Research on Substitution of Fasteners in Commercial Aircraft Production

FENG YU
Shanghai Aircraft Design and Research Institute, SHANGHAI, CHINA
email: fengyu@comac.cc

Abstract. The necessity of fastener substitution research in commercial aircraft production is analyzed. The principle of substitution of fasteners for commercial aircraft is analyzed from the perspectives of civil aviation regulations, technical requirements, operation and maintenance requirements, economic benefits, etc., and common fastener substitution scenarios are taken as examples to illustrate the positive effects of fastener substitution. The analysis believes that the reasonable application of fastener substitution in the production of commercial aircraft can effectively increase the production rate of the aircraft, and will have less impact on aircraft operations and maintenance.

1. Overview
There are many types of fasteners used in commercial aircrafts, and the amount of fasteners used is large. In the initial production stage of commercial aircrafts, because the scale effect has not yet formed, the problems of untimely supply of fasteners and lack of parts often occur. Individual fasteners are not in stock, so the procurement cycle is long, and the problem of parts lacking is prominent. In order to ensure the production node of the aircraft and the smooth development of the project, it is very necessary to carry out the research on the substitution of fasteners.

2. Substitution principles for commercial aircraft fasteners
The fastener selection catalog for commercial aircrafts belongs to the design data of the aircraft, and together with the aircraft drawings, installed equipment, software inventory, etc., constitute the design configuration of the aircraft. As shown in Figure 1.
The substitution of fasteners will cause the actual configuration of the aircraft to be inconsistent with the design configuration. Therefore, the minimum requirement for fastener substitution is to achieve the performance of the aircraft design configuration, to ensure the compliance of design configuration and actual configuration of aircraft meet the requirements of the regulatory agency. The substitution of fasteners should follow the following principles:

1. The substitution of transportation aircraft fasteners must meet the requirements of airworthiness standards\[1\], such as FAR25. For FAR25, it must meet the requirements of Article 25.603 Materials and 25.607 Fasteners.

2. The research and development of commercial aircraft usually involves international cooperation. The environment for aircraft operation is relatively open. Manufacturers and operating companies need to abide by internationally applicable intellectual property laws and regulations. Fastener substitution should avoid the use of other aircraft manufacturing companies, especially competitor’s corporate standard fasteners, unless authorized by the relevant company.

3. Fasteners used for substitution must have complete technical requirements, such as international general standards NAS, NASM, SAE AS, or mature fastener manufacturer standards, such as LISI's HI-LOK and HI-TIGUE.

4. Fasteners used for substitution must be located in the fastener selection catalog of the aircraft configuration file. If the fasteners not in the fastener selection catalog meet the requirements of (1), (2) and (3), the production unit should submit an application to the standard parts management unit before use, and the fasteners can be used for substitution after being added to the selection catalog.

5. The substitution of fasteners must consider the weight difference. In extreme cases, a large number of fasteners may be substituted in a local area. If the area is far from the center of gravity of the aircraft, the impact of the weight change must be accurately calculated, and the aircraft operator must be notified through formal written documents. On the one hand, for aircraft manufacturers, reducing the fasteners weight can increase the carrying capacity of the aircraft, and then increase the price of the aircraft, as shown in Figure 2\[2\]. It can also reduce the fuel consumption and reduce the operating cost of the aircraft, which is welcomed by airlines.
(6) The substitution of fasteners must consider the difference in mechanical properties. Any fastener substitution that leads to reduced mechanical properties must be signed by the designer and the strength personnel. If the key mechanical properties of the fasteners required by the structure are reduced, the fasteners may fail prematurely during the entire life cycle of the aircraft, causing danger. Strength personnel should evaluate whether the key mechanical properties of fasteners meet the requirements based on the actual situation of the structure.

(7) The substitution of fasteners must consider the maintenance differences, such as bolts need to use different disassembly tools due to different head types, or the increase of the bolt length and the addition of washers on the side of the nut. These changes need to be communicated to the aircraft operation and maintenance party through formal channels.

(8) Substitution can only be considered in the absence of fasteners, and cannot be used to solve design imperfections or design errors. Design errors can only be solved by modifying the drawings. When a manufacturer finds a fastener installation problem caused by a design error, if it does not inform the designer, the design error will not be corrected, and the mistake will be repeated. If the substitution of fasteners is not reflected in the drawings or the aircraft maintenance manual, on the one hand, it will cause the design data to be inconsistent with the actual aircraft, on the other hand, the aircraft operation and maintenance party cannot obtain relevant information, which will affect the operation and maintenance of the aircraft.

(9) The purpose of fastener substitution is to save time and improve economy. Therefore, the cost of fasteners used for substitution should be within an acceptable range. The types and specifications of fasteners should be compressed as much as possible, and expand the number of single fasteners in order to centralize procurement and form a scale advantage.

(10) As the fastener manufacturer changes the surface treatment process, or changes the fastener marking, etc., some fasteners can be used equivalently. For fasteners that are used equivalently, an equivalent catalog should be formed, and the manufacturer selects the fasteners in the equivalent catalog according to the inventory and arrival time.

(11) If the standard of fastener has changed, attention must be paid to compare the differences between the old and the new standards to confirm whether the standards meet the requirements of the latest airworthiness standards. It cannot be simply considered that the new standards and the old standards are equivalent use.

3. Research on alternative types of commercial aircraft fasteners

3.1. Substitution of UN and UNJ thread standards

There are two commonly used thread standards for aviation fasteners: UN (Unified Thread Standard) and UNJ (American Aerospace Thread). Compared with the UN standard, the thread of the UNJ
standard has an arc bottom, which can reduce stress concentration. Commonly used UN standards for commercial aircraft include UNC (coarse teeth) and UNF (fine teeth). Commonly used UNJ standards include UNJC (coarse teeth) and UNJF (fine teeth).

In the design, screws and nuts of the same thread standard are used for matching, and in production, when an absence is occurred, you can choose to substitute the fastener according to the thread standard of the screw or nut.

The UNJ internal thread will assemble with the UN series external thread. Mating the UNJ series external thread with the UN series internal thread should be avoided due to a potential interference at the minor diameter\(^3\).

Take the NAS1801 screw as an example. The thread standard is UNJF, which can only be used with the UNJF nuts, and UNJF internal threads can also be used with UNF external threads. Therefore, when the NAS1801 screw is lacking, it can be substituted by the NAS1096 screw with the thread standard of UNF. However, if the NAS1096 is lacking, the thread standard of the nut must be confirmed. Only when the thread standard of the matched nut is UNJF, can the NAS1801 screw be used instead.

3.2. Substitution of HT239 bolts and NAS1581 bolts

HT239 HI-TORQUE bolt is a patented product of HI-SHEAR. The bolt material is alloy steel and the surface treatment is cadmium plating. It is widely used in aircraft structures. For commercial aircraft manufacturers, there is a risk of supplying fasteners from a single supplier. Therefore, when choosing a patented fastener, other fasteners with the same function should be considered at the same time as a backup.

NAS1581 bolts comply with the National Aerospace Standards of the United States and can be supplied by multiple suppliers. When the material is alloy steel, the procurement specifications shall be in accordance with NAS4002. Compared with HT239 bolts, the diameter and length are the same, the mechanical properties are the same, and the thread standard is UNF. It should be noted that there are two head recess types for NAS1581, which are offset cruciform recess conforming to NASM14191 or NASM33781 or dovetail slot recess conforming to NASM33750, while HT239 has only one head recess type, which is dovetail slot recess conforming to NASM33750. Bolts with different head recess require different disassembly tools. If they are substituted without telling the aircraft operation and maintenance party, it will affect the maintenance of the aircraft. Therefore, it is necessary to use formal channels, such as aircraft maintenance manual, to inform the aircraft maintenance provider.

3.3. Substitution of NAS1805 and NAS1804 nuts

NAS1805 nut, self-locking, double hexagon, the material is A286 CRES or Inconel 718 nickel alloy, the thread standard is UNJF, the surface treatment is passivation, cadmium plating, or silver plating. When the surface treatment is passivation or cadmium plating, the nut can be used in an environment of 450°F. When the surface treatment is silver-plated, the nut can be used in an environment of 800°F.

NAS1804 nut, self-locking, double hexagon, the material is alloy steel, and the surface treatment is cadmium plating, which can be used in an environment of 450°F. Compared with NAS1805 cadmium-plated nuts, NAS1804 nuts have the same shape and size, the same thread, and the same mechanical properties. The applicable ambient temperature is all 450°F, so NAS1804 nuts can be used to substitute NAS1805 nuts with cadmium-plated surfaces.

3.4. Substitution of fasteners that affect the self-locking function or self-locking method

The bolt and nut self-locking is realized by the following methods or elements: cotter pin in accordance with NASM33540, safety wire in accordance with NASM33540, locking element in accordance with MIL-DTL-18240, self-locking nut. Take the commonly used NAS6204 bolt as an example. There are several types of bolts, such as undrilled, drilled head (safety wire hole), drilled thread (cotter pin hole), and self-locking (locking element). Undrilled and non-locking bolt needs to be matched with self-locking nut, drilled head bolt needs to use safety wire in accordance with NASM33540, drilled thread
bolt needs to be matched with castellated nut and inserted cotter pin, self-locking bolt needs to be matched with non-locking nut.

The self-locking ability of locking element is weaker than that provided by safety wire or cotter pin. Therefore, the safety wire or cotter pin should be used where the self-locking requirements of connections are high. Where undrilled bolt and self-locking nut can meet the self-locking requirement, drilled head bolt with safety wire or drilled thread bolt with castellated nut and insert cotter pin can be used instead.

Bolts containing self-locking elements in accordance with MIL-DTL-18240 shall not be used in parts where the locking element will encounter keyway, slots, cross holes or other thread interruptions.[4]

3.5. Substitution of alloy steel fasteners by titanium fasteners
Take swage-locking pins and collars as an example, NAS1465-1472 swage-locking pins are intended for structural applications requiring high performance and high strength permanent type fasteners in aerospace (structures) vehicles and associated accessories.[5] Mainly bear shear loads, The pin material is alloy steel, and the surface treatment is cadmium plate or nickel-cadmium plate, and it is used with NAS1080 swage-locking collar.

GPL8TP swage-locking pins are the latest products of Huck Fasteners. The shear resistance is the same as NAS1465-1472, and the tensile performance is better. The pin material is titanium. The surface treatment is aluminum coating or anodization. It is matched with 2TCC swage-locking. The installed weight of a single fastener combination is only 60%-70% of NAS1465-1472. Therefore, the use of titanium fasteners instead of alloy steel fasteners can reduce aircraft weight, improve aircraft performance, and reduce operating costs, especially fuel consumption.[6]

4. Conclusion
Commercial aircraft is a typical product of international division and cooperation. When the international political environment changes, the development and production of aircraft will be greatly affected. Aviation fasteners are the most widely used standard parts on aircrafts. The stability and risk resistance of the fastener supply chain have a key impact on aircraft production. Therefore, research on the substitution of fasteners will promote the development of commercial aircraft. It has a very positive meaning. Reasonable application of fastener substitution can increase the speed of aircraft production, maintain the safety and economy of the aircraft, and reduce the impact on operations and maintenance.

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