Interpreting "Design Requirements for High-Strength Lightweight Aircraft Fasteners"

《飞行器用高强轻量化紧固件设计要求》解读

1. Introduction

As aircraft design continuously moves toward lightweighting, high reliability, and long service life, conventional fasteners have become inadequate in weight reduction, strength performance, and environmental adaptability to meet modern technical requirements. Standardized procedures are urgently needed to regulate the design, material selection, manufacturing, and testing processes for high-strength lightweight fasteners. To this end, China Electromechanical Product Circulation Association (CMEPCA) has initiated the standard T/CMEPCA 091-2025 "Design Requirements for High-Strength Lightweight Aircraft Fasteners." The goal is to leverage high standards to support high quality, improve the performance and quality of China-made fasteners, and promote industry technological innovation.

Proposed and integrated by the Standard Working Committee of CMEPCA, the said standard was issued on July 25, 2025 and effective from July 31, 2025.

2. Scope

The standard defines terms and definitions for high-strength lightweight aircraft fasteners, outlines the design requirements, design principles and contents, and verification methods for such fasteners. The new standard applies to the design, production, inspection, assembly, and verification of lightweight aircraft fasteners and their components (hereafter referred to as "fasteners"). It specifies the design requirements, principles and contents, as well as design verification, including safety checks, static load test checks, fatigue test checks, and anti-corrosion performance checks, as well as marking, packaging and delivery.

3. Main Contents

3.1. Design Requirements

1. **Functional requirements:** Fasteners shall facilitate their function of connection, ensuring that clamped components do not separate during service. The fasteners should employ post-processing treatments such as surface finishing and sealed lubrication to keep the friction coefficient within a reasonable range, thereby reducing assembly problems for lightweight fasteners during use.

2. **Performance requirements:** Fasteners shall have adequate service life, strength, fatigue resistance, and anti-loosening performance. Specifically, titanium alloy materials shall guarantee a minimum tensile strength not less than 800 MPa, aluminum alloy materials shall guarantee a minimum tensile strength not less than 450 MPa, and carbon fiber materials shall guarantee a minimum tensile strength not less than 300 MPa, ensuring the safety and reliability of the fastening connection. Fasteners should employ surface coatings or plating to meet corrosion resistance technical requirements.

Titanium alloy tensile strength ≥ 800 MPa
Aluminum alloy ≥ 450 MPa
Carbon fiber ≥ 300 MPa

3.2. Design Principles

1. **Lightweight material design and selection principles**: Depending on the material of the connected part and the service conditions, choose high-strength-to-weight materials to replace steel fasteners (e.g., titanium alloy, aluminum alloy). Before employing titanium or aluminum alloys and other lightweight materials, perform design checks, reviews, finite element simulations, physical testing, and other validations to ensure that the connected structure's strength and stiffness meet design requirements.

2. **Minimum physical size structural design principle:** It is a must to satisfy fundamental theories such as elastoplastic mechanics, the third-strength theory, and the fourth-strength theory, in combination with thread mechanics and deformation coordination of the connection structure, to calculate the minimum physical design dimensions of elements such as the head, shank diameter, and engagement length. The safety factor of the fastener matched to the clamped parts must meet applicable external-load-related conditions. During the fastener design process, the practical safety factor should approach but not exceed this safety factor. When performance requirements are met, for the countersunk head structure we should preferentially use a small countersunk head; for standard head shapes, we should preferably use small hexagonal head or 12-sided head fasteners (without flange). Weight-reducing pockets (weight-reducing holes) may be added to the head as needed. Under the use requirements, the thread length should be moderate or short.

3. **Equal-strength structural design principle:** Lightweight design objectives are achieved under the premise of meeting the overall static and dynamic connection strength requirements, based on the principle that the safety factor of each structural element approaches that of the weakest structure. According to external loads and related conditions, employ advanced structural topology optimization simulation technologies for refined fastener design, ensuring better coordination and matching among structural elements to attain product lightweighting.

3.3. Design Content

1. **Lightweight material design and selection:** For material lightweighting, prioritize high strength materials for fasteners, such as titanium alloys and aluminum alloys. Based on layers and usage requirements, select from the options in Table 1.

2. **Minimum physical size structural design:** Including threaded connection dimensional structure design, rivet connection dimensional structure design, equal strength structural design, etc. The structural topology optimization design process is shown in Figure 1.

4. Design Verification

4.1. Safety Check

The standard fastener structures follow VDI-2230 Part I-2015. Non-standard fasteners shall use the Grade IV fastener model specified in VDI-2230 Part II-2014 for CAE simulation analysis or bench testing verification.

4.2. Static Load Test Check

Fastener static load test checks: Performance requirements of fasteners under tensile and shear loads shall comply with GB/T 16823 and GB/T 3098.

Connection joint static load test checks: Depending on service

Figure 1. Structural Topology Optimization Design Process

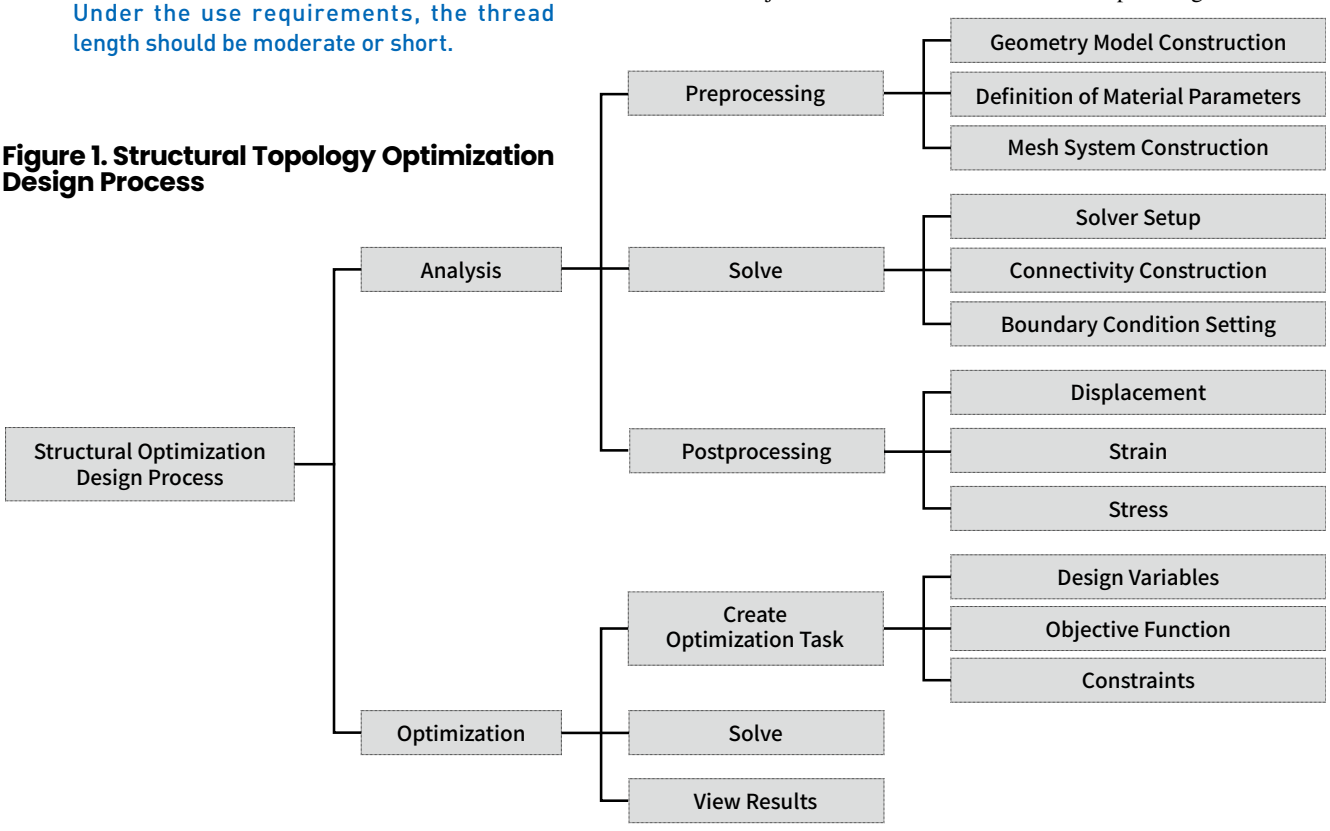

Table 1. Peak Sales and Market Share of Chinese NEVs (Data Compiled from Global News Releases)

Material Category	Grade	Tensile Strength (MPa)	Yield Strength (MPa)	Shear Strength (MPa)	Density (g/cm³)	Specific Strength (MPa·cm³/g)	Characteristics
Titanium Alloy (Rivet Type)	TAI	≥240	140–310	—	4.51	53.22	Requires relatively high corrosion resistance and oxidation resistance; mainly used for various rivets and washers
	TA2	≥400	275–450	—	4.51	88.69	
	Ti45Nb	≥448	414	345–410	5.70	78.60	Provides certain corrosion and oxidation resistance; suitable for applications requiring relatively high shear strength; mainly used for various rivets
	TB2	900	—	≥640	4.52	243.4	Used below 200 °C; requires good formability and excellent corrosion resistance; mainly used for rivets
Titanium Alloy (Threaded Type)	TB3	1100	1000	≥690	4.84	227.3	Used below 300 °C; requires excellent oxidation and corrosion resistance; mainly used for bolts, screws, and nuts
	TB8	1300	—	≥700	4.45	179.8–224.7	Tensile strength ≤1450 MPa; requires good high-temperature oxidation and corrosion resistance; long-term service below 540 °C; mainly used for high-locking bolts
	TC4	1100–1250	≥1035	≥670	4.43	248.3–282.1	Long-term service below 400 °C; suitable for applications requiring high strength; mainly used for various bolts and screws
	TC6	1180	—	—	4.55	259.3	Long-term service below 400 °C or short-term use at 450 °C; higher strength and service temperature than TC4
	TC16	1030–1180	—	≥670	4.48	229.9–263.4	Service temperature below 300 °C; stable in atmosphere and seawater; corrosion resistance superior to TC4; mainly used for bolts, screws, and nuts
Aluminum Alloy (Rivet Type)	7050-T73	482	400	283–317	2.82	170.92	High strength with excellent resistance to stress corrosion cracking and exfoliation corrosion; mainly used for rivets
Aluminum Alloy (Threaded Type)	7075-T73	≥469	≥386	—	2.81	166.9	Good oxidation resistance; T73 provides the best stress corrosion resistance; mainly used for various nuts, high-locking nuts and washers
	7055-T76	450–600	≥503	—	2.78	161.87–215.83	Good oxidation resistance; T76 offers good stress corrosion resistance; mainly used for bolts, with limited use for nuts

conditions, verify the ultimate loads of connection joints under shear, tension, and combined loads.

4.3. Fatigue Test Check

Fastener axial fatigue test check: Performance requirements of fasteners under tensile fatigue loads shall comply with GB/T 13682.

Fastener transverse loosening test checks: Performance verification tests for fasteners under transverse fatigue loads shall be conducted according to GB/T 10431.

4.4. Anti-corrosion Performance Check

Conduct neutral salt spray tests as per GB/T 10125. Conduct ammonium nitrate accelerated corrosion tests as per GB/T 5267.2. For other anti-corrosion treatments, negotiate the test methods.

5. Recommendations for Implementation

The implementation of the standard "Design Requirements for High-Strength Lightweight Aircraft Fasteners" aims to regulate the design, material selection, manufacturing, and testing processes for high-strength lightweight fasteners through standardization. It holds significant importance for improving the design, manufacturing quality, and inspection levels of high-strength lightweight aircraft fasteners. To better execute the new standard, aircraft fastener production and manufacturing units are recommended to formulate operable enterprise standards, manufacturing process documents, inspection documents, etc., based on the new standard's provisions and their actual conditions, further refining and clarifying the requirements. Aircraft OEMs and relevant group companies should define acceptance criteria for high-strength lightweight fasteners based on manufacturing and usage requirements, particularly the new standard's provisions on safety check, static load test check, fatigue test check, and anti-corrosion performance check in design verification. Thoroughly understand and apply the new standard to enhance the quality of high-strength, lightweight, and highly stable fasteners for aircraft, ensuring flight safety.