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Evacuation Assessment of Cabin Occupants in Luxury Cruise Under Fire Condition

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Abstract

To assess the evacuation safety of occupants in luxury cruise cabins under fire condition, FDS is used to simulate the fire condition of cabin layers while the fire-fixed fire-fighting facilities fail to work. The Available Safe Egress Time (ASET) is taken by the time when the smoke visibility, temperature and CO volume fraction of human eye feature height reach the critical value. Then, Pathfinder is used to simulate the evacuation of occupants in the cabin layers, and the safety results of occupants evacuation are evaluated in conjunction with the simulation results of FDS. Finally, the previous evacuation route is optimized, and the Required Safe Egress Time (RSET) of occupants under the optimized evacuation route is obtained by Pathfinder. The results show that in the original evacuation scene, the occupants are trapped in the stairs due to the effect of smoke. Optimizing the evacuation route of occupants above the fire layers are necessary. Occupants can complete safe evacuation within the available safe egress time while the evacuation route is optimized.

Keywords

Luxury cruise fire; Cruise occupants evacuation; Safe egress time; FDS+Pathfinder.

1. INTRODUCTION

The severity of ship fire consequences has been extensively studied by many researchers [1, 2]. The research works on ship fires mainly focuses on ship engine room fires [3-5], and a small amount of literature focuses on ship cabin fires [6, 7]. However, the cabin of the ship is densely populated, with many combustible materials and complicated decoration materials. After the fire, a large amount of toxic fumes is easily generated, which will seriously threaten the safety of occupants. It can be seen that the researches on fire in the cabin of ships are equally important.

When a fire broke out in the ship's cabin, the spread of smoke will affect the evacuation of occupants. However, in the previous research works, few literature have combined the study of ship cabin fire and personnel evacuation, and more have been done in isolation [6-10]. However, when a fire occurs, occupants must choose or change the evacuation route according to the actual situation, otherwise they will accidentally enter the dangerous area during the evacuation process, so it is necessary to combine the two to conduct research [11,12]. The article takes the cabin of a large luxury cruise ship as a research object, FDS was used to build a cabin fire model of a luxury cruise ship, the critical situation of smoke in the evacuation stairs was analyzed, the critical time of each monitoring indicator(visibility, CO concentration, temperature) was determined. The minimum of the three is used as the Available Safe Egress Time (ASET). Then, Pathfinder was used to calculate the evacuation time of the model, combining FDS simulation results to find the location points in the original evacuation scene that are not conducive to evacuation, and Pathfinder was used again to re-plan the evacuation

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route for occupants to get the final safe evacuation time to get the Required Safe Egress Time (RSET). Finally, the evacuation safety of the occupants on board is evaluated based on the simulation results, and the fire safety strategy of luxury cruise ships in specific fire scenarios is given.

2. MODEL ESTABLISHMENT AND PARAMETERS SETTING

2.1. Actual Parameters of the Original Luxury Cruise Ship

The large luxury cruise ship "Mariner of the Seas" has a total tonnage of 138,300 tons, a total length * full width * full height = 310m * 48m * 58m, with a capacity of 3732 passengers and a total of 1,555 cabins. The cabins are concentrated on the 6th to 10th floors, each with an area ranging from 20-40m2, the height of the each cabin is 3m, the height of the corridor is 2.1m, and the width of the corridor can be passed by two people side by side.

2.2. Establishment of the Fire Model

According to the actual situation of "Mariner of the Seas", FDS was used to build a luxury cruise fire model as shown in Figure 1: The location of the fire source is in the sixth-floor cabin close to Area 1, and the model has four stairs that run through 6-10th floors. Only the sixth floor was established and the specific parameters setting were as follows:

Setting of fire source: according to previous research results [13], the flammable materials (bedding, mattresses, curtains, etc.) in the cabins are simplified. The fire source power is 2.0MW and the burning surface size is 1m × 1m;

Grid division: considering the calculation accuracy and calculation efficiency at the same time, the grid size is set to 0.3m × 0.3m × 0.3m;

Firefighting facilities: it is assumed that the fixed firefighting facilities on the cruise ship have all failed to work;

Environmental conditions: normal temperature and pressure, wind speed is 0m/s, all cabin doors are closed;

Simulation time: setting to 1200s.

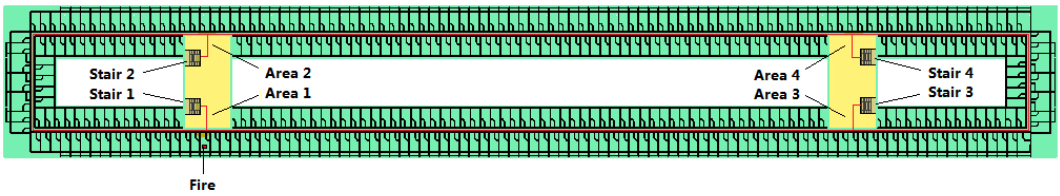

Figure 1. Fire model of the luxury cruise ship

2.3. Establishment of the Evacuation Model

According to the actual situation of "Mariner of the Seas" and the fire model in 1.2, a 6th to 10th floor occupant evacuation model is established as shown in Figure 2. Among them, there are 800 occupants to be evacuated on each of the 6th to 9th floors, and 600 people to be evacuated on the 10th floor; The occupants on the cruise are composed of men, women and children, the number ratio is 10: 7: 3; the speed of movement is 1.2m/s, 1m/s and 0.8m/s. The occupants are evacuated along the red route in Figure 1 through 4 stairs, and exiting from the 6th stair is considered to be evacuated.

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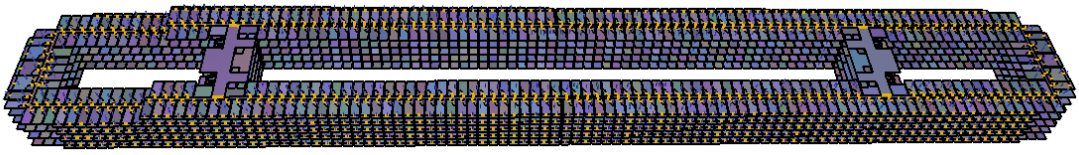

Figure 2. Evacuation model of the luxury cruise ship

3. ANALYSIS OF SIMULATION RESULTS

FDS was used to simulate the fire on the cabins of the cruise ship, the CO concentration, the temperature of the smoke layer and the visibility value was obtained at the characteristic height of the human eye. The minimum value is regarded as the Available Safe Egress Time (ASET); Pathfinder was used to simulate the evacuation of cruise occupants, and the total time for evacuation of passengers on board the ship was obtained, which was regarded as the Required Safe Egress Time (RSET). Comparing ASET with RSET, the evacuation safety of the cruise occupants is obtained, so as to evaluate the fire danger and corresponding measures of the cruise ship.

3.1. Analysis of FDS Results

Because the sixth stairs is the place where personnel evacuation must pass through from the 6th to 10th floors, the time it takes for the monitoring indicators of the sixth stairs to reach the limit that the person can withstand is used as the Available Safe Egress Time for the occupants. The monitoring equipment is set at the entrance of the stairs on the 6th to 10th floors and at the entrances of areas 1, 2, 3, and 4 to monitor the changes in the CO concentration, the temperature of the smoke layer, and the visibility value at a height of 1.6m above the ground.

Combined with Smokeview to monitor the development of cruise fires on the cabin level and the spread of smoke: The SOLAS Convention stipulates that "on passenger ships, all linings, windshields and ceilings shall be non-combustible materials, except in the cargo spaces, mail compartments, luggage rooms, sauna rooms or refrigerated outdoor spaces of service spaces." Therefore, when a cabin catches fire, the fire generally only spreads to adjacent areas through doors and windows, and rarely spreads through walls and ceilings. Here we study the situation where the doors and windows of the remaining cabins are closed. At this time, the fire smoke spreads through the fire compartment to the corridor and then to the left stairwell. Figure 3 shows the distribution of smoke at the end of the simulation. Smokeview shows that the smoke has covered the left area of the left stairs in about 300s, and between 300s and 1200s, the spread of smoke along the corridor to the right is not great, mainly due to the chimney effect when the smoke spreads up to the other floors on the left stairs. The temperature and density difference between the smoke and the air in the stairs makes the smoke spread along the stairs to the remaining floors [14]. The chimney effect also has a certain drainage effect on the horizontally spreading smoke, which prevents the smoke from spreading to the right, so it does not pose a threat to the right stair of the cruise ship.

Figure 4 shows the visibility, CO concentration, and smoke temperature values at 1.6m in each area of the evacuation stairs on the left side of the sixth floor of the luxury cruise ship. From Figure 4 (a), it can be clearly seen that the visibility at the entrance of Area 1 and Area 2 drops to a critical value of about 10m at about 110s. At this time, occupants on the sixth floor can only evacuate through the evacuation stairs on the right, but it will not affect evacuation of upper occupants; At around 150s, the visibility of Stair 1 and Stair 2 also dropped to a critical value of 10m. At this time, occupants who have not completed evacuation on the left need to transfer to the right stairs for evacuation. Figures 4 (b) and (c) show that the CO concentration and

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temperature at 1.6m in each area of the left stairs of the sixth floor did not reach the critical value within 1200s.

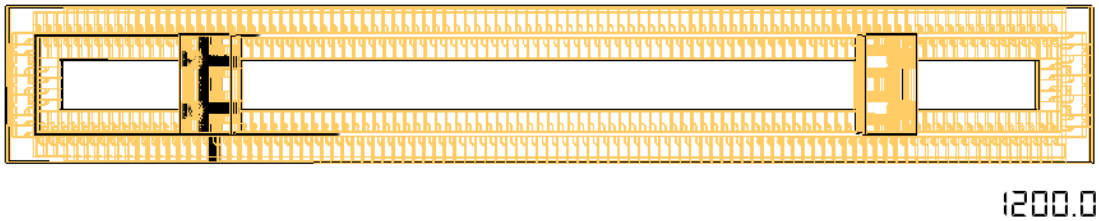
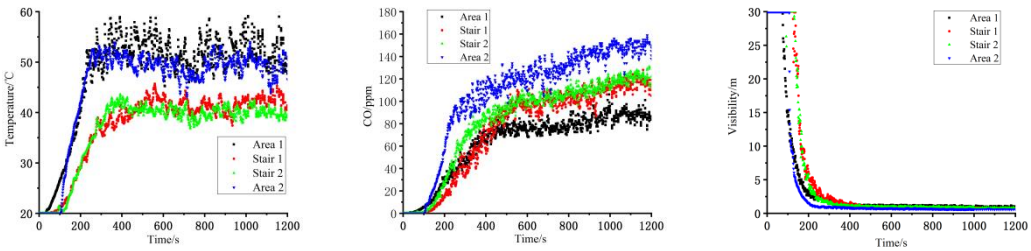


Figure 3. The spread of smoke at 1200s

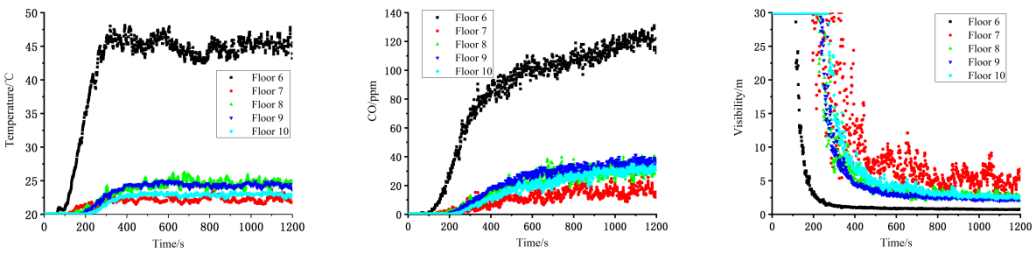


Temperature (b)CO Concentration (c)Visibility

Figure 4. Changes of monitoring indicators of the left stair on the sixth floor

According to the monitoring indicators in Figure 4, it is not difficult to find that the changes in stair 1 and stair 2 are close to the same. Therefore, when observing the changes in the visibility, CO concentration, and smoke temperature of the evacuation stair on the 6th to 10th floors on the left, only consider stair 1 and the corresponding stair on each floor above. Figure 4 shows the changes in the monitoring indicators of the left stairs on the 6th to 10th floors of the luxury cruise ship: The CO concentration and temperature on all floors have reached critical values. What really threatens the evacuation of occupants is visibility. According to Figure 5 (a), the visibility curve on the sixth floor is relatively stable, and the curve on the seventh to tenth floors fluctuates greatly. This is due to the smoke spreading up the stairs after the accumulation on the sixth floor. The time when the visibility of the left stairs on the 6th to 10th floors reaches the critical value is 150s, 286s, 294s, 288s, 342s respectively.

Using Smokeview to observe the spread of smoke on the sixth floor, it was found that in 1200s, the smoke would not spread to the stairs on the right side of the luxury cruise ship. Therefore, the specific time when each monitoring indicator of the luxury cruise ship reaches the critical value is shown in Table 1.



(a)Temperature (b)CO Concentration (c)Visibility

Figure 5. Changes of monitoring indicators of the left stairs on the 6th to 10th floor

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Table 1. Time when each monitoring indicator reaches the critical value

Monitoring area	Visibility critical time /s	CO concentration critical time/s	Temperature critical time/s
Stairs on the left side of the sixth floor	150	>1200s	>1200s
Stairs on the right side of the sixth floor	>1200s	>1200s	>1200s

3.2. Analysis of Pathfinder Results

Considering the fire situation encountered during the evacuation process, combined with the simulation results of FDS, the evacuation model was set to close the entrance of Area 1 and Area 2 on the sixth floor of 110s, and the occupants on the sixth floor could not enter the left stairs, only turn to the right stairwell to complete the evacuation. At 150s, the exits of Stair 1 and Stair 2 on the sixth floor are closed, and the occupants on the 7th to 10th floors cannot enter the stairs and can only turn to the right stairs for evacuation. The simulation results show that the evacuation time for all occupants on the cruise is 1016s. However, based on the FDS simulation results and the 3D view of Pathfinder, it's not difficult to found that when the visibility on the left stairs dropped to the critical value, a large number of occupants remained in the stairs for evacuation. As shown in Figure 6.

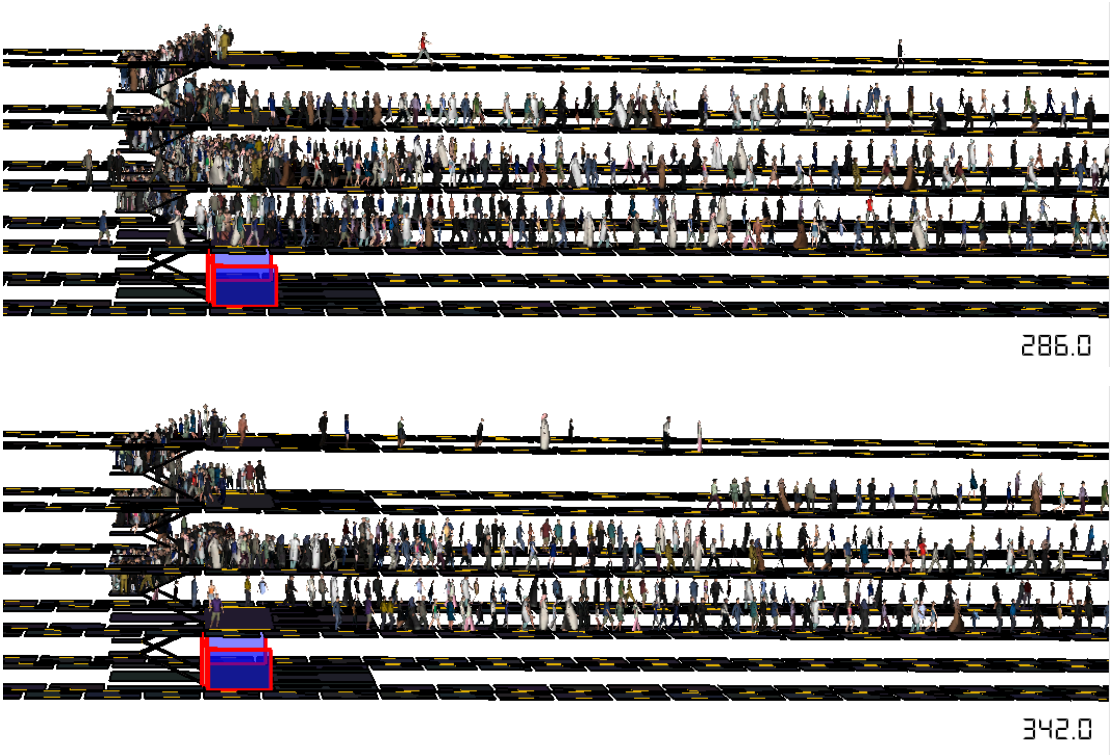

Figure 6. Detention of occupants when reached the critical time

Combined with Pathfinder 3D view, the reasons for the occupants' detention were analyzed: at 150s, the exits of Stair 1 and Stair 2 on the sixth floor are closed. At this time, the evacuation occupants on the left can only go up the stairs to the nearest floor and evacuate through the stairwell on the right side of the cruise ship. The upper-level occupants did not realize the situation and continued to evacuate downwards, resulting in crowded and detention in the stairs. Table 2 shows the comparison of the Available Safe Egress Time (ASET) and the Required Safe Egress Time (RSET) of the trapped occupants on the 7th to 10th floors.

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Table 2. Comparison of ASET and RSET on the 7th to 10th floors of the left stairwell

Time/s	Floor 7	Floor 8	Floor 9	Floor 10
ASET	136s	144s	138s	192s
RSET	385s	373s	353s	360s

It can be seen from Table 2 that the length of detention of the stairs on the left is about 385s, and the occupants left the stairs completely at about 535s. However, due to the spread of smoke, the visibility of the entire left stairs dropped to a critical value of 10m at about 342s, hindering the evacuation of occupants. In this situation, it is easy to cause panic and stepping accidents.

In view of occupants safety considerations, to ensure the safe evacuation of occupants, in addition to taking measures to suppress the development of the fire or prevent the spread of fire smoke to the stairs, it is also possible to achieve safe evacuation by changing the evacuation route of the occupants. The reasons for the detention of occupants in the stairs have been analyzed above. The evacuation situation in this case is optimized as follows: all floors above the fire floor are evacuated through the stairs away from the ignition point, that is, the sixth floor can be evacuated through the left stairs within 150s, and after 150s, they can be evacuated to the right stairs; occupants on 7th to10th floors are all evacuated through the stairs on the right. According to Pathfinder's 3D view, it can be found that when the visibility of the left stairs on the 286s falls to a critical value, there are no more occupants to be evacuated in the left stairs, so there is no threat to occupants. The evacuation time after the improvement is 1126s.

$$TREST = Tperc + Tresp + Tmove \tag{1}$$

In the formula: Tperc is the occupants perception time, and Tresp is the occupants response time time. Refer to the existing researches,taking both values for 30s.

Combined with formula (1), the final value of RSET is 1186s. With reference to Figure 8, the improved evacuation model has evacuated about 300 occupants in the first 150s compared with the improved model, After that, more than 300 occupants merged into the evacuated crowd on the right stairs, but according to the curve change in Figure 7, it did not have a significant impact on the evacuation on the right. Although the optimized solution increases the evacuation time, it still meets TREST < TAEST, that is, after the evacuation route is optimized, all occupants can complete the safe evacuation within the available safe egress time.

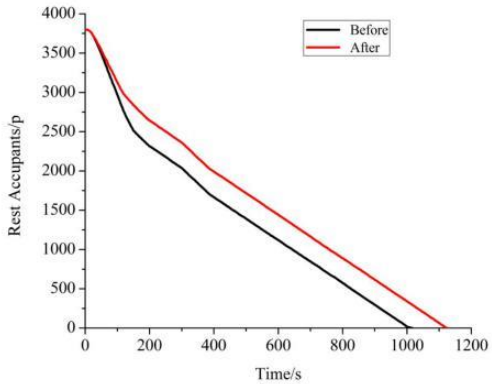

Figure 7. Changes of the number of occupants to be evacuated before and after the improvement of the evacuation model over time

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3.3. Assessment of the Evacuation Safety

Taking into account the most dangerous scenario of a cruise fire: fire protection facilities have all failed to work, and the ignition point is close to an evacuation stair. If occupants on the upper floors close to the ignition point still evacuate through the stairs close to the ignition point, the occupants will be easily trapped in the stairs, and the occupants on the upper floor will not be aware of the situation and continue to evacuate downward, resulting in congestion, detention or even stomping in the stairs.

In this case, it is suitable to use stairs near the ignition point to evacuate some occupants on this floor in a short time. The occupants on the upper floors are not suitable for evacuation through these stairs, and must be guided by cruise staff to evacuate through the stairs away from the ignition point.

4. CONCLUSIONS

Considering the failure of all fire-fighting facilities of luxury cruise ships, setting up fire scenario under the most dangerous conditions, the results obtained by FDS simulation, taking the actual situation of occupants evacuation at the time of a fire into account, rationally planning the path of occupants evacuation using Pathfinder, and the fire safety strategies of luxury cruise ships in specific fire scenarios are given.

The stair close to the fire source will be covered by smoke in a short time, and the visibility will be reduced below the critical value first, and then the smoke will spread through the stairs to the upper floors, affecting the people to be evacuated in the stairs;

The smoke spreads up through the stairs very fast. In order to prevent the occupants above the fire floor from being trapped in the stairs due to the effect of smoke, the guidance of the staff is needed, that is, all occupants above the fire floor are supposed to be evacuated through stairs away from the ignition point.

Occupants above the fire floor were guided to the stairs away from the ignition point for evacuation, which increased evacuation pressure on the side stairs, but despite this, the evacuation efficiency of the whole ship was not greatly affected, and was almost consistent with the efficiency before the evacuation model was improved.

In the simulation, only the power of the fire source of 2KW is considered. In actual situations, the clothes carried by passengers will also increase the number of fire loads in the cabin; In addition, due to the limitation of the simulation conditions, the spread of smoke through the stairs to the areas outside the stairs on the upper floors is not considered. These contents need to be further improved in future work.

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