Optimization Method for Grading Civil Aircraft Cabin Space Under Airworthiness Regulations

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Abstract. In the confined space of civil aircraft cabins with limited length and height, achieving a rational and efficient utilization of cabin space through the reasonable layout of cabin facilities, spatial allocation of seats, and equipment facilities is an important means to enhance the competitiveness of the civil aviation market, drawing significant attention from airlines. This paper proposes a graded optimization method for cabin layout that meets airworthiness regulations. By balancing and optimizing the requirements definition, influencing factors, and design conditions of cabin layout design, the method achieves an optimized arrangement of simulated cabins, ensuring both economic efficiency and improved passenger comfort. It provides valuable guidance for the cabin layout of civil aircraft and the redesign of in-service aircraft cabins.

1. Introduction

In the context of meeting airworthiness regulations, the cabin layout of modern civil aircraft must fully consider passenger experience, comfort, and the economic benefits for airlines. Therefore, in the confined space of aircraft cabins with limited length and height, achieving a rational and efficient utilization of cabin space through the reasonable layout of cabin facilities, spatial allocation of seats, and equipment facilities has become a key research focus in the field of civil aircraft cabin design. According to a report on cabin layout optimization by L.E.K., in practical terms, airlines can typically achieve approximately $50 million in EBITDA profit growth within a year after reconfiguring their cabins, and the optimization of cabin layout (LOPA)[2] is a crucial component of these reconfigurations. Therefore, optimizing cabin layout is a crucial aspect of cabin design, subject to the constraints imposed by airworthiness regulations.

The cabin layout design must comply with the airworthiness standards and operational standards of transport aircraft, taking into account the diverse design requirements of different stakeholders, including passenger comfort, safety management, market operations, etc [3]. Cabin layout design is influenced by various factors such as aircraft cabin layout, interior structure, decoration and equipment, cabin lighting, cabin systems, safety, and comfort, making the optimization of cabin layout design challenging. [4] Traditional design methods face difficulties in balancing these factors, leading to the introduction of mathematical methods as an important trend in cabin design research.

Zhu Wensheng and Yu Xiongqing integrated knowledge and regulations of cabin layout design into geometric models, developing a rapid design system that can generate layout schemes automatically [5]. Liao Huijun and Zhang Shuguang, in their use of parametric design methods for the design of a blended-wing-body aircraft cabin, took the placement guidelines for emergency exits, exit pathways, cabin aisles and galley, lavatories, etc., from airworthiness provisions as design parameters. Pan Lijun et al. considered aisle width, maximum number of side-by-side seats, emergency exit arrangement, and emergency evacuation as cabin design indicators. While these research results effectively meet the requirements of cabin design optimization, any modification in cabin layout design may lead to significant changes in optimization workload. [6] In order to meet the engineering development needs for improving cabin space layout design, this paper proposes a hierarchical optimization method. This method allows changes to be made within the corresponding levels for modification requirements, reducing the workload associated with design optimization resulting from changes.

2. The Cabin Space Hierarchical optimization model

Zhang Chenhu proposed a four-step optimization method in the conceptual design stage of business jets, providing an optional solution for the overall aircraft design stage. Based on this, this paper, following the development approach for the aircraft cabin, defines a three-level optimization model design. The three-level optimization model for cabin space is shown in Figure 1.
Fig. 1. The three-level optimization model for cabin space

The first level includes cabin integrated design, which involves defining the cabin cross-section, cabin length and area division, location types and quantities of doors and emergency exits, cabin partitioning and seat arrangement, and cabin aisles and emergency evacuation pathways.

The second level is cabin product integration layout, which includes the positioning, dimensions, and quantities of the galley, lavatory, wardrobe, and Luggage bins, the number and location of flight attendant seats, the arrangement of passenger service units, oxygen masks, and life-saving equipment, as well as cabin lighting, entertainment, and communication products.

The third level is cabin industrial design, which encompasses the styling and surface decoration of cabin products, cabin space, and human-machine ergonomics.

2.1. Cabin Cross-Section Optimization

Cabin cross-section design is a crucial spatial definition for the main cabin, serving as the dimensional envelope for locating cabin interior facilities. The internal layout design of the cabin cross-section involves the selection and determination of various control parameters, which must meet the minimum design standards specified in civil aircraft airworthiness requirements. The internal area dividing and layout design of the cabin divide the cabin into several areas, such as first class, business class, and economy class, based on different comfort levels. These areas are separated from each other, with the first-class section towards the front, followed by the business class, and the economy class towards the rear. In addition to passenger areas, the cabin layout also needs to consider the arrangement of areas such as the galley, lavatory, wardrobe, service area, and boarding aisle.

The layout of emergency exits and emergency routes is essential to ensure the safe evacuation of passengers in emergency situations. The type and quantity of emergency exits are determined by the number of passengers in the cabin, which, in turn, limits the maximum passenger capacity of the aircraft. The type, size, and allowed number of passengers for emergency exits dictate the overall aircraft evacuation capability.

The width of cabin aisles should meet the needs of passenger movement and emergency evacuation, ensuring that different-sized carts have good maneuverability. The aisle width varies in different cabin sections, and the widths for various areas are referenced in Table 1.

<table>
<thead>
<tr>
<th>Passenger Seats number</th>
<th>The minimum width of cabin aisle (mm)</th>
</tr>
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<tbody>
<tr>
<td>≤10 Seats</td>
<td>300</td>
</tr>
<tr>
<td>11 to 19 Seats</td>
<td>300</td>
</tr>
<tr>
<td>≥20 Seats</td>
<td>380</td>
</tr>
</tbody>
</table>

Table 1. The minimum width of cabin aisle

Under the above constraints, the cabin layout model for a certain type of aircraft is illustrated in Figure 2 as an example:

Fig. 2. Cabin layout of a certain wide-body aircraft

2.2. Cabin Product Layout Optimization

The layout of cabin products includes the arrangement of the galleys, cabin seats, lavatories, Luggage bins, lighting equipment, and the placement of cabin emergency and life-saving equipment. It is subject to the following constraints:

The number and size of galleys are determined by the number of seats and the design range of the aircraft.

Lavatory placement should be outside the direct line of sight of the galley and is constrained by electrical and water/waste pipelines. The quantity is determined by cabin segmentation and the number of seats in each segment. For economy class, one lavatory is generally suitable for up to 60 people. Beyond 60 seats, an additional lavatory can be added for every additional 50 people. If there is an independent first-class cabin, a lavatory should be provided in that section. For a first-class cabin exceeding 20 seats, an additional lavatory is needed for every additional 25 seats.

Luggage bins are located above the cabin, and the spacing between the doors of the racks on the upper sides of the aisle must meet the spatial size requirements defined by the cabin cross-section while ensuring the seating height. The size of the Luggage bins complies with the required volume per passenger as determined by
aircraft design. An optimal design is to plan for as many carry-on luggage as possible in advance.

The goal of cabin lighting equipment layout is to provide passengers with a comfortable and warm lighting environment, meeting the needs for reading, resting, and information display. The arrangement needs to consider the different scenarios for cabin crew and passengers, such as take-off/landing, level flight, dining, and rest, with different combinations and presentations of lighting.

Cabin emergency and life-saving equipment include emergency medical equipment, emergency evacuation equipment, and emergency life-saving equipment. The layout of these devices should consider quick access in specific scenarios and should be equipped with conspicuous markings or signs. The layout should minimize the occupation of cabin storage space and be comprehensively designed based on the cabin design scenario.

For example, in the business class of British Airways’ A350 [7], lie-flat business seats are arranged in the traditional 2+2+2 configuration. By optimizing the cabin layout, 16 seats can be accommodated in the business class space, and with the layout optimization, more seats have been added. The number of passengers in business class has increased by 20%, as shown in the arrangement in Figure 3-4, bringing significant competitive advantages to the airline.

### 2.3. Cabin Products Optimization Design

Cabin interior products are designed to provide passengers with a comprehensive travel experience. The design of these products must ensure that their functions meet user needs while also meeting aesthetic and decorative requirements. The design of both functional and non-functional cabin products needs to adhere to the constraints imposed by airworthiness regulations. The design of functional cabin products is better aligned with user behaviour, with convenient operation and intuitive identification enhancing passengers’ sense of product acceptance. The optimization of cabin product design also considers the impact of decorative effects on space, adhering to surface decoration requirements to enhance the overall visual comfort of the cabin and, consequently, improve the passenger experience.

### 3. The analysis of optimized results for cabin space layout

Under the constraints of airworthiness regulations, the overarching goal of optimizing the cabin layout of commercial aircraft is to enhance cabin space utilization and comfort. This paper employs a hierarchical spatial optimization approach to propose a novel design for the cabin space, specifically in the context of Airbus Airspace aircraft design. The new design standard emphasizes spaciousness, considering and implementing optimizations from the perspectives of high ceilings, legroom, Luggage bins, and other facility spaces. Spatial considerations now extend beyond merely seat width. Refer to Figure 5 for a schematic representation of the Airbus Airspace cabin model segment [8]. Airspace achieves this goal by incorporating the perception of high-tech international cabins into narrow-body aircraft. This method is widely applied in the fields of user research and interactive design, and it is equally applicable to cabin layouts.
between the lavatory and the last row of seats. In the optimized design, the lavatory's outer wall panel exhibits a concave shape, allowing for a shared portion of the seat back space with the last row of seats. This enhancement contributes to an improved longitudinal space in the cabin layout. Notably, the standard 37-inch rear lavatory has undergone optimization, resulting in a narrowed configuration of 27 inches. After the optimized design, the cabin has been increased by 10 inches.

Fig. 6. Before optimization design of cabin layout for a specific aircraft model

Fig. 7. After optimization design of cabin layout for a specific aircraft model

4. Conclusion

Through hierarchical optimization, the complex optimization objectives in terms of aircraft cabin overall layout, cabin equipment arrangement, and cabin product design are differentiated into three levels. This approach facilitates segmented optimization design, effectively reducing the complexity of cabin design optimization. Each level's constraints and optimization objectives are significantly reduced, lowering the difficulty of each optimization design step. Simultaneously, the hierarchical and step-by-step optimization increases the flexibility of cabin design optimization, allowing for rapid and iterative iterations. While meeting the requirements of airworthiness regulations, this method aligns cabin layout design more closely with the needs of airlines, thereby enhancing the operational efficiency of the aircraft. Practical application on a certain type of aircraft cabin layout design demonstrates its high engineering value.

References