Calculation Method of Cabin and Cargo Compartment Load limitation for Civil Aircraft

Jiehong Pan

{panjiehong@comac.cc}

Shanghai Aircraft Design and Research Institute, Shanghai, China

Abstract. The load limitation of cabin bay and cargo compartment is an important condition for the structure strength design of aircraft floor and the basis for stowage operation. Currently, there is no uniform standard for calculating and analyzing the loading limitation of cabin bay and cargo compartment in domestic civil aircraft. The strength design and verification methods of cabin bay and cargo compartment floor and its supporting structure are diversified and complicated. At the same time, in the actual operation process, if the specified loading limitation is exceeded, the floor of the cabin bay and cargo compartment and its supporting structure may be damaged, further affecting the flight safety of the aircraft. Therefore, combined with the loading situation of the actual operation scene, this paper puts forward a reasonable calculation method for the loading limitation of the cabin bay and cargo compartment, which provides reference for the structure strength design of the floor and its supporting structure and the operation stowage.

Keywords: cabin bay, cargo compartment, load limitation.

1 Introduction

The load limitation is an important input for the design of the floor(including flat and sloped floor) and its supporting structure for the aircraft. The corresponding load limitation includes the floor linear load limitation and the floor compartment load limitation.The total weight of civil aircraft is composed of the operational empty weight, payload and fuel, the payload is composed of passengers and carry-on baggage, registered luggage, cargo and mail. Combined with the actual operation scenario, the cabin load mainly considers passengers and their carry-on baggage, and the cargo floor structure mainly carries various cargo, mail or registered luggage[1]. The cargo loading modes include bulk loading, container loading, pallet loading and combined loading, so it is necessary to calculate the bulk loading and the consolidation equipment loading separately.The cabin bay and cargo compartment floor structure is shown in Figure 1. For example, civil aircraft has two loading modes at the same time[2]. The structure design shall be designed according to the maximum load limit.The verification is completed by calculation analysis and test verification method, and is included in the aircraft weight and balance manual as the basis for operation stowage.Currently,the calculation and analysis methods about the loading limitation of cabin bay and cargo compartment are relatively mature in foreign countries, but domestic technical conditions are not yet mature.Therefore, it is necessary to determine a reasonable calculation and analysis method for the loading limitation of cabin bay and cargo compartment.

MSIEID 2023, December 08-10, Guangzhou, People's Republic of China

DOI 10.4108/eai.8-12-2023.2344818

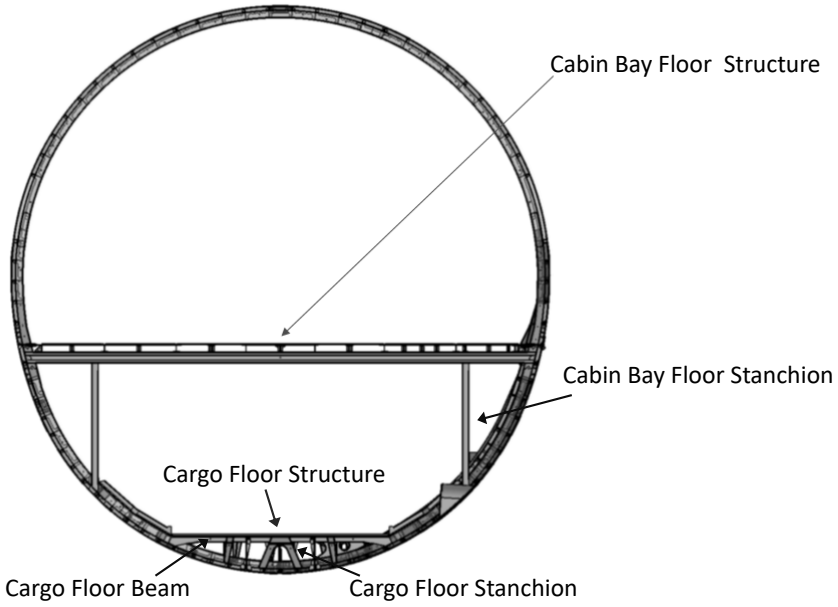

Figure 1. Cabin Bay And Cargo Compartment Floor Structure

2 Cabin bay load limitation

2.1 The floor linear load limitation

The cabin floor linear load limitation, also known as the operating load limitation, refers to the maximum load that can be carried by the fuselage length of any given aircraft floor. equal to the weight of the floor structure and the ratio of the length of the floor, the length of the floor is the length of each connection point on the floor. The calculation formula of the cabin floor linear load is as follows[3]:

$$P_L = （W_{passenger} \bullet n + W_{seat}） / L \quad (1)$$

Above formula:

P_L——Floor linear limitation, kg/m.

$W_{passenger}$——Standard average passenger weight, kg.

n——Number of single row seats.

W_{seat}——Total weight of single row seats, kg.

L——Seat row spacing, m.

Calculating parameters considerations:

- The typical section of the cabin is selected to calculate the total load of the single row, including the total weight of the passengers, seat and the carry-on baggage.
- Usually selecting the smallest row spacing among the various layouts of the cabin.
- Considering the weight increase trend of standard average passenger weight and the development space of subsequent models, some design margin can be given in the final selection of cabin floor line load.

2.2 The floor compartment load limitation

The cabin floor compartment load limitation is also called range load limit, which refers to the maximum load that any surface unit of the aircraft floor, preventing the load from exceeding the aircraft structural capacity (floor support beam, floor frame column, floor panel and frame, etc.), and the value is equal to the ratio of the weight carried by the floor to the floor area. The calculation formula of the cabin floor compartment load[4] is as follows:

$$P_S = (W_{passenger} \bullet n + W_{seat}) / S \quad (2)$$

Above formula:

P_S——Floor compartment load limitation, kg/m.

W_{seat}——Total weight of single row seats, kg.

S——Product of net cabin width and minimum row spacing, m^2.

Cabin bay floor loading limitation airworthiness verification shall include test verification and computational analysis methods to ensure the structural strength safety margin:

- The floor panels shall be shown by material identification test and computational analysis, including bending test and shearing test, as shown in Figure2 and Figure3. The structural strength calculation and analysis shall be completed according to the identification test results to ensure the bending and shear safety margin of the floor panels.

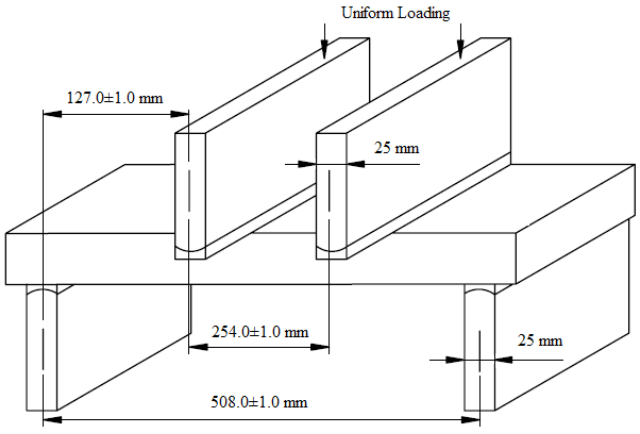

Figure 2. Certain Aircraft Floor Panels Bending Test Schematic Drawing

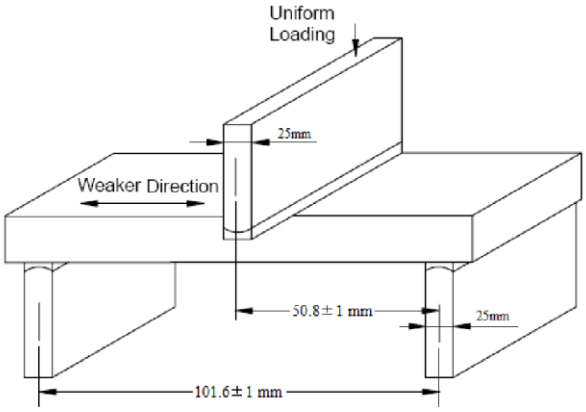

Figure 3. Certain Aircraft Floor Panels Shearing Test Schematic Drawing

- The floor support structure is shown by computational analysis, the load calculation model is established, and the load is transferred to the cabin floor support structure through the seat leg, the load includes the passenger weight and the weight of the carry-on baggage, according to the CCAR25.785 (f) clause "The passenger's own weight must be designed in accordance with the user's 77kg (170lb)". In accordance with CCAR25.1557 (a), "Carry-on baggage shall be considered as not exceeding 9kg (20lb)", the weight of the seat is calculated according to the weight status of the designed seat, The maximum load factor is considered for emergency landings in accordance with CCAR25.561.

3 The cargo compartment loading limitaiton

3.1 Bulk loading

3.1.1 The floor linear load limitation

The floor linear load limitation for bulk loading is calculated as follows:

$$P_{limited} = V_{cargo} \bullet \rho \bullet \eta \quad (3)$$

$$P_L = P_{limited} / L_C \quad (4)$$

above formula:

$P_{limited}$——The cargo floor total load limitation, kg.

P_L——The cargo floor linear load limitation for bulk , kg/m.

L_C—— region length,m.

V_{cargo}——Volume of cargo hold, m^3.

ρ——Average density of cargo,usually fall in between190~230kg/m^3.

η——the utilization rate of volume[5],usually No more than 90%.

3.1.2 The floor compartment load limitation

The calculation method of The floor compartment load limitation is the same with the cabin floor compartment load limitation .and the calculation formula as follows:

$$P_S = P_{limited} / S_C \quad (5)$$

Above formula:

P_S———The cargo floor compartment load limitation linear for bulk , kg/m.

S_C——— region area, m^2.

The calculation example is shown in Figure 4, where the two bars at the four corners act directly on the floor in the rectangular figure. The surface area used to calculate the contact load consists of the outer contour of the red region.

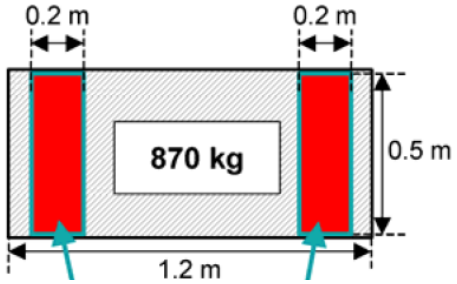

Figure 4. Schematic Diagram Of the Floor Compartment Load Limitation

3.2 Consolidation equipment loading

3.2.1 The floor linear load limitation

When designing a hold with container and pallet loading capacity, the structural bearing capacity usually needs to meet the requirements of container and pallet loading. According to the size space of the cargo hold, different sizes of containers and pallets can be selected. Each type of container and pallet has its own standard size and limit load, which is shown in table 1.

Table 1. Different Specifications ULD Standard Size And Load Limitation[6]

Size	Length(m)	Width(m)	Height (m)	Own weight (kg)	Load limitaiton (kg)
LD-1	1.534	down：1.562 up：2.337	1.626	79~170	1587
LD-2	1.534	down：1.194 up：1.562	1.626	60~100	1224
LD-3	1.534	down：1.562 up：2.007	1.626	68~168	1587
LD3-45	1.534	down：1.562 up：2.007	1.143	60~100	1134
LD3-45W	1.534	down：1.562 up：2.438	1.143	60~100	1134

Size	Length(m)	Width(m)	Height (m)	Own weight (kg)	Load limitaiton (kg)
LD-4	1.534	2.438	1.626	104~172	2449
LD-5	1.534	3.175	1.626	195~272	2948
LD-6	1.534	down：3.175 up：4.064	1.626	165~220	3175
LD-8	1.534	down：2.438 up：3.175	1.626	117~170	2449
LD-9	2.235	3.175	1.626	213~327	4627
IATA-PMx	2.438	3.175	1.626	117	5103
IATA-PAx	2.235	3.175	1.626	90~127	4626
IATA-PKx	1.534	1.562	1.143	31	1134

After the standard container or pallet arrangement scheme is selected, the total load of the cargo hold is limited according to the allowed containers and pallets, and the calculation formula as follows:

$$P_{limited} = P_{ULD} \bullet m \tag{6}$$

$$P_L = P_{limited} / L_C \tag{7}$$

Above formula:

$P_{limited}$——The total load limitation, kg.

P_L——The cargo floor linear load limitation for consolidation equipment , kg/m.

L_C—— region length,m.

P_{ULD}——Load limitation for single consolidation equipment[7], kg.

m——Number of consolidation equipment.

3.2.2 The floor compartment load limitation

The calculation formula as follows:

$$P_S = P_{limited} / S_C \tag{8}$$

Above formula:

P_S——The cargo floor compartment load limitation linear for bulk , kg/m.

S_C—— region area, m^2.

In view of the above calculation formula, the following instructions are added:

- If there are different combinations of container loading arrangement schemes[8], calculate them separately and take the maximum one.
- The cargo space can be divided into several areas, and the cargo floor linear load and limited load of each area are given respectively[9].
- The limited load design of the cargo hold for combined loading first divides the cargo hold, and then calculates it separately with reference to the limited load design of bulk loading and container loading[10].

The cargo compartment loading limitation airworthiness verification shall include static test verification and computational analysis methods to ensure the structural strength safety margin:

- The floor panels (including flat and sloped floor) shall be shown by static test and computational analysis. Select the size and area of the test piece, fix it on the test bench, load it step by step according to the target limited load, measure the deformation of the test piece, and calculate the static strength safety margin of the floor panel through the deformation.

- The floor support structure is shown by computational analysis, Combined the linear load limitation and the floor compartment load limitation, load calculation model is established, Loading limited load, the bending and shearing safety margin of cargo hold floor support structure is calculated and analyzed. The load is calculated according to the maximum load limitation of bulk cargo and container load.

4 Conclusion

Combined with the actual operation scenario of civil aircraft, this paper provides the load limitation of cabin bay and cargo compartment. Combined with the weight balance manual and other relevant materials of mature foreign models, the loading limit calculation and analysis are carried out according to this method.

The loading limitation of cabin include floor linear load and the cabin floor compartment load limitation. The calculation methods of floor linear load and floor compartment load limits of cargo compartments are given according to bulk loading and Consolidation equipment loading respectively, which provide reference for civil aircraft design. The structural strength design is calculated and analyzed according to the load determined by the above method, and the airworthiness verification is completed in combination with relevant tests to ensure that the above load limitation is met. Eventually, it is included in the aircraft weight and balance manual for the operator's stowage use. Operational stowage must meet the loading limit to ensure the safety of aircraft operation.

In the future, the relevant information of mature foreign aircraft models will be further studied in combination with the actual operation scene, and the calculation method of the load limitation of the floor panel in the cabin bay and cargo compartment, and the verification method of the structural strength of the floor panel will be deeply studied. The rationality and scope of the analysis method will be to provide a reference method for the reasonable selection of the floor panel for domestic civil aircraft.

References

[1] Bertola, L. Aiding take-off and reducing civil aircraft weight using the electromagnetic catapult, 5, pp. 3-8. (2017).

[2] Huo, X. , Wu, Y. , Boymelgreen, A. , & Yossifon, G. Analysis of cargo loading modes and capacity of an electrically-powered active carrier, 10, pp. 6-10.. (2019).

[3] Wei, L. , Qing, T. , & Bing, L. Double-deck bi-directional loading technology based on airliner cabin floor structure. Acta Aeronautica et Astronautica Sinica, 5, pp. 12-15. (2018).

[4] [Meyer-Rusitschka, K. , & Kwik, H. Aircraft`s cabin module, has pallet forming floor element of cabin compartment, where pre-installed component e.g. seat, is pre-installed onto pallet, and quick release fastener securing pallet to floor structure. DE102006017596A1, 15, pp. 3-6. (2007).
[5] Zhang. Racial and ethnic disparities in utilization rate, hospital volume, and perioperative outcomes after total knee arthroplasty (vol 98, pg 1243, 2016). The Journal of Bone and Joint Surgery. American Volume(6), 99/A, 6, pp. 22-30..(2017).
[6] International, S. . Wide-body and standard-body aircraft lower deck cargo compartment uld capacities, 7,pp. 4-10..
[7] Sin, M. S. , Kim, D. H. , & Lee, J. S. Individual Vacuum Consolidation Methods Drainage Vacuum Inspection Equipment. KR101815804B1, 18, pp. 5-13..(2018).
[8] Drummond, J. M. , & Sokatchev, E. Dual superconformal symmetry of scattering amplitudes in n=4 n = 4 mathcontainer loading mathjax super-yang–mills theory. Nuclear Physics B, 828(1-2), pp. 317-374. (2010).
[9] Chew, E. P. , Huang, H. C. , Johnson, E. L. , Nemhauser, G. L. , Sokol, J. S. , & Leong, C. H. Short-term booking of air cargo space. European Journal of Operational Research, 174(3), pp.1979-1990. (2006).
[10] Mireia, A. , Elena, A. , Nell, E. , Ibá ez Laura, Cecilia, F. , & Jaén Angels, et al. Monitoring hiv viral load in resource limited settings: still a matter of debate?. Plos One, 7(12), e47391. (2012).