Numerical simulation of thermal environment in 320,000 tons VLCC engine room

Anqi Niu¹, Mingxuan Guo¹, Jianli Wang¹, Meiqi Chen¹, Guoliang Jin¹, and Shenghai Wang*¹

¹Ship Mechatronics Laboratory, Dalian Maritime University, Dalian, LiaoNing, 116026, China
*Corresponding author’s e-mail: shenghai_wang@dlmu.edu.cn

Abstract. The engine room is the power center of the ship, including the main diesel engine and many other equipment, to maintain the stable operation of equipment in the engine room, to provide a comfortable working environment for the crew. The temperature and humidity in the engine room must reach a certain standard. There are ventilation systems in the engine rooms of ships, but we don't have a good way to direct the layout of the ventilation system.

This paper takes 320,000 tons of VLCC as an example, uses FLUENT software to numerically simulate the temperature field and velocity field in the engine room, obtains the temperature distribution of the entire engine room, analyzes the simulation results, and proposes a ventilation layout optimization plan. Finally, the full text is summarized and the plan for further research is discussed.

1. Introduction

The engine room of a ship is the heart of the entire ship. It includes a variety of mechanical equipment such as main diesel engine, auxiliary machinery, boilers and pumps. It is the power center and power center of the entire ship. Therefore, ensuring the stable operation of the equipment in the engine room is an important condition for ensuring the normal operation of the ship. The main equipment, such as main diesel engine and auxiliary diesel engine, emit a large amount of heat into the engine room due to heat radiation during operation, and various tanks and steam pipes in the engine room also emit a large amount of heat at the same time, which will cause the temperature in the engine room to rise. Due to the uneven distribution of the heat source, the temperature distribution in the engine room has a larger gradient, the temperature near the heat source is higher, and the temperature at the non-heat source is lower.

The high temperature in the engine room will reduce the air density and the amount of air entering the cylinder, which will result in insufficient combustion of the diesel engine, which will have a great impact on the speed, and sometimes lose about 10% of the propulsion efficiency. Generally, the air inlet temperature of the diesel engine supercharger is required to be 45-50 °C. As the temperature changes, the accuracy and sensitivity of the instrument will be greatly affected, or even fail[1-2].

Both the VLCC and 45,100-ton bulk carriers of our factory had the problem of high engine room temperature during the trial voyage. Generally, they were solved by increasing the fan, but the effect of reducing the engine room temperature was not obvious. There is currently no better way to judge the engine room. The reason for the high internal temperature, Therefore, it is hoped that the method of numerical simulation can be used to improve the design means, find out the reasons for the high temperature in the engine room, and propose corresponding solutions. By changing the ventilation
effect and arranging the location of the equipment, the ventilation effect in the engine room is improved, and the temperature in the engine room is reduced to provide a good working environment for the crew.

Using finite element numerical simulation technology, the temperature field and velocity field of the entire engine room space can be simulated, which provides a basis for studying the ventilation performance of the engine room and optimizing the ventilation design scheme [3-4].

2. Materials and Methods

2.1. Establishment of finite element model
This paper is based on the 320,000-ton VLCC built by Bohai Shipyard as the research object, and uses NAPA STEEL to establish a three-dimensional model of the engine room, equipment and ventilation ducts. Import the 3D model into ANSYS for meshing. Calculate after setting the boundary conditions and parameters in FLUENT.

The main heating equipment of the engine room includes main diesel engine, auxiliary diesel engine, main air compressor, miscellaneous air compressor, oil-fired boiler, fresh water cooler, lubricating oil cooler, condenser, oil pump, sea water pump, fresh water pump, water tank ballast water treatment equipment, etc.

In order to calculate the results accurately, it is necessary to approach the real object as much as possible when modeling. If the amount of modeling is too large and complicated, the meshing is also troublesome, so the necessary simplifications should be made when modeling. Regardless of the pipes in the engine room, the shape of the equipment should be as close as possible to regular shapes such as cylinders and cuboids.

2.1.1. Air duct modeling
The air duct model is modeled completely according to the actual size. As shown in figure 1 the four main air ducts are only built to the height of the first floor of the building, and the fan is not built. Add the air supply volume of the fan at each air inlet during calculation.

![Figure 1. Three-dimensional model of the air duct in the engine room.](image)

2.1.2. Modeling of main heating equipment
This paper has carried out necessary simplifications on the main heating equipment. For example, the diesel engine is only built into a cuboid, and the motor is built into a cylinder, which facilitates the subsequent meshing. Regular grids are more efficient and easy to converge in finite element calculations as shown in figure 2.
2.1.3. Meshing
This calculation model is meshed in ANSYS. When meshing, it is necessary to consider the impact of mesh accuracy on the calculation results and the requirements of computer mesh accuracy on computer memory. Due to the irregular structure of the model itself, a deformed grid will be generated when the grid is divided, which will directly lead to non-convergence of the calculation. The model built by NAPA STEEL cannot be directly meshed when imported into ANSYS. Because NAPA STEEL’s model is a surface element, FLUENT cannot use this element to calculate, so we have to import the model into the DM software for geometric repair. Then import it into ANSYS to mesh. The finite element model of the engine room and the finite element model of the ventilation pipe are shown in figure 3.

2.2. Setting of boundary conditions Determination of thermal load of main equipment
The main factors affecting the thermal environment in the engine room are the injection and flow of air and the heat dissipation of the main equipment. The temperature of the main diesel engine, diesel generator, oil tank, etc. In the engine room should be higher than the temperature of the air in the engine room, and the temperature of the sea water pipeline should be lower than that of the air in the engine room. There are many equipment pipelines in the engine room and the temperature and heat dissipation are not the same, resulting in a huge workload when setting the boundary conditions. Diesel generators and boiler air inlets absorb air from the engine room, and the intake amount varies with different working conditions. The heat dissipation of equipment also varies with different
working conditions. For the convenience of calculation, we take the rated working conditions of the equipment.

In the model, the platform, bulkhead, and the outer surface of the equipment are all set as wall surfaces, the upper ends of the four main air ducts are set as air inlets, each small air hole is set as air outlets, and the top of the engine room shed is the hot air outlet. The air supply volume of each main road is 24.44 kg/s, the supply temperature in summer is 27℃.

2.3. formula

2.3.1 The heat dissipation of the main diesel engine and auxiliary diesel engine [5]

The calculation formula of main diesel engine heat dissipation is as follows:

$$q_d = P_d \cdot L_d$$  \hspace{1cm} (1)

Where:
- \( q_d \) -- Diesel engine heat dissipation, kW;
- \( P_d \) -- Shaft power at maximum continuous power of diesel engine, kW;
- \( L_d \) -- Diesel engine heat loss.

2.3.2. Heat dissipation of the alternator

The formula for calculating the heat dissipation of the alternator is as follows:

$$q_g = P_g \cdot (1 - \eta)$$  \hspace{1cm} (2)

Where:
- \( q_g \) -- Heat dissipation of air-cooled alternator, kW;
- \( P_g \) -- Power of air-cooled alternator (except for standby generators), kW;
- \( \eta \) -- The efficiency of the alternator, it is calculated as \( \eta = 94\% \).

3. Engine room ventilation simulation

3.1. Model assumptions

Due to the complicated equipment layout, air flow and heat transfer in the engine room, we have to make some assumptions to make the calculation problem simple:

a. Assuming that the temperature of the air is constant and the relative humidity of the air is not considered.

b. The operating conditions of the equipment in the engine room refer to the normal operating conditions of the ship at sea.

c. The air flow in the engine room is set as an incompressible steady state flow, and the air density is assumed to be constant.

d. The influence of oil, gas and dust on the physical properties of the air is not considered.

e. The loss of wind pressure in the air duct is not considered.

f. The heat dissipation of the pipeline is not considered.

3.2. Thermal analysis of summer conditions

The engine room is divided into four parts: the bottom of the engine room (7.9m from the baseline), the first deck (13m from the baseline), the second deck (21m from the baseline) and the third deck (28m from the baseline).

Numerical simulation analysis of the entire engine room was carried out for the summer environment. The analysis found that the air flow effect in the engine room was poor, the air flow at the bottom of the engine room was relatively weak, the air supply was insufficient, and the engine room design temperature was too high. The temperature in the bottom of the engine room (7.9m from the baseline), the first deck engine room and the area between the second deck are significantly higher. There are dead zones for air flow at the bottom of the engine room and the first and second deck engine rooms. Cold air supply is a problem which leads to high temperatures in these areas. The temperature in the third and fourth deck areas is relatively good. Due to the high bottom temperature,
the highest temperature in the fourth deck area is also about 55°C. The crew will feel obviously uncomfortable. The average temperature of the fourth layer area is also obviously higher, which will also make the crew feel uncomfortable.

Figure 4. Summer temperature distribution of the section at 7.9m from the baseline.

Figure 4 shows the temperature distribution of the section at a height of 7.9 m from the baseline. The red area in the middle is the temperature of the device in the engine room. This device is the device with the largest heat generation in the engine room, so the temperature is relatively high. The temperature in other areas is affected by the ventilation effect. The influence is relatively low. Because the front of the engine room is far away from the heating components, the temperature is the lowest. Since there is no supply of cold air on the starboard side, the temperature in the engine room is very high. This requires a corresponding amount of cold air to be provided to the area during the design process. In order to analyze the temperature in the engine room, this example selected three points, shown as the yellow cross point position from figure 4. The temperature distribution of the three points is (shown from left to right) poin1=3.2072e+02 [K], poin2=3.3350e+02 [K], poin3=3.2499e+02 [K], it can be found from the temperature of three points that the bilge temperature is between 50-60°C, the human body will feel very uncomfortable. The ventilation effect needs to be improved.

Figure 5. Summer temperature distribution of the section at 13m from the baseline.

Figure 5 shows the temperature distribution of the section at a distance of 13m from the baseline. It can be clearly seen from figure 5 that the air flow line distribution in this layer is insufficient, so the heat exchange effect is not good. However, compared to figure 4, the ambient temperature in Figure 5 is still relatively better. The temperature in the area near the main diesel engine and the starboard side
is affected by the bottom tank and the main diesel engine, and the high temperature area is still relatively large.

Figure 6. Summer temperature distribution of the section at 21m from the baseline.

Figure 6 shows the temperature distribution of the section 21m from the baseline. Compared with figure 5, it can be found that the temperature in figure 6 is significantly reduced. The two high-temperature areas in the front are two heat-generating auxiliary equipment, which have a greater impact on the temperature of the entire area. The temperature in the middle area is relatively high because it is affected by the high temperature at the bottom. The temperature drop in the area is directly related to the larger air flow in the area, and the heat exchange effect in this area is significantly better than the heat exchange effect at the bottom. Four points are also selected in this section, shown in figure 6 as the position of the yellow cross point. The temperature distribution of the four points is (shown from left to right) poin4=3.0972e+02 [K], poin5=3.1343e+02 [K], poin6=3.4779e+02 [K], poin7=3.3821e+02 [K], it can be found from the temperature of the four points that the temperature in the middle area is still high, and the human body will feel uncomfortable. The temperature in the border area has been reduced, but it is still between 30-40 ℃ and needs to be further reduced.

Figure 7. Summer temperature distribution of the section at 28m from the baseline.

Figure 7 shows the temperature distribution of the section 28m away from the baseline. From the figure, we can see that the maximum temperature in this area is 55 ℃. The temperature is higher and the human body will obviously feel uncomfortable. This area is located in the red area of the graph. The temperature in other areas is lower, which is related to the lack of more heat-generating equipment in this area and the good ventilation effect in this area.
4. Results & Discussion
From the above simulation results, it can be found that the summer engine room temperature of this ship type is too high, which is not conducive to crew operations and needs improvement. According to the results of the numerical simulation analysis, it can be found that the bottom of the bilge is obviously insufficient in air flow, and the air cooling effect is not good. It is necessary to increase the bottom air volume and flow effect. The cooling air supply is obviously insufficient, and the bottom air supply needs to be supplemented. The air supply near the fourth deck can basically meet the requirements. This shows that the total air flow can basically meet the actual cooling requirements at present. The only problem is the insufficient bottom supply capacity.

5. Conclusions
The research on this subject has the following conclusions in future work:
1. Study how to simplify the engine room model to make the calculation results closer to the actual ship, and how to determine the accuracy of equipment heat release rate and other parameters;
2. Consider the influence of hot air buoyancy drive on air flow;
3. Optimized design for local ventilation. Calculate several local vents to see if the streamlines are uniform, and adjust the position and angle of the vents to optimize the design according to the calculation results;

Acknowledgments
This paper thanks colleagues for their help or encouragement.

References
[1] Yu X X, Sun P T, Xia Z F, et al. (2004) Natural ventilation for engine room on ship. Journal of Dalian Maritime University, 02:23-25.
[2] Dong Y P. (2003) CFD simulation and study on air-conditioning in large space building. Tianjin university.
[3] Zhao B, Li Y, Li X T, et al. (2000) Numerical Analysis and Improvement of Air Flow Pattern for The Great Hall of the People. Building thermal energy ventilation and air conditioning, 04: 5-8.
[4] Murakami S, Kato S, Nakagawa H. (1997) Numerical Prediction of Horizontal Noniso thermal 3-D JetinRoom Basedon the Model Transfer. 01:38-48.
[5] Zhou S. (2010) The numerical simulation of internal thermal environment of marine diesel engine room. Dalian Maritime University.