Material Application Changes in Aircraft Structure Improvement

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Abstract. Excellent aircraft structure is an indispensable condition for the success of aircraft, and materials play a key role in the manufacturing of aircraft structures. The progress of the aerospace industry is closely related to the innovation of materials, and materials are also the prerequisite for high-tech breakthroughs to a large extent. In the past development, with the development of science and technology and the continuous progress of aerospace technology, the performance requirements of aircraft mechanics and high temperature resistance have been continuously improved, and the applied materials have also been iteratively innovated and improved. The purpose of this paper is to analyse the development history of aircraft materials from wood to metal materials to aluminium alloy, titanium alloy and composite materials, and to deeply understand the innovation reasons, application orientation and future trend of material application, to provide a clearer idea for the development direction of materials, to help improve the performance of aircraft.

Keywords: Aircraft Structural Materials, Wood Cloth Structure, Aluminium Alloy Materials, Titanium Alloy, Composite Materials

1 Introduction

Due to the disadvantages of safety and efficiency exposed by the traditional aircraft structure in different dynamic environments, optimising its structural design and strength design has become a hot topic in the current aerospace field. Aircraft shape structure design is the core element of aircraft design optimisation, which directly affects many aspects such as flight performance, economy, safety and environmental sustainability of aircraft. The improvement of aircraft structure is the core focus of the aerospace industry for efficiency bottlenecks, environmental protection pressure, technological change, etc. Therefore, with the iteration of technology and the expansion of tasks in the field of aerospace, in the current rapidly developing low-altitude economic field, the demand for aircraft performance is evolving to a higher dimension [1,2]. It is urgent to improve the performance of aircraft through the improvement of aircraft structure, break down barriers to achieve breakthroughs, and promote aircraft to be more efficient, green and intelligent.

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This paper summarises the material selection and structural design of the aircraft and analyses the advantages and disadvantages under different conditions by conducting a horizontal comparative analysis of different materials at the same time, to derive relevant laws and results. Given the improvement history of aircraft structural design, we will explore the application of composite materials, the application of intelligent materials, the optimisation of weight reduction of metal materials and other material selection on the performance of aircraft and explore the factors and directions of aircraft structural design improvement. Summarise existing research and analyse the material factors that need to be considered in aircraft structural design, the impact and how to produce the impact, to provide a more intuitive and in-depth theoretical basis for the goal and development direction of aircraft structural improvement.

Excellent aircraft structural design is an indispensable condition for the success of aircraft, which needs to be achieved through the manufacturability of the structures. The manufacturability design of the structure plays an important role in greatly reducing aircraft costs, improving quality and reliability, and shortening the research and development cycle, greatly improving the economy and efficiency of aircraft structural design. Under the condition that the design requirements of function and strength performance are met, the key factors of manufacturability such as simple design, material selection, suitable tolerance, flexible alternative manufacturing scheme, and the clarity and conciseness of technical data will also affect the structural design of the aircraft, which is a consideration that cannot be ignored in the design. Selection of materials: As the "one generation of aircraft, a generation of materials" in the aerospace field says, materials and aircraft are promoting each other and constantly developing and progressing, and materials also play a role in promoting the innovation of aircraft manufacturing. The use of materials in the aerospace field is an important driving force for the transformation and innovation of aviation technology. Materials are an important basis for ensuring product performance, viability and service life. They have the characteristics of priority development and key breakthroughs [2-4].

2 Traditional wood and wood cloth structure

Aircraft were born from the 1920s to the traditional wood and wood cloth structure of aircraft materials.

Because the aircraft needs to withstand the huge aerodynamic forces generated during flight, the selection of materials requires sufficient strength based on being as light as possible. Therefore, more than a hundred years ago, the Wright brothers, the inventors of the first manned aircraft at the beginning of the 20th century, used wood and cloth as the main materials. The early aircraft structure beams and fuselage skeletons were composed of wooden strips and wooden three-piece splints, and the wing surface was made of varnished linen, which is also known as the wooden fabric structure. The wooden pole and the laminate are usually spliced with glue or bolts. The wings are covered with varnished linen and connected to the wing rib frame by sewing. Before the 1920s, wood-cloth structures had always been the mainstream of aircraft structures [2,4]. However, the bearing capacity of wooden structures is poor due to the nature of their materials.

3 Alloy material

With the development of technology over time and the continuous improvement of aircraft performance, it is obvious that the strength and rigidity of the wooden cloth structure itself cannot adapt to the new requirements given to aircraft [5]. The shortcomings of poor safety and the fragile structure of wooden structures are constantly exposed. People gradually realise that the safety of metal applications is greatly improved compared with wooden structures, so the gold in aircraft materials [6]. The proportion of the use of the genus part is constantly increasing. After the invention of Duralumin, which can be strengthened over time, in France in 1906, the form of all-metal load-bearing skin structure emerged. However, due to the higher economic cost of aluminium alloy than that of wooden structures, there are still many wooden aircraft in service in civil aviation [2,4,7]. To this day, aluminium alloy is still one of the important aviation materials. For example, ARJ21 branch airliners are made of aluminium alloy. Almost all commonly used aluminium alloys, whether it is deformed aluminium alloy or cast aluminium alloy, and the quality of aluminium parts exceeds 75% of the net quality of the aircraft. However, with the continuous development of aerospace technology and the demand for high-performance materials, aluminium is facing serious challenges in terms of performance and specifications. It must be developed towards higher strength, lighter, more reliable and longer life, while also showing excellent service performance in extreme environments. To meet these strict requirements, from the commonly used 7075-T62, 7075-T73, 7075-T73511, 2024-T42, 2024-T3511, 2024-T3 and other traditional aluminium alloy materials to the recently developed aluminium lithium alloys: 2196, 2198, 2099, etc [8]. People need to constantly explore new heat treatment processes and material microstructure regulation technologies, constantly improve and integrate, and innovate new aluminium alloy materials, such as aluminium and lithium alloy, to improve the comprehensive performance of aluminium alloy.

4 Titanium alloy material

In the late 1950s, human beings entered the era of supersonic speed, and aircraft materials began to pay special attention to high-temperature resistance, lightweight and high-strength indicators to cope with the extreme flight environment. Therefore, titanium alloy is applied as a new type of aviation material that is fatigue-resistant, corrosion-resistant and high-temperature-resistant, breaking through the bottleneck of thermal barriers. High-temperature titanium alloy has excellent characteristics in three aspects:①High temperature resistance: high-temperature titanium alloy can maintain stable performance at a high temperature of 600~700℃. It can withstand the strong air friction and aerodynamic heating effects that a hypersonic vehicle will be subjected to when flying at supersonic speeds.②Lightweight: high-temperature titanium alloy has relatively low density (4.43~4.5g/cm^3) and high strength, which can realize the lightweight design of the vehicle and reduce the energy consumption and cost of the flight.③High strength: high speed of sound vehicle needs excellent strength to cope with the huge aerodynamic pressure and load when flying at high speed. While high-temperature titanium alloys have excellent high-temperature strength, the application of titanium alloys in aeroplanes provides an effective guarantee for improving engine power, reducing the weight of parts, and increasing the range and safety of aeroplanes. However, due to the limited reserves of titanium, the low thermal conductivity of titanium alloy and the characteristics of easy-to-stick knives, its mechanical cutting performance is relatively poor, resulting in high application costs and other problems, which seriously hinders the large-scale application of titanium alloy in the aviation field, limiting it to the engine and the fuselage exposed to high-temperature environment [2,7,9].

5 Composite materials

In the 1970s, composite materials were born as a new generation of aviation materials. Composite materials refer to materials made of two or more different substances combined in different ways. It can give full play to the advantages of various materials, overcome the defects of a single material, and expand the scope of application of materials. Take carbon fibre and silicon carbide fibre-reinforced aluminium alloy matrix composites as an example. For carbon fibre resin matrix composites, carbon fibre provides excellent strength and rigidity, while the resin matrix plays the role of bonding fibres, transferring loads, and protecting fibres from environmental influences. Carbon fibre resin-based composite materials replace traditional metal materials due to their high specific strength and specific modulus, and are often used to make reinforced wall panels for aircraft. Due to the characteristics of lightweight, high strength, easy processing and moulding, excellent elasticity, chemical corrosion resistance and good weather resistance, composite materials have gradually replaced wood and metal alloys and are widely used in aircraft structures.

Compared with the previously applied metal structures, composite materials are assembled with many fasteners and connectors, and all contents, including different properties and material components, are designed into the same structure by laying design and components, which not only reduces the number of parts and the weight of the structure, but also improves the assembly procedure. At the same time, carbon fibre reinforced plastics (CFRP) are usually moulded by a pre-impregnated, hot-pressed tank curing process. First, the pre-impregnated material is laid layer by layer on the surface of the mould and then put into a vacuum bag for vacuum. Sealed and finally sent to the hot-pressed tank for curing. Due to the different direction and angle of the fibre of the carbon fibre layer, the composite material is different from the metal material. At the same time, considering the chemical shrinkage effect of the resin matrix and the difference in the thermal expansion coefficient of the Mold and the component, the curing of the component has anisotropy, so it can be based on the number of paving boards and The control of the angle ensures that the structural design meets the requirements of coupling, rigidity and strength, and avoids linear differences in the structure[5]. With the continuous expansion of the application of space vehicles in speed and airspace, the selection of aircraft materials has gradually increased the performance requirements for the components and structure of composite materials, and the extreme service temperature environment that needs to be met has also risen to a new height. Therefore, in order to make space vehicles in a severe high-temperature environment can still work normally, must design a reasonable structure, so as to ensure that the equipment in a normal temperature environment of good operation. At present, the more widely used thermal protection structure composites with integrated heat protection, heat insulation and load-bearing, as a kind of lightweight and multi-functional sandwich structure, usually adopt the connecting structure to connect the high-temperature-resistant upper panel and lower panel. In service, the upper panel overcomes the influence of external heat while bearing aerodynamic loads. The lower panel is connected to the fuselage structure to share the structural loads between the panel and the fuselage. The upper and lower panels are made of high-temperature-resistant composite materials, which are characterised by light weight and low thermal conductivity. The core material adopts high-performance aerogel as the heat-insulating material, which can improve the heat-insulating property of the material structure, and the upper and lower panels and the core material are combined into a whole by ceramicized reinforcing bars or stitching technology, so that the structure has excellent heat-insulating property and good load-bearing capacity [10]. However, composite materials also have problems such as poor impact resistance and poor processing performance. It is necessary to continuously develop and improve, strengthen the research and development of composite materials, and apply composite materials with higher performance to aircraft material selection, and further develop all-composite aircraft with composite materials [2,4,5,7,11,12].

6 Conclusion

For more than a hundred years since the birth of aircraft, the selection of materials for aircraft structures has undergone a cyclical improvement from non-metallic materials to metal materials and finally back to non-metallic materials, and with the needs of development, the selection and development of aircraft structural materials seems to be endless. The progress and development of aviation technology constantly promote the renewal of aviation materials. At the same time, the emergence of new materials and the progress of manufacturing technology and physical and chemical testing technology have provided an important material and technical basis for the design and manufacture of aviation products, thus continuously promoting the development of the aviation industry. Therefore, we need to pay attention to the research and development and application of aircraft structural materials to effectively promote the development of aviation.

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