Analysis of Flow Field Characteristics of Unequal Distance Fans

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Abstract. This paper establishes the simulation model of the unequal-distance fan, obtains the details of the flow field when the fan works by CFD simulation method, and analyses the internal flow field characteristics of the unequal-distance fan from three aspects: streamline trace distribution, pressure distribution and velocity distribution, so as to get the working condition of the fan, which is of great significance for the design and transformation of the fan structure.

1. Introduction
With the rapid development of China's economy, people's living standards and consumption levels have been significantly improved, which makes buyers put forward higher requirements for ride comfort and NVH performance. Under the condition of high-speed driving, the noise of engine mostly comes from the noise of cooling fan[1]. The low performance of cooling fan will affect the heat dissipation effect of engine, resulting in the decrease of engine efficiency and the increase of emission. Therefore, for the sake of environmental protection and energy saving, the major automotive factories require automotive parts manufacturers to carry out research and development of cooling fan technology to produce high-performance engine cooling fans with high efficiency, low noise and low energy consumption as far as possible[2].

An automobile cooling fan will be tested after it is manufactured. Whether the performance index of the fan meets the requirements can be verified by the performance experiment of the fan. Flow field is an important parameter to test the aerodynamic performance index[3]. Yong Cho et al.[4] calculated the unsteady viscous flow field of cross-flow fan by solving two-dimensional incompressible Navier-Stokes equation with unstructured triangular mesh algorithm. By calculating the performance and aerodynamic noise of the variable pitch cross flow fan, it is found that the A-type random pitch impeller can adjust the frequency of the rotating noise passing through the blade, which reduces the BPF noise by 5.7 dB compared with the equidistant fan. In recent years, with the widespread use of computers, computational fluid dynamics (CFD) has developed rapidly based on numerical simulation methods out of fluid theory. The application of CFD method to the performance noise analysis of cooling fans can accurately simulate the dynamic flow field of fans, and obtain more detailed flow field than the experiment. Through the display of computer windows, researchers can understand the flow field characteristics of fans more intuitively.

The main idea of numerical calculation of flow field is to discretize the control domain by using finite volume method and to solve each element after discretization. At present, the two main solutions are separated solution and coupled solution.
The fan is a typical rotating machine[5] and the blade rotation is unsteady flow. The performance simulation of the fan at constant speed can be carried out by using the multiple reference system method. The MRF model can transform the unsteady rotating problem into the steady rotating problem, that is, the dynamic reference system is used in the rotating region around the fan, and the static reference system is used in the other regions of the fan.

In this paper, the fan aerodynamic performance test is carried out on the C-type duct test rig[6]. Firstly, the geometric model of the fan and the flow field model of the fan test pipeline are established, and then the model is meshed. After setting the relevant parameters of the model, the simulation calculation is started to get the flow field of the unequal-distance fan. According to the streamline trace distribution, pressure distribution and velocity distribution, the internal flow field characteristics of the unequal-distance fan are analyzed, and then the work condition of the fan is obtained. That is of great significance to the design of the fan structure.

2. Analysis of results of fan flow field characteristics:
Streamline describes the curve of velocity vector at a certain time in the flow field. The velocity direction of a point on the streamline is tangent direction. The streamline is continuous and disjoint. The trajectory of particles in the flow field is described by the trajectory. The flow state of the fluid is independent of time under steady flow condition, so the streamline and the trajectory are coincident. As can be seen from figure 1, the flow line of the fluid in the duct model is basically consistent with the actual flow situation. The air flow in the inlet pipe is smooth. After passing through the cooling fan, the direction of the air flow changes from axial to radial, which corresponds to the cooling system and the outlet area of the pipe are directly connected to the engine. Therefore, such flow can reduce the impact of the fluid on the engine, reduce the drag of the fluid flowing through the engine, and reduce the aerodynamic noise of the system.

![Figure 1. Streamline of CFD pipeline model.](image)

The pressure distribution on the cooling fan surface needs to be analyzed in the internal flow characteristics. The pressure distribution includes the static pressure distribution, the dynamic pressure distribution and the total pressure distribution. The static pressure distribution on suction surface and pressure surface of an unequal distance fan is shown in figure 2. From the static pressure distribution nephogram of fan suction surface, it can be seen that the static pressure value of fan blade suction surface is small and increases from leading edge to trailing edge. Because the blade suction front edge and middle area are negative pressure and there is a reverse pressure gradient along the flow direction, the flow boundary layer is gradually thicker, suction surface retains a large number of low-energy distribution.
airflow, interaction forms eddy current, therefore, fan suction surface becomes an important source of aerodynamic noise.

From the static pressure distribution nephogram of the pressure surface of the fan, it can be seen that the static pressure distribution on the pressure surface of the whole blade is relatively uniform, and the different blades of the unequal distance fan are slightly different. The static pressure values of the blade tip and middle region are larger, which indicates that this is the main work part of the blade, the static pressure values of most blades near the blade root region are smaller, because the linear velocity of the blade root part is small [7]. Pressure surface static pressure is mainly positive pressure, and there is a pressure difference between pressure surface and suction surface, which leads to gas reflux, and has an impact on static pressure in the tip area of blade pressure surface. It is one of the main reasons for loss of static pressure efficiency of fan. Therefore, it is important to study the pressure distribution around fan for improving the design of fan structure.

![Static pressure nephogram of suction surface](image1)

![Static pressure nephogram of pressure surface](image2)

Figure 2. Cloud image of static pressure distribution of non-equidistant fans.

The dynamic pressure distribution on suction and pressure surfaces of unequal distance fans is shown in figure 3. The dynamic pressure of a small part of the middle of the suction surface of a blade is larger, and the maximum dynamic pressure of the suction surface generated in this area decreases gradually from the trailing edge to the leading edge, while the dynamic pressure of the leading edge and the area near the root of the blade is smaller. The distribution of the dynamic pressure of the blade pressure surface is not so uniform, the dynamic pressure value of the small part near the tip and the middle of the blade is larger, the dynamic pressure at the tip of the blade is the maximum, and the dynamic pressure of the small area near the root of the blade at the rear edge of the pressure surface is the smallest.
The total pressure distribution of suction surface and pressure surface of an unequal distance fan is shown in figure 4. The sum of static pressure and dynamic pressure is total pressure. From figure 4, it can be seen that the total pressure on the suction surface trailing edge of fan blades with different distances is positive, especially in the middle part to the tip part. The total pressure decreases from the middle to the front edge of suction until the total pressure at the front edge of the suction is negative. The distribution of total pressure on the blade pressure surface is relatively uniform, and the maximum pressure is generated in the tip part, and the minimum total pressure is generated near the blade root part of the blade trailing edge. The total pressure in the middle of the blade pressure surface is positive.

Velocity is also an important parameter in CFD simulation of fan flow field. The distribution of absolute and relative velocities on the pressure surface of an unequal-distance fan is shown in figure 5. Because the dynamic pressure of the fan is proportional to the square of the velocity, the velocity distribution on the pressure surface of the fan is the same as that of the dynamic pressure on the pressure surface. From figure 5, it can be seen that the velocity of the air flow in the blade root is relatively low, because the middle disc of the fan is closed and the air flow cannot pass through. The speed increases with the increase of the radial radius of the fan and reaches the maximum at the tip of the blade, which is due to the maximum rotational linear speed of the blade at the tip of the fan.
maximum radius. The fan blade velocity distribution shown in figure 5 is consistent with the actual flow field characteristics.

![Fan Blade Velocity Distribution](image)

**Figure 5.** Cloud map of velocity distribution of unequal distance fans.

### 3. Conclusion

This paper establishes the flow field model of fan duct test-bed and simulates the flow field characteristics of fan working by CFD method. The flow line of the fluid in the duct model is basically consistent with the actual flow. The gas flow in the inlet pipe is smooth. After passing through the cooling fan, the direction of the air flow changes from axial to radial. The static pressure value of the suction surface of the fan blade is small and increases from the leading edge to the rear edge. Static pressure distributes uniformly on the pressure surface of the whole blade, and there are slight differences among different blades of different-distance fans. Static pressure values of the tip and middle regions of the fan blade are larger, while those of most blades near the root regions are smaller. The dynamic pressure of a small part of the middle of the suction surface of an unequal-distance fan blade is larger, and decreases gradually from the trailing edge to the leading edge, while the dynamic pressure of the leading edge and the area near the blade root is smaller. The distribution of the dynamic pressure of the blade pressure surface is not uniform, and the dynamic pressure value of the small part near the tip and the middle of the blade is larger, which produces the maximum dynamic pressure at the blade tip, and the rear edge of the pressure surface is close to the blade. The dynamic pressure of a small part of the root area is the smallest.

### Acknowledgments

The authors wish to acknowledge the Fundamental Research of the Guangzhou Civil Aviation College (NO. 18X0431, 17X0413, 18X0433, 18X0417).

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