Research on the lining and Equipment Layout of Passenger-to-Freighter Conversion in Civil Aircraft Main Cargo Compartment

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Abstract. Passenger-to-freighter conversion is the prevailing disposal method for numerous older civil aircraft currently in service after completing their passenger transport missions. It significantly enhances the economic benefits throughout the aircraft's life-cycle, saving costs for airlines and generating profits for logistics companies. The lining of the main cargo compartment, as an essential component in the passenger-to-freighter conversion process, plays a crucial role. It provides interfaces for a wide range of existing and newly added cargo equipment while also serving to protect the aircraft structure and accommodate cargo in the main cargo compartment. Additionally, it must meet requirements related to fire resistance, sealing, decompression, and structural strength. Moreover, as an exterior component, it must also be aesthetically pleasing, practical, and easy to maintain. This article primarily explores the composition of the main cargo compartment lining in freighter aircraft, the arrangement of relevant equipment within the lining, and their respective design requirements and guidelines.

Keywords: civil aircraft; Passenger-to-freighter; main cargo lining; equipment arrangement.

1 Introduction

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. It serves as the 'cabin lining' for the freighter aircraft, with the 'passengers' being replaced by cargo items like containers, pallets, and bulk cargo that rely on the cargo handling system for loading. As aircraft have evolved towards being faster, capable of long-haul flights, and larger in size, the capacity of the main cargo compartment has gradually increased. the number of equipment and functionalities within the main cargo compartment has increased from being minimal to comprehensive, from simple to complex, and from outdated to more modern and automated.

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The main cargo compartment, being the primary cargo space in civil freighter aircraft, is also the interface between the airline's cargo handling operations and the cargo carried by the aircraft. It provides various sensors necessary for the operation of the main cargo compartment, which are crucial for crew members, including pilots and escorts, as they directly relate to the safe operation of the aircraft. In addition, the lining of the main cargo compartment lighting, environmental control, communication, and other essential equipment to create a comfortable working environment for crew members. This ensures that both the crew on the freighter aircraft and ground personnel can use the main cargo compartment safely and efficiently in various scenarios[1].

2 Literature review

The reasons for the anticipated increase in air cargo demand in China over the next 20 years are examined in this article, along with the reasons why standard body freighters will predominate in the industry. 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[2].

According to Mlynarčík's study, the application of this transformation throughout the modern history of aviation is examined in this offered study on the subject of converting passenger aircraft to freight versions, together with the current environment...This paper's major objective is to clarify and further this process, which has gained momentum in recent years and has a lot of potential going forward. When there is such a great demand for passenger aircraft to be converted to cargo versions due to the COVID-19 pandemic and its considerable impact on general aviation, this study is extremely important[3].

Niţă's study forecasts the market size and global distribution of freighter conversions and highlights several significant business potential cases in the field of aircraft cabin conversion and refurbishing. This indicates that scenarios for cabin alteration or conversion, as well as their frequency and duration, must be determined. According to the data, 38000 cabin redesigns will be carried out during the next 20 years. There will be about 2500 cargo conversions from jetliners and 25000 VIP-standard cabin modifications available on the market[4].

3 Main Cargo Compartment lining Composition

The main cargo compartment lining needs to firstly ensure that it can accommodate the maximum number of containers that the main cargo compartment can hold while ensuring that all containers are separated from the aircraft's structure by interior panels[5]. Additionally, in accordance with fire prevention and ventilation decompression requirements, the minimum distance between the containers after loading and the lining panels must not be less than 2 inches. A typical cross-section of the main cargo compartment is shown in Figure 1 (the shaded area represents the cross-section of the containers):

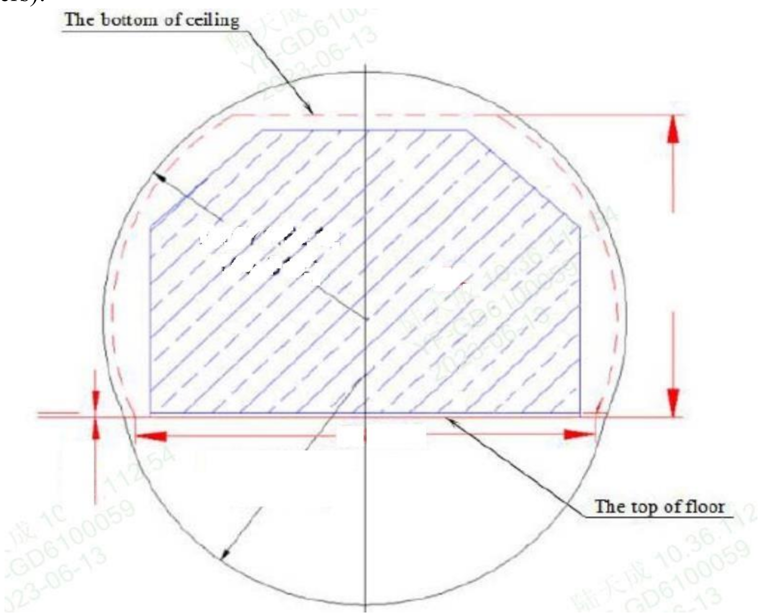

Fig. 1. Typical Cross-Section of Main Cargo Compartment

The added lining components of the main cargo compartment after the passenger-to-freighter conversion in civil aircraft, their constituent parts, and their characteristics and functions are as shown in Table 1:

Table 1. Main Cargo Compartment Components and Their Functions

No.	Parts	Components and Functions
1	Main Cargo Compartment Ceiling	Located at the top of the main cargo compartment, partitioned along the aircraft frames, it is typically composed of sheet material as the primary structure and peripheral substructures. It serves to protect the aircraft's upper structure, concealing and accommodating upper EWIS (Electrical Wiring Interconnection System) lines and equipment. Behind it, there is typically an arrangement of structural brackets, smoke detectors, main cargo compartment lighting, air conditioning vents, buzzers, and other equipment.
2	Main Cargo Compartment Side Panels	Located on both sides of the main cargo compartment, partitioned along the aircraft frames, it is typically composed of sheet material as the primary structure, return air grilles, and peripheral substructures. It serves to protect the aircraft's fuselage structural frames on both the port and starboard sides, absorbs excessive loads, and provides pressure relief ventilation through the return air grilles. It also offers installation interfaces for various components, such as controllers, access panels, and storage compartments. Behind it, there is insulation and soundproofing material.

No.	Parts	Components and Functions
3	Main Cargo Compartment Rear Bulkhead	Located at the rear of the main cargo compartment along the longitudinal axis, partitioned vertically, it is typically composed of sheet material as the primary structure, access panels, and peripheral substructures. It serves to protect the aircraft's rear bulkhead station, including fuselage frames and pillars, absorbing excessive loads, and providing installation interfaces for access panels, storage compartments, and other equipment.
4	Main Cargo Compartment Door Area lining	Located inside the main cargo compartment door, closely connected to the main cargo compartment door, it is typically formed as a single unit through composite material hot pressing. It serves to protect the aircraft's main cargo hold door structure and the equipment installed on it, providing installation interfaces for some equipment and concealing the cables behind.
5	Main Cargo Compartment Forward Bulkhead (unnecessary)	Located at the front of the main cargo compartment along the longitudinal axis, closely connected to the 9G wall. It serves to protect the 9G wall structural components, absorb excessive loads, and provide installation interfaces for the escort's door opening, equipment, and related control interfaces.
6	Main Cargo Compartment lining Floor	Covering the upper part of the main cargo compartment lining floor, it is closely related to the structure and cargo handling system. It has functions such as anti-skid.

4 Types of Materials Used for Main Cargo Compartment lining

4.1 Composite Materials

The extensive use of laminates and honeycomb panels as primary materials for the main cargo compartment lining is due to their high strength, good fire resistance properties, and low density. These composite materials typically consist of prepreg material, honeycomb core, adhesive film, inserts, and surface coatings. The selection criteria are as follows:

a. In areas requiring contour conformity (e.g: side panels at fuselage frame positions), laminates can be chosen due to their good malleability.

b. For critical equipment and structural areas that require protection, honeycomb panels can be used for their stiffness and durability.

c. When numerous devices need to be installed or specific interfaces provided, openings or embedded inserts can be incorporated into composite components to save on structural bracket placement.

d. Considerations such as weight and manufacturing cost are essential.

e. Enhancing interchangeability by using the same materials for similar parts can reduce operational costs during airline operations.

4.2 Metal Materials

For the installation of lining components onto the aircraft structure, a significant number of secondary structural components are employed. These typically include various longitudinal elements such as longitudinal beams, transverse beams, conformable stringers, and stiffeners, as well as various types of fasteners. The selection principles for relevant application scenarios are as follows:

a. For the purpose of weight reduction, most secondary structures are made from aluminum alloys.

b. For metallic materials exposed within the main cargo compartment, considering the somewhat corrosive environment, materials such as stainless steel, titanium alloys, etc., may be selected depending on whether their installation location requires meeting certain strength or fire resistance requirements.

c. The selection of standard components must meet manufacturing and maintenance requirements. Depending on the situation, fasteners with various functions such as quick-release, shock absorption, ease of operation, etc., may be chosen.

5 Arrangement of Main Cargo lining

The interfaces of the main cargo compartment lining can be categorized by type into internal installation interfaces, structural installation interfaces, and installation interfaces for system equipment.

5.1 Internal Installation Interfaces

The main body of the main cargo compartment lining is composed of independent sheets of various shapes and sizes. The connections between these sheets, known as internal installation interfaces, are crucial due to the large volume of the main cargo compartment. Internal installation interfaces are categorized based on the types and thicknesses of sheets used in different positions:

a. Overlapping: Primarily used for connecting thin sheets such as laminates. These sheets have significant elastic deformation, allowing two sheets to be overlapped and directly connected to the secondary structure through fasteners.

b. Butt-Joint: Mainly used for connecting thicker honeycomb panels. Since honeycomb panels have high rigidity and exhibit some thermal expansion and contraction, a certain gap needs to be maintained at the butt joint. Additionally, considering the presence of gaps, sealing and fire resistance requirements need to be thoroughly considered when designing connectors[6]. Figure 2 illustrates a typical installation configuration for butt-joined honeycomb panels.

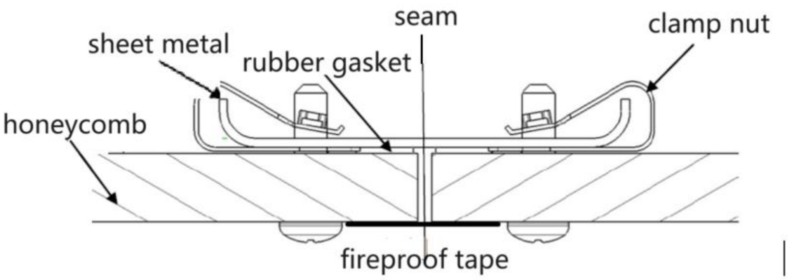

Fig. 2. Typical Butt-Jointed Honeycomb Panels

c. Corner Connection: In irregular areas of the main cargo compartment lining, there are often numerous corners that require connecting. This is typically achieved by using profiled components with certain angles for the connection. Similar to butt joints, sealing and fire resistance requirements need to be considered. Figure 3 illustrates a typical corner connection configuration:

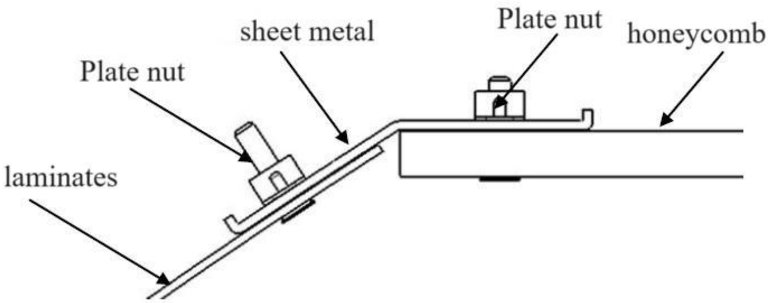

Fig. 3. Typical lining Corner Connection

5.2 Structural Installation Interfaces

The interfaces between the main cargo compartment lining and structural installation must consider the actual installation environment. Typically, freighter aircraft are converted from retired passenger aircraft, and the installation positions of the main cargo compartment lining are usually the remnants of the original passenger cabin decor. The installation environment can be complex, and each station and frame must be assessed individually. For interfaces in the bulkhead area, it may be necessary to add structural components like pillars and beams to securely install the entire bulkhead of the main cargo compartment.

For manufacturability and maintainability reasons, lining panels are usually not directly connected to structural components. Instead, they are indirectly connected to the structure through various sheet metal components or profiles mentioned in this section. Therefore, traditional fasteners such as rivets and captive nuts, as well as new types of fasteners like vibration-damping nuts, can be used for connections depending on the actual installation environment.

5.3 System Equipment Interfaces

The main cargo compartment lining provides numerous installation interfaces for system equipment. The layout and design of these equipment and interfaces need to consider functionality, maintainability, accessibility, interchangeability, and other characteristics. Here are some common system equipment:

a. Main cargo compartment lights, which provide illumination when the cargo compartment is in use by crew members.

b. Air conditioning vents or pressure balance systems, used to regulate the environmental temperature and pressure inside the main cargo compartment.

c. Smoke detection systems, used to detect potential fires, smoldering fires, etc., within the main cargo compartment and transmit signals to crew members.

d. Pathways and devices for venting dangerous quantities of smoke, extinguishing agents, or toxic gases from the cargo compartment

e. Necessary indicator lights, buzzers, speakers, and other devices.

f. Necessary safety-related equipment such as main cargo compartment door restraint nets, fire extinguishers, etc.

g. Necessary storage and fixed equipment space (areas).

For all system equipment that needs to be installed in the main cargo compartment lining, the layout and design of installation interfaces should be based on the specific placement requirements, overall functionality, and interchangeability of the respective professional disciplines. The connection form should focus on meeting manufacturing and maintenance requirements while considering sealing and fire resistance characteristics. A typical representation of equipment installation and the lining panel cross-section is shown in Figure 4:

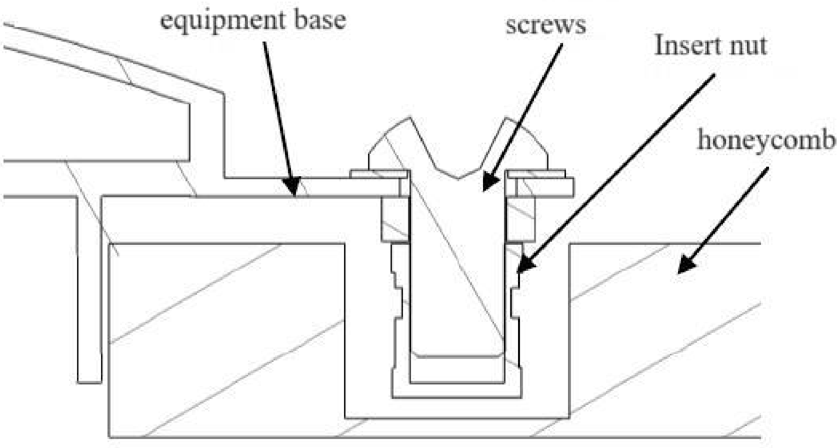

Fig. 4. Typical System Equipment Connection (inserts)

6 Main Cargo Compartment lining Layout Principles

6.1 lining Component Layout

The principles for the layout of main cargo compartment lining are as follows:

a. Interchangeability Requirements: The main cargo compartment lining is typically partitioned along the longitudinal axis. If multiple panels have the same equipment positions and quantities, they can share the same part number, enhancing interchangeability, reducing the number of components and LRUs (Line-Replaceable Units), and lowering manufacturing and operational costs.

b. Maintainability and Accessibility Requirements: The main cargo compartment falls into the category of moderate to heavy corrosion areas, and many lining panels and the equipment installed on them require regular maintenance. Typically, the panels in the main cargo compartment lining are designed to be removable, allowing for maintenance during airline operations and various inspections. Therefore, the layout of equipment needs to consider maintainability and accessibility requirements. When necessary, inspection access panels can be added, and a certain restraint system provided.

c. Exterior Dimension Requirements: As lining components, the main cargo compartment lining also needs to meet aesthetic and tidy requirements. Apart from necessary overlaps and seams, efforts should be made to ensure the integrity of the lining envelope, with a unified transitional design at the interfaces between lining panels and various equipment. The dimensions should be as spacious as possible while meeting minimum cargo-carrying requirements.

6.2 Main Cargo Compartment Equipment Layout

The primary principle for the layout of main cargo compartment lining equipment is to meet its functional requirements. For example:

a. The layout of main cargo compartment lights should ensure sufficient, uniform, and appropriate brightness throughout the entire main cargo compartment lining and the area near the main cargo compartment door when it is open.

b. The placement of air conditioning vents and smoke detectors should not only meet quantity requirements but also ensure that the spacing between them does not cause interference, ensuring the smooth functioning of both.

c. Devices for venting dangerous quantities of smoke, extinguishing agents, or toxic gases should be arranged according to established venting procedures, and their positions and dimensions should be determined through relevant validation[7].

7 Conclusion

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

a. It is shown that the main cargo compartment lining needs to firstly ensure that it can accommodate the maximum number of containers that the main cargo compartment can hold while ensuring that all containers are separated from the aircraft's structure by lining panels.

b. It is concluded that the specific arrangement of the equipment in main cargo compartment depends on a comprehensive evaluation of the aircraft's pre-conversion state, considering factors such as the equipment's installation environment, EWIS layout, etc., to improve manufacturing and conversion efficiency.

c. While meeting their functional requirements, equipment layouts should also be coordinated as much as possible with the interchangeability, maintainability, accessibility, and aesthetic requirements of the main cargo compartment lining.

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