Civil Aircraft Cabin Lighting Design and Verification

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Abstract. Regarding the equipment in the cabin of a civil aircraft, the complexity of their shapes, the huge quantity, and the high requirements for engineering experience in cabin lighting design will result in huge change costs when design errors occur. This paper proposes a general cabin lighting design method, summarizes the elements that need to be considered in the cabin lighting design, and completes the cabin lighting design according to the design elements. In addition, the digital simulation method is used for verification during the design process. Finally, the data will be verified on the real sample, which checks the correctness of the design process, and lays the foundation for the future aircraft cabin lighting design and verification.

1. Introduction

For civil aircraft, the cabin lighting will be blocked by many unexpected designs. Standards such as SAE AIR512, SAE ARP711, and SAE ARP712 put forward requirements for all lighting indicators in the cabin. In order to meet the design requirements, engineers usually select and arrange lighting equipment based on previous aircraft design and layout experience. However, with the development of aircraft technology, the market has higher and higher requirements for the comfort of civil aircraft cabin. In addition, cabin lighting is closely related to comfort. Therefore, it is particularly important to find a solution to meet the customer's individual visual effect requirements and the cabin lighting that can meet the design requirements. This article will focus on the cabin lighting design and use digital optical simulation to solve the cabin lighting design problem, and finally verify it under the real cabin sample.

2. Cabin Lighting Design

As the size of the civil aircraft cabin remains unchanged, in a standard single-aisle aircraft, the luggage, seats and passengers in the cabin become the main obstacles to the spread of light. According to the layout of cabin equipment, the combination of cabin light transmission design and cabin decoration needs to be considered to ensure that the cabin gets uniform and sufficient light. This will allow passengers to get comfortable cabin lighting in the limited cabin space.

However, due to the convenience of passengers during boarding and the profitability requirements of airlines, larger suitcase and more compact seating arrangements have become the development trend. Therefore, in order to ensure that the light can be irradiated uniformly and continuously in the cabin with more equipment and limited space, the best design method is to use the entire ceiling and side walls as the light source to realize the cabin illumination. However, such a large area of the light source not only increases the difficulty of system design, but also challenges the stability of the system.
under strong vibration conditions and the overall weight control of the aircraft. As a consequence, it is a good design strategy to design small lamps and use ceiling and side walls to achieve diffuse reflection of light. According to this design strategy, there are three main control objectives for cabin lighting design, lighting equipment design, lighting equipment layout and cabin decoration design.

The goal of the cabin lighting design is to make the cabin decoration panel emit light evenly, so that the cabin can get continuous and uniform light. In order to achieve this goal, the engineer analyzed the shape and layout of the cabin decoration, and verified the relationship between them and the light by design simulation. According to the verification, the light is perpendicular to the decorative board, and the light obtained on the decorative board will form a light spot with a clear boundary between light and dark, which is very detrimental to the overall reflection of the decorative board. In addition, by rotating the decorative panel to a certain angle, and then illuminating the decorative panel from the side, the lighting effect obtained by the decorative panel will be improved to a certain extent. However, the lighting effect will also change along the interior panel, which is detrimental to the overall uniform lighting effect of the cabin. If the decorative board is designed as a parabola, a very uniform lighting effect can be obtained on the decorative board as shown in figure 1.

Figure 1. Cabin lighting and interior matching design

According to the above design verification results, when the ceiling and side wall panels are designed to be parabolic arcs, and the lighting equipment uses LED light strips designed to emit light at a certain angle, then the light irradiates the decorative panels to form a wall washing effect. According to design experience, the main light Gaussian distribution of the wall washer should illuminate more than 2/3 of the decorative board, and the surface treatment of the decorative board needs to ensure the diffuse reflection effect and light color to ensure that the cabin has sufficient lighting without Produce unnecessary reflected glare. At the same time, in order to ensure the coverage of 2/3 of the light on the decorative board, the Gaussian distribution of the light output of the lighting equipment needs to be designed according to the line type of the decorative board. The final cabin lighting design scheme is shown in the figure 2 below.

However, the feasibility of the cabin lighting design scheme still needs to be verified. In particular, some part of light may be blocked by the back of the cabin seat in this scheme, which may cause the visual impact of the overall cabin lighting. Therefore, in order to ensure the correctness of the scheme, it is essential to establish a virtual cabin close to the real cabin environment for lighting simulation. In addition, the cabin lighting design is verified by the cabin lighting visual simulation diagram and the comparison of the simulation calculation index and SAE512[1] Aircraft Cabin Illumination standard index.
3. Lighting simulation process

The accuracy of cabin lighting simulation calculation is based on the establishment of a complete virtual aircraft environment. The virtual aircraft environment established by cabin lighting simulation mainly includes an accurate 3D aircraft model, the optical model of the real lamp or the optical model modified based on the real lamp, an optical model of the material surface, and a detailed cabin layout. Cabin lighting simulation calculation is mainly composed of two parts: cabin lighting index simulation and optical simulation based on human visual model. Usually, after the compliance verification about Comparison between simulation results and standard of cabin lighting index, the subsequent cabin visual ergonomics evaluation analysis is carried out. If the requirements cannot be met, it is necessary to determine the design problem through the ray trajectory reverse tracking method in the simulation, and re-optimize the cabin design. Aircraft lighting environment simulation process is shown in figure 3 below.

![Figure 3. Process of Lighting Environment Simulation](image-url)
4. Cabin lighting simulation

4.1 Cabin lighting modeling

4.1.1 Cabin light source modeling. The purpose of cabin light source attribute modeling is to provide close to real light source attributes for cabin simulation. The light source attribute model is usually in the '.IES' format. This description method is proposed by the Illuminating Engineering Society of North America, which describes the light intensity distribution of the light source in space. For the existing lighting equipment, the light track is usually used to test the light intensity distribution of the real lighting equipment, and the IES file is generated to ensure the consistency of the simulation data and the real lighting equipment, so as to ensure the reliability of the optimization verification; for the development of new aircraft, create the IES file, or use the IES file of existing lamps to adjust, can realize the light source modeling. After that, new design requirements can be put forward for the research and development of lamps through the simulation results. This simulation is modified on the IES file of the existing lamps, and finally generates a light intensity distribution IES file suitable for cabin lighting as shown in figure 4.

![Real Washlight IES file](image)

**Figure 4. Real Washlight IES file**

4.1.2 Cabin Material Lighting module. The material optical property model is'.BSDF'[2]and'.BRDF'[3] format model, BSDF (Bidirectional scattering distribution function) bidirectional scattering distribution function. This description was proposed by Paul Heckbert in 1991 to characterize the optical scattering properties of the object surface. In the calculation of reflected light, the default is that the object does not have light transmittance, so only the BRDF function is used to indicate the light properties of a certain material. The geometric relationship of BRDF is shown in Figure 5 below. The BRDF model usually builds shaders directly in CATIA to achieve rapid application. The properties of BRDF are measured using test equipment with integrated functions to measure various material samples used in the real cabin, usually including cabin plastics, aluminum, leather, textiles, and composite materials, painting, filming, etc. to ensure the true reflection of the material in the simulation. The figure 6 below shows the BRDF properties of a certain blue seat fabric used in the cabin.

The BRDF function relationship is as follows:

\[
BRDF(\theta_1, \varphi_1; \theta_o, \varphi_o) = \frac{dL_o(\theta_o, \varphi_o)}{dE_i(\theta_1, \varphi_1)}
\]

![BRDF axis](image)

**Figure 5. BRDF axis**
Radiance (LO) is the radiant flux per unit area and unit solid angle along the radiation direction, and the expression is:

$$L_O(\theta_O, \varphi_O) = \frac{dL\Phi_O(\theta_O, \varphi_O)}{dA \cdot \cos \theta_O d\omega_O} \quad (2)$$

Radiance (LO) is the radiant flux per unit area and unit solid angle along the radiation direction, and the expression is:

$$E_t = \frac{d\Phi_t(\theta_t, \varphi_t)}{dA} \quad (3)$$

d\Phi is the unit radiant flux, dA is the small facet of the reflecting surface, d\omegaO and d\omegaI are the solid angle elements, \thetaO and \thetaI are the elevation angles of the reflected light and the incident light, \omegaO and \omegaI are the azimuth angles of the reflected light and the incident light.

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4.2 Cabin lighting simulation

According to the process shown in Figure 3, the virtual aircraft cabin shown in Figure 7 is established, and the lighting scene in the 30% brightness mode is simulated. The simulated light source is the main cabin lighting IES, and the interior materials include side wall film, luggage, ceiling film and carpet which color chosen from MIL-STD-595C[4]. After completing the digital simulation, the average value of the aisle floor luminance between the third and fourth rows is 76.1657lx. It is verified by simulation that in the 30% brightness mode, the cabin luminance index meets the minimum requirements of SAE ARP512 for the cabin aisle area in Annex A. After completing the lighting index verification, the engineer completed the cabin human visual simulation. From the simulation results, it can be found that there is no obvious shadow on the side wall of the cabin. Therefore, it is verified that the partial light occlusion of the seat back will not have a significant impact on the cabin lighting.
After completing the simulation verification, the design team built a real cabin environment sample section based on ARINC825[5] BUS control. At the same time, in order to verify the rationality of the lighting design on the sample section, the testers adjusted the lighting to the 30% brightness mode. There were 6 random test points on the cabin floor in the third row and the fourth row to measure with an illuminance meter, and obtained 6 recorded values of 86.2lx, 85.9lx, 84.8lx, 77.7lx, 74.3lx, 58.2lx, and the arithmetic average was 77.9lx, the original The record is shown in Figure 8 below. It can be easily seen that in the 100% brightness mode, the cabin illuminance index can reach 200lx nearly, which meets the minimum requirements for the cabin aisle area in SAE ARP512 [1] Annex A, which proves the rationality of the cabin lighting design.

What is more, the actual test index is very close to the index 76.1657lx obtained by the simulation, which also proves the reliability of the lighting simulation from the side.
5. Conclusion
This article summarizes the design ideas and methods of cabin lighting, and proposes considerations related to cabin lighting design, and forms the result of cabin lighting design according to the design ideas. At the same time, this paper carried out simulation design verification on the cabin design results, and finally carried out index verification on the real samples, which showed the correctness of the cabin lighting design ideas and methods, proved the rationality of the cabin lighting design results, and proved it from the side. Under the conditions of simulation modeling based on the actual measurement data of the cabin, the consistency between the simulation verification results and the final physical verification results provides a certain basis for the feasibility of further civil aircraft cabin lighting airworthiness verification under virtual environment conditions in the future.

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