for PBS and WBS. In the conceptual design phase, PBS detailed to ATA chapter "system" level is established through the steps of stakeholder needs capture, functional analysis, requirements analysis, and design synthesis. In the preliminary design stage, PBS detailed to ATA section "subsystem" level is established through the same steps. In the detailed design stage, the main manufacturer and supplier work simultaneously to further decompose PBS and establish PBS in the detailed design stage. The PBS of each stage can ensure the correctness and integrity of PBS through the steps of design validation.

The steps of stakeholders need capture, function analysis, requirement analysis, and design synthesis, which is the systems engineering process recommended by the civil aircraft enterprise as the main manufacturer at present. The stakeholders need capture, function analysis, and requirement analysis, which are to sort out the implicit requirements of the design. Design synthesis is a highly creative step. In the whole R&D organization, such development steps are used together to develop products in an integrated way. PBS construction and layer-by-layer subdivision are also the results of the systems engineering process of various design specialties. The technical documents of requirement analysis, function analysis, and product scheme description in the development process are the direct basis for PBS construction.

Every stage of development, including conceptual design, preliminary design, and detailed design, should follow the systems engineering process, and promote the progress of the project step by step through the steps of stakeholder needs capture, function analysis, requirement analysis, and design synthesis.

In the process of capturing the needs of stakeholders, the concepts of operation, manufacture, support, and retirement of aircraft products are formed by identifying complete stakeholders, capturing and integrating their needs, establishing efficiency indicators, and forming and confirming the stakeholder needs of products.

In the process of function analysis, carry out function identification and definition, generate and confirm function architecture, and form function list, function architecture, and function interface.

In the process of requirement analysis, the functional requirements are formed by quantitative definitions such as product performance, and the non-functional requirements of products are formed by analyzing the needs of stakeholders, project objectives and constraints, and the requirements documents of aircraft products are formed by standard language description.

In the stage of design synthesis, the design synthesis activities of aircraft, systems, equipment, software, and hardware are carried out hierarchically, and the design work of overall, pneumatic, structural, strength and each system specialty is coordinated, the design iteration of function, requirement and product design scheme is carried out, and the alternative design, trade-off evaluation, scheme selection and scheme decomposition of design synthesis are carried out, to promote the development of design and achieve the optimal design.

After such a process, the established PBS meets the requirements of aircraft design, functions and requirements, and is iteratively refined one after another. In the detailed design stage, it reaches the levels of "aircraft", "group", "system", "subsystem", "sub-subsystem" and "equipment", which can make PBS have structure, content and meet the original situation and internal requirements of product design. The PBS established in this way is highly consistent with the actual product design in terms of development procedure and PBS content. PBS itself can guide the progress of research and development activities and is a valuable technical document.

After forming the design scheme of each level, the PBS of the given level has been built accordingly. Because the PBS file contains the decomposition of requirements and functions, it is necessary to proofread the decomposed requirements and functions. In the later engineering stage, PBS is proofread similarly. With the progress of the project, a small amount of PBS can be modified when the PBS of each edition is revised.

In the process of requirement validation, confirm the requirement and complete the requirement validation summary. In the later requirements verification process, it is determined that the expected functions have been correctly realized and all requirements have been met, to ensure that the safety analysis of each system is effective. In this way, the requirement validation and verification work are carried out layer by layer to ensure that the products at all levels are fully validated and verified.

Among the serialized models and derivative models, the basic project PBS is the basis of these follow-up projects. In several basic model projects, the decomposition methods of PBS also influence each other. The decomposition of PBS reflects the technical path of aircraft design of civil aircraft research and development enterprises.

3.5 Two Strategies for PBS Compilation

When establishing PBS, there are generally two strategies. One is from top to bottom, when the project first compiles PBS, it compiles the PBS structure in detail to the "subsystem" level of PBS that meets the requirements of aircraft functions and requirements. In the later stage, it gradually carries out the edition change according to the actual development of the project. The other is to gradually refine PBS as the project progresses. In the conceptual design phase, PBS goes to the ATA chapter in detail. In the preliminary design stage, PBS goes to the ATA section in detail. In the detailed design stage, PBS is further decomposed downward. The third project KT currently adopts the second strategy.

4. Detailed Discussion of an Example

4.1 Consideration for Specific Preparation of PBS

The author planned and organized the compilation work of PBS for DR. In the early stage, the PBS of DR was an implicit PBS, which was reflected in the WBS work package. The airframe part includes the fuselage, wing, pylon, and tail. The system includes avionics working packages such as passenger cabin, and airborne systems such as flight control system, landing gear system and engine. After the company entered the detailed design phase, the first edition PBS for DR was developed in the phase of project organizational change of IPT team which emphasizing product work package.

PBS is the core tree structure linking technology and management. PBS is the foundation of WBS, and OBS and CBS can be compiled based on PBS and WBS. At the same time, PBS is the foundation of configuration management and technology management.

The general idea of PBS construction is: according to the product characteristics of DR, according to the structure and system decomposition of the aircraft, PBS documents are formulated to scientifically and completely express the main characteristics of all levels of product composition of DR. The idea of product breakdown structure construction is to use the idea of systems engineering, through the processes of stakeholder needs capture, function analysis, requirement analysis, and design synthesis, to gradually decompose highly complex integrated products into simple products with a single function and independent structure that are easy to realize. In the process of product decomposition, the rationality of system design, product realization, and technical management should also be considered.

The DR products delivered by the project are highly complex and integrated. Therefore, in order to construct the work breakdown structure of DR, the product decomposition of DR must be completed to form the product breakdown structure. The reasonably decomposed product breakdown structure is the main part of the project work breakdown structure.

The PBS was established in the detailed design stage of the DR project, because it is the first edition of PBS, and mainly for the correctness of PBS. The PBS of the project systematically was put in order and constructed according to the hierarchical order of aircraft, group, system and subsystem in a top-down manner. PBS decomposes the physical composition of products step by step from top to bottom, from coarse to fine, and finally establishes a product structure system containing multiple levels.

Based on the analysis and integration of aircraft functional baseline requirements, the work

package level of "aircraft" is determined. The objectives and requirements of the aircraft business and design of the DR project are the foundation of PBS construction.

Then the product decomposition sets up the hierarchy of "group", which is the hierarchy between the aircraft and the system. The dispersed ATA chapters are classified according to the logic of product design. At the same time, it is the most important hierarchy for downward decomposition and distribution of aircraft functions, which embodies the design requirements for decomposition and distribution of aircraft functions according to specialties.

On the basis of the decomposition of "aircraft" and "group", further decomposition of product units shall be divided according to ATA chapters and sections, which fully reflects the decomposition and integration relationship of the system. Referring to the ATA chapter and section division principle, the concepts of system, sub-system and sub-subsystem are given priority when the product is decomposed step by step. Each product unit has its own development requirements and functions, which are convenient for product design definition, analysis, design, inspection and test, as well as the decomposition and distribution of development requirements and functions, thus realizing the successive decomposition and integration of products layer by layer.

The complete PBS file consists of two parts. One is the tree structure of PBS, and the other is the unit description of PBS. The structural framework describes the overall picture of product composition, and the unit description describes the basic functional attributes of each product unit. The structure frame is represented by the tree diagram or decomposition table, and the unit description is filled in according to the template requirements. Special specifications for units shall be compiled so that the development requirements and specifications are comprehensive, systematic, not repeating, not missing, and unique.

In DR, the tree structure of the first edition PBS used for WBS compilation is 4-level, and the 4-level PBS structure includes aircraft level, "group" professional level, system level and subsystem level. Compared with ATA 2200, it increases the level content of aircraft level and "group" professional level.

In terms of form and content, there is a big difference between PBS and ATA Spec 2200. But the "system" and "subsystem" of PBS, and the "chapter" and "section" of ATA spec 2200, there is a corresponding relationship. Such as the ATA chapter 21 "air conditioning" really corresponds to the PBS "air conditioning system" system-level unit. Section 40 of chapter 21 ATA directly corresponds to the unit of the "heating" subsystem in PBS.

The architecture of PBS is compiled from the chapter of ATA to ensure the integrity of PBS as a whole and the consistency of each unit at the level. Of course, because the PBS is compiled by the main manufacturer, there are some adaptive changes at the level, such as the power plant has dropped by one level and appears as a system.

The PBS structure of the first edition of the DR project adopts the hierarchical division of ATA chapters. Except that the ATA chapters are coordinated with each other at the hierarchical level, the division of ATA chapters meets the analysis requirements of the functions and requirements of the project. In the process of product development, the design of aircraft and systems can be mapped to ATA chapters conveniently. The Joint Concept Definition Phase (JCDP) and Joint Definition Phase (JDP) sub-stages of the pre-development stage of the aircraft form the aircraft scheme and each system scheme. In these two sub-stages, the functional definition and requirement definition of aircraft and systems have been fully discussed, and the design scheme, functional analysis, and requirement analysis of aircraft and systems are coordinated.

Each PBS unit has a PBS unit description. Unit description is including product name, serial number, functional description, product composition, installation location, interface relation, selection of standard parts and materials, important parts, special process technology, and special specifications. The special specifications in the unit description, together with the PBS structure tree, form the specification tree for the entire aircraft.

4.2 Level Overview of PBS for DR Project

In the process of the first edition DR project PBS decomposition, the granularity of product content and the management scope of work units are considered to achieve manageable and controllable

product systems. The total number of work units of the product decomposition structure is controlled at about hundreds, and the whole structure is controllable. The level and unit of decomposition have a good matching degree in the matching process with the distribution baseline, and can realize the consistency of the content and requirements of the product unit and the product baseline. This product breakdown structure can reflect the organization and division of the actual technical work in the development of the DR project. It should be noted here that the PBS hierarchy is modeled after the ATA section, but the definition and content of the PBS modules are based on the specific design of the aircraft and systems in the aircraft program.

DR project, the total number of first edition PBS units, has hundreds of units. From top to bottom, PBS includes an aircraft-level first-level unit. Eight specialized technical "groups" of secondary-level units, are including airframe, propulsion system, avionics system, mechanical system, flight control system, environmental control system, electrical system and commercial carrier system. Dozens of sections and system-level three-level units, including structural product units such as sections of airframe and wings, and system product units such as air conditioning and navigation. Hundreds of subsystem-level four-level units are further subdivided from three-level units. The division of subsystems and equipment in the later edition of PBS will be roughly close to two or three thousand items. Such PBS unit distribution is in line with the capability limitation of the main manufacturer's technical management.

The ideal specific PBS framework reflects the structural hierarchy of the product and the subordinate relationship of technical management, and takes aircraft, groups, systems, subsystems, sub-subsystems and thousands pieces of equipment as the principle of decomposition. Thus, the product breakdown structure is highly consistent with the division of work, organization and development procedures, and can be used as the basis for WBS compilation and IPT team.

When compiling PBS, it is necessary to correctly select the level depth of PBS in each stage according to the requirements of each stage. The PBS depth of the DR project lags behind the project stage. In the early stage of detailed design, the first edition of PBS includes four levels: aircraft, group, system and subsystem. In the subsequent KT project, the depth of PBS level was advanced due to the accumulation of experience.

The top layer of PBS describes the basic characteristics of the whole plane. Including the description of pneumatic layout; the description of the engine, fuselage, tail wing, outer wing, and landing gear; and the description of voyage, weight, design life, and cabin arrangement. The top-level PBS also includes a description of the 8 levels 2 units and the functional baseline of the aircraft level.

The second layer of PBS describes eight technical packages, including airframe, propulsion system, avionics system, mechanical system, flight control system, environmental control system, electrical system, and commercial carrier system. It divides the whole aircraft into a few technical packages, simplifying the complexity of the aircraft. The power plant, in ATA2200, is a “group" that has been downgraded to a system in this project.

The third layer of PBS directly refers to the ATA chapter, i.e. aircraft systems, such as air conditioning systems and oxygen systems. In this way, the definition of PBS is simplified.

The fourth layer of PBS directly uses the level of ATA section, i.e. the level of aircraft subsystems. This also simplifies the definition of PBS.

The fifth and sixth layers of PBS define the sub-subsystems and equipment levels of aircraft, which is the result of the joint work of civil aircraft research and development enterprises and suppliers. Such PBS ensures the detailed design of aircraft and systems, and the systems are coordinated with each other. From the equipment level down, there are software and hardware, which are the components of the lowest level of aircraft decomposition - equipment level.

In the PBS of the second edition of the DR project currently being planned, the PBS structures of the fifth and sixth layers are listed. The functions and requirements of the systems are the direct sources of PBS product item setting in Layer 5 and Layer 6. For example, the air filtering function of the air conditioning system is the design source and basis of the air filtering device in the system. Another example is the discharge function of the system, which is also the design basis of the

system discharge equipment. In most cases, it is a comprehensive function or requirement of the system, and a group of devices is needed to realize it together.

4.3 Category Overview of PBS for DR Project

The second level of PBS is important, dividing the whole plane into eight professional technology "groups" of product packages. Among them, the airframe is structural and the others are systematic. The system category includes flight control system, mechanical system, avionics system, electrical system, power system, environmental control system, and commercial carrier system.

The airframe comprises a fuselage, wings, tail wings, and pylons.

The flight control system includes the flight control system and the automatic flight system.

Mechanical system, including landing gear system and hydraulic system.

Avionics system includes communication system, indication and recording system, navigation system, core processing system, airborne maintenance system, information system, and cabin system.

Electrical system, including power supply system, lighting system, EWIS, mechanical and electrical system.

The propulsion system, including the power plant, fuel system, auxiliary power system, inert air system, fire protection system, and nacelle. The power plant, in ATA2200, is a "group" that has been downgraded to a system in this project.

The environmental control system, including the air conditioning system, the anti-icing and rain removal system, the oxygen system, and the air source system.

The commercial load system, including signs/labels, equipment/decorations, the water/waste water system, the cargo hold, and the partition.

4.4 Preparation Process of PBS for DR Project

When the first edition of PBS was formulated, the DR project had entered the stage of detailed design, PBS had mature aircraft design system engineering documents as references. PBS input of the DR project was including ATA2200, aircraft design, aircraft functional decomposition structure, system function definition, and requirement definition. The preparation of PBS is discussed in detail in the following subsections.

The preparation method of PBS for DR is as follows:

1) Project management professional, first discuss with the designers, draw up a PBS of ATA section detail level under each ATA chapter; Refer to the requirements, functions, and design scheme documents of the preliminary design stage of the DR, the definition of ATA section or the discussion with various specialties shall be taken as the basis and starting point for further iteration. The key idea is dividing the product breakdown structure according to the design scheme. When there is no better definition of a subsystem, the definition of the corresponding subsystem of ATA2200 can be directly adopted. It should be noted here that the PBS hierarchy is modeled after the ATA chapter and section, but the definition and content of the PBS unit is based on the design of the aircraft and system, with considerable degrees of freedom.

2) check with the design scheme. After defining the details of ATA section PBS, comparing with "definition of aircraft" and "overall technical scheme of aircraft", the conclusion is that ATA section PBS can include a design scheme. In each PBS node of the ATA chapter, there is a system-level design description file, which is used to confirm the correctness and integrity of PBS. At the same time, the design of configuration items has also begun to set up, configuration files and PBS are also mutually supporting, PBS can be used to classify configuration items.

3) check with functional decomposition structure. According to the function definition of the aircraft and the system function definition, the function breakdown structure of the aircraft is drawn up, and the function requirements are issued according to the system level of the ATA chapter, so that each ATA chapter system has clear function requirements; when preparing the subsystem level PBS, function requirements breakdown further. At the same time of preparing PBS, the functions of this work package are required for each PBS work package to ensure that each product is

functional. In this way, when drafting PBS, the PBS item was designed through functional decomposition and distribution.

4) check with ATA2200. The proposed PBS needs to be compared with ATA2200 item by item. If there is any inconsistency, it needs to be discussed. After discussion, how to set the specific PBS point should be determined. Since the DR project is an autonomous design aircraft, PBS is mostly set to the DR project's own design.

In this way, the PBS of the DR project can succinctly express the scope of aircraft design and development to be carried out, ensure that the PBS can meet the requirements of guiding the development process, and finally generate the PBS structure.

In preparing the text of DR project PBS's unit description, two main measures were specially added. First following the subdivision of PBS, the functions of the aircraft are decomposed and distributed along the aircraft, groups, systems and subsystems to ensure the level-by-level matching of functions and products. The second measure is to decompose the distribution baseline along with the aircraft, groups, systems and subsystems, and the whole product breakdown structure is a specification tree.

5. Discussion on the Current Ideal Practice of PBS

In the current working logic, the ideal PBS method is to carry out according to the development stage, repeatedly use the steps of stakeholder needs capturing, functional analysis, requirement analysis and design synthesis, continuously iterate, and define PBS layer by layer from system ATA chapter level, subsystem ATA section level to the next sub-subsystem level to realize the system engineering process.

5.1 Conceptual Design and Demonstration Stage

At the stage of project approval, it is necessary to carry out "market analysis and product planning" and "conceptual scheme demonstration". In the market analysis and product planning work, the potential business opportunity report and the concept development phase work plan should be drawn up. In the conceptual scheme demonstration work, stakeholder identification reports, market analysis reports, functional definitions of civil aircraft product systems, preliminary development objectives of the project, commercial requirements and objectives of civil aircraft product systems, user requirements analysis reports, and civil aircraft product system schemes shall be drawn up, and the first edition of PBS shall be formed.

In the feasibility demonstration stage, we should carry out the function definition of the civil aircraft product system, the requirements and objectives of civil aircraft product system development, the conceptual scheme demonstration of civil aircraft product system scheme, the function analysis of aircraft function definition, the requirement analysis of aircraft-level requirement definition, the design description document of aircraft and the design synthesis of PBS, so as to replace PBS.

5.2 Engineering Design Stage

In the overall aircraft scheme definition phase/joint concept definition phase (JCDP), functional analysis documents such as aircraft functional definition, aircraft functional architecture description, system functional definition, and aircraft functional interface control documents shall be prepared. And requirements analysis documents such as aircraft level requirements definition, General Technique Specification (GTS), system top-level requirements definition, system-level requirements definition shall be prepared. And it is necessary to draw up the requirement validation documents such as the aircraft requirement validation summary report and the system top-level requirement validation summary report. It is also necessary to draw up the Design synthesis work such as the aircraft design description document, the aircraft design verification summary report, the system design description document, and PBS. And change the PBS again. PBS at this time is defined to the detail level of the ATA chapter - system.

In the preliminary design phase/joint definition phase (JDP), functional analysis documents such as system functional definition, system functional architecture description, system-level functional interface control documents, and other functional analysis documents shall be drawn up. Requirements analysis documents such as GTS, system-level requirements definition, equipment

top-level requirements document, equipment requirements definition, and other requirements analysis documents shall be drawn up. Requirements validation documents such as system requirements validation summary report, equipment top-level requirements validation summary report, and other requirements validation documents shall be drawn up. Design synthesis documents such as aircraft technical specification, system design description document, physical ICD, system architecture design verification summary report and PBS shall be drawn up, and PBS shall be changed again. PBS at this time is defined to the detail level of the ATA section - subsystem.

In the detailed design stage, the requirement analysis document for equipment requirement definition shall be prepared, the requirement validation document for equipment-level requirement validation summary report shall be prepared, and the design synthesis document for physical ICD, PBS, equipment description document, equipment architecture design verification summary report shall be prepared, and PBS shall be changed again. In this case, PBS is further split from the dimension of the product and defined to the next low level of the ATA section and equipment - sub-subsystem and equipment.

When PBS and WBS are changed in the mid-term of the DR project, PBS and WBS are based on the preliminary design level, and no further separation is carried out at the detailed design stage.

5.3 Trial Production, Verification, and Flight Test Stage

In the full trial production stage, we will carry out the work of product implementation, verification, safety evaluation and qualification examination, and update PBS according to the configuration management method. In the flight test phase, we will carry out verification, safety evaluation and qualification examination, and update PBS through configuration changes. At the stage of batch production and industrialization, complete the validation summary report of the civil aircraft product system and update PBS through the configuration change. In these stages, PBS will not be subdivided into more detail levels, but will only adjust and update PBS content.

At present, near the stage of airworthiness certification of the project, to establish the aircraft PBS detailed to "sub-subsystem" and "equipment" of DR project is been planning, so as to form a complete PBS of the whole aircraft project, reflecting the complete state of engineering design of the project, and realizing the inspectability and count of aircraft products. As the project is close to mass production, it is convenient and easy to establish detailed PBS. It can improve the success and correctness of PBS and accumulate experience in compiling PBS by adopting a later time than the formal stage.

5.4 Positive PBS Design Procedure

In the whole process, stakeholders need capture, function analysis, requirement analysis, and design synthesis steps to ensure that the PBS design procedure is a forward product design procedure while emphasizing the design synthesis steps, considering design synthesis to be the most creative step. PBS is the first step of design synthesis. Through repeated iterations, the systematic formulation of PBS is realized. At the time PBS was compiled, the entire research and development organization was simultaneously working on an organization level systems engineering process.

6. Results and Discussions

6.1 PBS Compilation Practice and Innovation

In the process of working out the project's work breakdown structure, the most active and effective is to work out the project's product breakdown structure in advance. Through the compilation of the product breakdown structure, the product scope of the aircraft development project will be clarified, and the content of the project to be designed and developed will be known, so as to know how to develop the aircraft project.

The typical method for drawing up the product breakdown structure for project development is systems engineering and analysis. There are two cases of developing product breakdown structures using systems engineering processes, one is DR and the other is the KT. Among them,

the product breakdown structure of DR is the first one and has gone through a complete process, but PBS of "sub-subsystem" and “equipment” level plan to be compiled at the end period of the project. The product breakdown structure of KT is carried out with the progress of the project. At present, KT has not passed the preliminary design review PDR, and there is no official PBS detailed to the low level of sub-subsystem and equipment.

The division logic of item PBS is the hierarchy of "aircraft", "group", "system", "subsystem", "sub-subsystem" and “equipment”. Though the hierarchical division of PBS is referring to ATA2200, due to the hierarchy of "group", "sub-subsystem" and “equipment”, the hierarchy of PBS is unique, which is from the hierarchy.

6.2 Project Management Documents such as OBS and WBS are Based on PBS

IPT team and WBS are based on PBS. In the OBS of the project, the level 0 IPT corresponds to the level of the aircraft, the level 1 IPT corresponding group or professional level, the level 2 IPT corresponding system, and the level 3 IPT corresponding subsystem. In the vertical division of IPT, there are aircraft overall design team, airframe team, propulsion system team, avionics system team, mechanical system team, etc., which is consistent with the vertical division of PBS.

WBS of the civil aircraft development project is built based on PBS. In the part of products, WBS structure and PBS structure are basically the same. When compiling WBS, refer to PBS from aircraft level to subsystem level. PBS is taken as the main body of the WBS structure, and the system integration work package is set under the parent node of PBS. Under the top-level WBS elements, the life cycle elements of trial production, test, flight test, and customer service are set. In this way, the WBS framework of the project is set up.

6.3 The Chapter Division of ATA is Basically the Same as PBS

Since the principles of PBS and ATA-based system breakdown structure are consistent, it promotes that the development plan and the project plan are the same from the source. For example, the product structure and composition of the air conditioning system, as well as the development method, are consistent with the development plan and project plan at the product level. This simplifies the decision-making process, and the structure and level of technical decision and management decision are consistent.

The hierarchy of PBS is similiar to ATA Standard Numbering System, layered the aircraft product into aircraft, group, system, subsystem, sub-subsystem and equipment. And the identification of PBS element is flexible and determined by the aircraft design scheme.

Because PBS and ATA-based system breakdown structure are consistent in principle, in order to solve risks and problems, the work scope that needs to be divided can be consistent in product scope by directly defining the product breakdown structure. The formulation of PBS not only uses management methods but also has technical methods.

6.4 PBS is the Basis of Aircraft Serialization Design, Aircraft Function Definition, and Aircraft Certification Plan

PBS is an effective tool for aircraft serialization design. When designing serialized aircraft, the PBS of the project should be compiled first to clarify the market requirements, functional requirements and product change scope of the serialized aircraft. Starting from this document, the project market and operation objectives, the profitability of the aircraft development project, and feasibility study text of the technical and economic aspects of the project should be compiled. On this basis, it is decided whether to carry out the development of the serialized aircraft.

PBS is developed based on the functions of aircraft. The hierarchy of groups corresponding to PBS is a series of main functions of this aircraft project. This is a set of functional requirements for the aircraft. After the functions are decomposed and distributed, the products are decomposed into systems and subsystems through the group of aircraft. Therefore, in the product, the functional requirements of the product in the project are realized.

In the implementation of the DR project, the preparation of the certification plan was carried out prior to PBS, resulting in the difference between the developed products of CP and PBS. However, since PBS is based on ATA2200 and the systems engineering process, there is little difference

between the two. From the perspective of PBS, it is very convenient and direct to understand the organizational form and division of labor interface of CP. In the ideal process, the CP is drawn up after PBS, and the two should be consistent as far as possible so that the CP requirements can be implemented both administratively and technically.

6.5 Elements of Systems Engineering Management Support PBS

In the DR project, the source of PBS was reviewed by the systems engineering process. At the same time of compiling PBS, the aircraft-level function definition file was compiled, the decomposition and distribution of aircraft-level functions were carried out, and then the system-level function definition file was compiled. When compiling the product breakdown structure, the functions were also distributed to specific subsystems.

In DR, PBS reviewed the design description document of the product. From the aspect of product design, it is ensured that PBS and product design are consistent. This is PBS's own requirement, which is also the fundamental reason why PBS of DR can be widely used.

In DR, due to the application of PBS results in product development plan and product development organization, the process of configuration management of the project is relatively smooth, and it is relatively easy to determine the technical decision point and the implementation process of technical decision. In the trial production of the DR test type, the configuration carding is more accurate than the SJ project. In the preparation process of formal production, configuration management is more accurate and convenient.

In the later stage of the detailed design of DR, the project introduced requirement management, as PBS met the design requirements and functional management requirements. Project requirement management has not encountered any problems at the PBS (first edition) level. Requirements management's requirements were successfully introduced to the whole project.

For the preparation of PBS, there is a conceive that in the PBS preparation process, there is an additional link for requirement validation, and there is a self-validation process in the PBS preparation process. In this way, the PBS compilation process itself can validate whether PBS is complete and correct, and can explain the correctness of PBS itself in the compilation process.

7. Conclusion

7.1 The Compilation of PBS is Increasingly Integrated with the Systems Engineering Process

From the project level, PBS is a very critical management tool. The method used for compiling PBS is a method for systems engineering and analysis of aircraft products. The systems engineering application of PBS has also developed from the application of the concept of systems engineering, to the application of the method of product analysis and function analysis of systems engineering. Now using the method of systems engineering is to compile PBS in the system process of the whole development project organization.

Through the discussion and analysis of PBS, the product scope of the project can be clearly defined, the market objectives of the project can be clearly defined, and the resource requirements and profitability of the project can be clearly defined, so as to determine the implementation content of the project and decide whether to implement such an aircraft product project from the perspective of feasibility analysis of the state and enterprises.

In the formulation of PBS, the systems engineering method of function analysis, requirement analysis, and design synthesis was combined. When the product was decomposed layer by layer, the function and requirement of the product were already decomposed and distributed. The decomposition of a product is a physical framework of a product. While decomposing the physical framework, the framework of function and requirement is decomposed simultaneously according to the structure of the product. In this way, the design of the product is realized and the function and requirement of the product are realized. When the product scope is defined, the realization prospect of the product is determined.

7.2 PBS can Guide Project Design

In the process of product development, the product breakdown structure gradually opens up and subdivides with the progress of the project. At the same time, the work breakdown structure is also gradually subdivided. In this way, the continuous management of the target and process of the project is realized. The decomposition structure of products is always determined one step earlier than the development process, which can play a guiding role in the product development process.

Due to the systems engineering process, is used as a PBS compilation method. The content of PBS reflects the actual product requirements of the project, as well as the design requirements in terms of functions and requirements. PBS can play a guiding role in the design.

In this way, the original intention of establishing the project PBS is achieved. By establishing a PBS structure with a single function, simple structure and easy realization, the complexity of the project is greatly reduced, and the success rate of the successful implementation of the project is significantly improved.

7.3 PBS is the Project General Manager's Management Commitment to Project Development

The application of PBS is slightly further prospected. When signing the PBS document of the product, the project general manager of the project promised the design and engineering scope of the product project, as well as the market objectives and functions of the product. Furthermore, the company's business objectives and aircraft product development are coupled, giving the project economic objectives and responsibilities.

In this way, when making project management and technical decisions, the decision point and decision influence of the project general manager are integrated on the PBS of the project. A dynamically updated PBS has become the successful foundation of the civil aircraft development project.

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9. Copyright Statement

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