

Civil Aircraft Passenger-to-Freighter Main Cargo Compartment Lining Validation Technology

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Abstract. Passenger-to-freighter conversion is a common practice in the aviation industry, especially for older civil aircraft that have completed their passenger service missions. Converting these aircraft into freighters extends their operational lifespan by several years, significantly increasing the overall economic benefits throughout their life-cycle. The main cargo compartment lining is a crucial component of the P2F conversion process. It must meet the requirements outlined in CCAR-25. This paper, based on experiences in civil aircraft Passenger-to-freighter conversions, examines the CCAR-25 regulations, verification methods, and qualification criteria applicable to main cargo compartment lining systems, with a focus on important aspects of these regulations.

Keywords. civil aircraft; Passenger-to-freighter; main cargo lining; CCAR-25 regulations; Validation Technology

1. Introduction

Due to the lack of new-build factory produced freighters in the standard-body sector, the passenger-to-freighter (P2F) conversion of existing passenger aircraft is the only source of revenue for this market. An analysis of the whole fleet of Chinese commercial jets suggests a sizable supply of B737/738 and A320/321/P2F potential aircraft. This strongly shows that China could simply supply itself with its own standard body freighters and be self-sufficient. The main conversion houses are now entering numerous cooperative agreements with Chinese MROs because they are fully aware of the market potential[1].

The lining of the main cargo hold, as an essential component in the passenger-to-freighter conversion package, is a crucial lining feature that needs to be installed in every civil aircraft undergoing cargo conversion. The main cargo compartment lining comprises primarily of the main cargo compartment ceiling, main cargo compartment sidewall panels, main cargo compartment door lining, main cargo compartment forward/aft bulkheads, and various system equipment arranged within the lining.

For the system-level verification activities of the main cargo compartment lining, it mainly involves the verification of the functionality, performance, human-machine interface, and other aspects of the main cargo compartment. Based on the classification of airworthiness changes, it falls under the category of major changes and is subject to the requirements of CCAR-25. There are currently ten existing compliance methods for airworthiness verification, as shown in Table 1[2]:

Table 1 Airworthiness Verification Compliance Methods

0	1	2	3	4	5
Compliance Statement	Explanatory Document	Analysis/Calculation	Safety Assessment	Laboratory Testing	Ground Testing
6	7	8	9		
Flight Testing	Aircraft Inspection	Simulator Testing	Equipment Certification		

The lining of the main cargo compartment is typically converted from the passenger cabin during the aircraft-to-freighter conversion process. Its design has a certain degree of continuity, so its verification is mainly carried out through MOC1, MOC2, and MOC4 methods. Partial verification can also be done through MOC6 and MOC7 if necessary.

2. Literature review

There are numerous sub-systems that make up the civil aircraft's equipment and furnishings system, including the pilot seat, observer seat, cabin attendant seat, galley, restroom, passenger seat, overhead bin, cockpit lining, cabin lining, cargo lining, emergency equipment, passenger service unit, and placards/markings. The certification of the FAR25.562, 785, 815, and other rules typically uses inspection (MOC7) as one of the means of compliance for certification. The Equipment and Furnishings System's subsystems are substantially different from one another in every way. They each have distinct roles, guiding ideologies, and system architectures. The inspection of the Equipment and Furnishings System is complicated by these variances. Numerous aspects require attention. The inspection requirement and Pass/Fail criteria for the Equipment and Furnishings System were discussed in this article[3].

Depressurization is one of the primary methods for fighting on-board cargo fires, which pose a serious threat to freighter aircraft and must be put out immediately. Liquid pool and cardboard box fire tests were carried out to investigate the impact of low pressure on in-flight fire and precisely assess the fire hazard during this emergency circumstance. Depressurization could contain the cargo fire by lowering the radiant heat flux and mass burning rate, but it was unable to extinguish the flames. Depressurization makes liquid fires more intense and boosts the flame's high-temperature area, making it easier for cargo liners to burn through. Depressurization could reduce the intensity of a solid fire's burning and put out the visible flame, but it couldn't stop smoldering. Smoldering enhances the chance of flashover by accumulating smoke with high carbon particles and combustible gas. The greatest threat to solid fires comes from the flashover brought on by pressure recovery during the landing. Along with depressurization fire suppression, other synergistic fire control techniques and the combustion characteristics of the loads should be taken into consideration[4].

3. Main Cargo Compartment lining-Related Provisions

In this chapter, we categorize and review the relevant CCAR-25 provisions related to the main cargo compartment lining. The content of provisions from other CCAR chapters is not included in this chapter's review. Additionally, due to the uniqueness of aircraft models, different aircraft models may be subject to different provisions, and not all provisions listed may apply.

3.1 Strength-Related Provisions

Strength-related provisions include material level, component level, system level, and more. The specific applicable provisions are as follows:

Table 2 Strength-Related Provisions for Main Cargo Compartment lining

NO.	Provision Number	Title
1	25.305(a)(b)	Strength and Deformation
2	25.307(a)	Proof of Structure Compliance
3	25.365(e)(f)(g)	Pressurized Compartment Loads
4	25.561(b)(c)(2)	Emergency Landing Conditions-General
5	25.613(a)(b)	Strength Properties of Materials and Material Design Values
6	25.619	Special Factors
7	25.625(a)(b)(c)	Joint Factors

Since the installation environment of the main cargo compartment lining is generally similar to that of the aircraft before cargo conversion, with similar installation methods, most of the strength-related provisions can be verified using Compliance Statement (MOC1) and Analytical Calculations (MOC2), drawing parallels with the aircraft's state before cargo conversion.

3.2 Manufacturing-Related Provisions

The design and verification of the main cargo compartment lining also require thorough consideration of the manufacturing-related clauses in Part 25, particularly whether the relevant materials and manufacturing processes meet the requirements and whether the design configuration and related maintenance procedures comply with the provisions mentioned in these clauses. The relevant clauses that need to be satisfied are summarized in Table 3:

Table 3: Manufacturing-Related Clauses for Main Cargo Compartment lining

NO.	Clause	Title
1	25.603	Materials
2	25.605	Manufacturing Methods
3	25.611(a)	Accessibility
4	25.1529	Continued Airworthiness Documents

3.3 Specific Cargo Compartment Clauses

Typically, mainstream passenger-to-freighter aircraft models in the market have cargo compartments that are classified as Class E cargo compartments[5]. These cargo compartments, as spaces designed to carry cargo, must comply with specific cargo compartment clauses outlined in Table 4:

Table 4: Specific Cargo Compartment Clauses

NO.	Clause	Title
1	25.787(c)	Stowage compartments
2	25.853(a)	Passenger cabin lining
3	25.855(a)(b)(d)(e)(f)(g)(h)(2)	Cargo and baggage compartments
4	25.857(e)	Cargo compartment classification

E-class cargo compartments are defined in the regulations by the following four criteria:

- 1) They should have an approved, independent smoke detection or fire detection system that provides warnings at the pilot or flight engineer station.
- 2) They should have means to cut off ventilation airflow into or within the cargo compartment, with controls accessible to the flight crew from the flight crew compartment.
- 3) They should have means to prevent the entry of hazardous quantities of smoke, flames, or toxic gases into the flight crew compartment.
- 4) Required crew emergency exits must be accessible in any loading condition.

Compared to the lower cargo compartments (Class C) in standard passenger aircraft, E-class cargo compartments do not require fixed fire extinguishing or fire suppression systems inside the cargo compartment. However, they still require measures to prevent the entry of hazardous quantities of smoke, flames, or toxic gases into crew compartments, such as the flight deck and observer's compartment. Therefore, it is necessary to cut off relevant ventilation ducts and establish an exhaust system to vent smoke outside the aircraft in case of a fire inside the cargo compartment. Additionally, there are additional requirements for crew emergency exits. In summary, the lining

design of E-class cargo compartments must meet stringent fire and flame resistance requirements, making fire testing a critical aspect of the verification process.

4. Verification Methods for Main Cargo Compartment lining Clauses

4.1 Summary of Compliance Verification Methods

In the first chapter, ten compliance verification methods (MOC) were mentioned, covering MOC1, MOC2, MOC4, MOC6, and MOC7 for main cargo compartment lining. Specific aircraft models may require additional methods. In this chapter, the main cargo compartment lining design clauses are categorized based on compliance verification methods, as shown in Table 5:

Table 5: Main Cargo Compartment lining Design Clauses by Compliance Method

NO.	Compliance Method	Associated Clauses
1	MOC1	25.603,25.605,25.787(c),25.1529,25.855(a),25.857(e)
2	MOC2	25.305(a)(b),25.307(a),25.365(e)(f)(g),25.561(b)(c)(2),25.611(a), 25.613(a)(b),25.619,25.625(a)(b)(c)
3	MOC4	25.613(a)(b),25.853(a),25.855(d)
4	MOC6	25.855(h)(2)
5	MOC7	25.611(a),25.855(b)(e)(f)(g)

Some clauses may be verified using multiple compliance verification methods, and the specific method to be used should be determined based on the aircraft model and its design configuration, following consultation and agreement between the certification authority and the applicant.

4.2 Key Clauses and Experimental Research

This chapter will explore the verification strategies and potential tests associated with important clauses related to the main cargo compartment lining.

4.2.1 Typical Verification Approaches

The typical verification approaches for select main cargo compartment lining clauses are outlined in the following table. on the premise of meeting the requirements of the airworthiness clause , consider meeting the comfort requirements as much as possible to improve the comfort passengers[6].

Table 6: Compliance Verification Approaches for Main Cargo Compartment lining

NO.	Clause	Compliance Verification Approach	Notes
1	25.305(b)	For strength calculations and analysis of the main cargo compartment lining and its installation, use ultimate load calculations to demonstrate structural integrity without significant deformation, or ensure that the analysis fully accounts for deformation effects, or prove that the methods and assumptions used adequately address deformation effects to show compliance with the strength and deformation requirements of this clause.	
2	25.365(f)	For strength calculations and analysis of the main cargo compartment lining and its installation, demonstrate strength compliance with the requirements of 25.365(e) while considering synthetic differential pressure loads generated under special conditions.	
3	25.561(c)(2)	When conducting strength verification for decorative panels, demonstrate that the installation design can secure each object under the conditions of 561(b)(3). For items frequently	

NO.	Clause	Compliance Verification Approach	Notes
		disassembled, use a 1.33 factor for joint coefficients to demonstrate that connection strength meets the requirements.[7]	
4	25.603	Provide an explanation of the materials used for main cargo compartment lining components, including an approved list of material specifications and indications of compliance.	Material list and corresponding material specifications.
5	25.611(a)	Describe accessibility measures for objects with normal operational and maintenance requirements within the main cargo compartment lining through main cargo compartment lining drawings, system installation drawings, or system description documents. Demonstrate accessibility and ease of operation through onboard inspections.	Onboard inspections (MOC7).
6	25.613(a)(b)	Provide an explanation of materials and specifications corresponding to the main cargo compartment lining product and demonstrate that material strength performance data used in the strength analysis is derived from approved airworthiness test data. Conduct laboratory tests for structures lacking material allowable values and fittings to establish allowable values for strength analysis.	Necessary laboratory tests (MOC4).
7	25.625(b)	Analyze the installation design of the main cargo compartment lining structure to demonstrate that joints not using a 1.15 joint coefficient are made according to approved manufacturing methods and are supported by comprehensive test data or have employed larger special factors.	
8	25.787(c)	Describe the loading scheme for the cargo compartment and the position of lighting fixtures to demonstrate that light shields protect the bulbs to prevent cargo from striking them.	
9	25.853(a)	Perform a combustion test on the design features of the main cargo compartment lining to demonstrate that materials meet flammability requirements.	Key test; details in 3.2.2 below.
10	25.855(a)(b)	Explain through drawings or onboard inspections that the main cargo compartment is of the corresponding grade and that its lining complies with requirements separate from the aircraft structure.	
11	25.855(d)	Perform a combustion test on materials such as restraining nets and netting in the main cargo compartment to demonstrate compliance with flammability requirements. 25 Appendix F, Part I.	Part I of Appendix F of CCAR25
13	25.855(h)(2)	Verify the sealing measures between the main cargo compartment lining and the 9g wall. Demonstrate through flight tests that it can prevent the entry of dangerous amounts of smoke into other occupied compartments (cockpit, crew compartment, etc.). If the aircraft is equipped with devices that discharge smoke or toxic gases, verification may also be conducted to ensure their proper functioning.	Flight tests (MOC6).

4.2.2 Key Test Clauses

Regarding the planning of combustion tests for the main cargo compartment lining, as CCAR-25 does not specify the specific flame resistance requirements for E-class cargo compartments, reference can be made to the following documents for verification planning:

FAA Advisory Circular AC 25-18[8], "Transport Category Airplanes Modified for Cargo Service," issued on June 1, 1994, provides guidance on compliance verification work for cargo or convertible aircraft modifications with respect to relevant FAR clauses. It mentions that the flame resistance and heat penetration characteristics of the main cargo compartment lining must comply with the verification test requirements of FAR 25.855 and FAR 25 Appendix F Part III, as revised by Amendment 25-60, and the relevant requirements of FAR 121 and 135. However, it does not specify the scope of main cargo compartment lining that need to meet the verification test requirements of Part III of Appendix F[9].

The latest amendment, CS 25 Amendment 13, introduced CS 25.855(c)(2) by EASA[10]. It states: "Cockpit voice and flight data recorder systems, windows and systems or equipment within, or in the vicinity of, Class E cargo compartments shown to be essential for continued safe flight and landing according to CS 25.1309 must be adequately protected against fire. If protective covers are used, they must meet the requirements of Appendix F, Part III."

Based on the above information, it can be concluded that any equipment mentioned in the clauses above should be protected by the main cargo compartment lining. Additionally, this portion of the lining should meet the requirements of Part III of Appendix F of CCAR-25. Therefore, planning a fire penetration test for the main cargo compartment lining is necessary, and during the design phase, efforts should be made to position the mentioned equipment away from areas of the lining that may be more susceptible to fire penetration.

5. Summary

Based on the results and discussions presented above, the conclusions are obtained as below:

1) Since the installation environment of the main cargo compartment lining is essentially the same as that of the passenger compartment lining before the aircraft's conversion to cargo, and the installation methods are similar, it is advisable to use the compliance demonstration (MOC1) and analytical calculations (MOC2) for verification whenever possible. This approach helps avoid unnecessary testing.

2) As the main cargo compartment is classified as an E-class cargo compartment, it has higher fire resistance requirements compared to the original passenger compartment lining. However, due to the nature of its conversion, it may not fully meet the requirements for flame penetration resistance, similar to C-class cargo compartments. Therefore, it is possible to plan tests for flame penetration resistance in key areas, following the guidance provided in CS 25.855(c)(2).

3) Different cargo aircraft models may have varying requirements for the main cargo compartment lining based on their functions and classifications. Additionally, the same clauses may have multiple compliance verification methods. In practice, the specific requirements and verification methods should be determined based on the individual aircraft model and its design configuration, and agreement with the certification authority should be reached for the certification process.

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