Analysis of the Axial Fan Performance Mounted on a 4.5kW Aviation Motor

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Abstract. Integrating an axial flow fan with the rotor is a sufficient cooling method for high-speed and high power density motors. Different from the axial fan design work under ideal intake condition, i.e. the intake flow of the fan is axial and uniform, the flow in actual engineering is more complex, which means the flow characteristics of an integrated fan are changed and disturbed. It leads to a performance penalty of the fan, and in some conditions it makes the fan stall, so it is important to get a knowledge of the flow characteristics and the performance of the integrated fan. A certain 4.5kW aviation motor with integrated axial fan is taken as the research object. Firstly, the motor-fan coupling simulation model and ideal axial intake simulation model are established, in which the mass flow rates are same, then calculation is conducted. Secondly, the simulation results are analyzed and compared, focusing on the performance of the axial fan, especially the static pressure rise, and the conclusion is obtained that the static pressure rise in ideal axial intake situation is higher than that in coupling situation. Furthermore, the reasons for the characteristics change are explored, finding that the increase of flow turbulence due to the more complex wind road structure is the main cause for these changes. This paper investigates the flow characteristics and axial fan performance mounted a whole motor, making a contribution to better understand the changes in fan performance under motor-fan coupling situation.

1. Introduction
With the rapidly development of UAV(unmanned aerial vehicle) industry, researches on aviation motor are also booming. The development tend of aviation motor is smaller size, lighter weight and higher power density, which puts a new requirement of more efficient cooling method. Meanwhile, integrating an axial fan with rotating shaft has become a popular way because of the high integration, good adaptability and high volume power density [1]. Generally, researchers take ideal axial intake environment as the condition when they carry out the axial fan design and its independent performance analysis [2,3]. The advantage lies in the fast simulation speed and simple model, but it usually means that the simulation result and actual result do not coincide with each other, so compensation is carried out by increasing the design index margin. In the case of integrating an axial fan with motor, considering the complex internal structure and fan rotating, the measurement work in actual engineering is difficult, so researchers always choose the simulation method to analyze the internal flow characteristics and fan performance [4]. To get the most accurate result, it is necessary to
construct the model highly similar to the actual motor structure, if we still use the ideal axial intake model, there will be a deviation. At present, there are few researches working on the flow field characteristics and fan performance in motor-fan coupling situation, and most of them mainly focus on near fan part of the motor coupled to the fan [5-7].

Therefore, in order to explore the difference in axial fan performance between actual work situation and ideal design situation, and understand the internal flow field characteristics in motor-fan coupling situation better, it is necessary to calculate and analyze the flow field in motor-fan coupling environment.

2. Research object and method

2.1. Research object

A certain 4.5kW aviation motor is taken as the research object. It is an inner rotor motor, with axial-radial mixed air inlet and axial air outlet. The three-dimensional structure diagram of it is shown in Figure 1, so as the inside wind road. The basic geometric parameters of the axial fan in the motor are shown in Table 1.

| number of blades | maximum outer diameter/mm | hub radius/mm | hub width/mm | tip clearance/mm |
|------------------|---------------------------|---------------|--------------|------------------|
| 5                | 89                        | 35            | 10           | 0.5              |

Figure 1 Three-dimensional structure and inside wind road diagram of 4.5 kW aviation motor

2.2. Research method

Firstly, the simulation models in motor-fan coupling situation and ideal axial intake situation are established, and the flow field are obtained by conducting the simulation. Then the axial fan
performance and the flow characteristics are compared and analyzed in two different situations, mainly focusing on the flow field characteristics and the static pressure rise of the axial fan. Finally, the reasons for the differences are explored to better understand the changes of fan performance in actual motor-fan coupling working situation.

3. Simulation modelling and conducting
Considering the complex structure and small size of the actual motor, it is difficult to take the actual measurement work. Therefore, simulation model is often adopted to replace the actual one. In this part, the simulation models in coupling situation and ideal axial intake situation are established and conducted to get the results of axial fan performance and internal flow field.

3.1. Simulation model establishment
Figure 2 shows the overall process of simulation modelling and conducting.

![Figure 2 Process of simulation modelling and conducting](image)

Because only the air flow field is focused on, some simplifications are made in coupling situation, such as just keeping the inner wall surfaces of the model and ignoring some geometric structures like end caps. To get stable external flow field consistent with actual working situation, the inlet and outlet channels are extended. For the ideal axial intake situation, the geometric structures of the motor are removed completely, and the entire flow field is approximately a cylinder. The length of the inlet and outlet flow channels are consistent with that in coupling situation, so are the rest parameters.

Considering calculation efficiency and accuracy, both models are divided by unstructured grids. To increase the calculation accuracy, the mesh density of axial fan edges and some inner walls is increased. Finally, the motor-fan coupling simulation model with 2.41 million grids and the ideal axial air intake simulation model with 0.78 million grids are obtained, as shown in Figure 3.
3.2. Boundary conditions and solution model setting
The actual working environment is open to air, so the inlet and outlet boundary conditions in coupling situation are set as pressure inlet and pressure outlet. The inlet total pressure is set to 0 pa, and the outlet static pressure is set to 0 pa. The boundary conditions are set as mass flow inlet and pressure outlet in ideal axial intake situation. The inlet mass flow rate is consistent with that in coupling situation, and the outlet static pressure is also set to 0 pa. The flow field is a connected domain in two situations, so there is data exchange on the surfaces between the rotating fluid and static fluid, and the boundary type of those surfaces are set as “interface”. The boundary type of the rest surfaces is set as “wall”.

The solver is FLUENT, and k-ε model is selected as the turbulence model because of the combination of robustness and high precision. Solution method is the most widely used pressure coupling equations implicit algorithm-SIMPLE (Semi-Implicit Method for Pressure-Linked Equations) algorithm, and three-dimensional steady-state mass conservation and momentum conservation equations are chosen as the control equations. Considering the flow complexity in the motor-fan
coupling case, the convergence criterion and relaxation factor are smaller than default, the values under ideal axial intake situation are selected as default.

4. Comparison and analysis of axial fan performance

4.1. Comparison of axial fan performance

In the 4.5KW aviation motor, the axial fan provides the power to air flowing, so the flow characteristics near the axial fan and the performance of it need to be paid attention to.

![Image](image.png)

**Figure 4 Static pressure cloud diagram of fan wall**

The static pressure clouds of the fan wall under the two situations at 3000 rpm are shown in figure 4. It can be seen from Figure 4 that in the coupling case, the static pressure rise on the fan wall is less than that in the ideal axial intake situation. In both cases, the maximum static pressure appears in the blade tip area. In the coupling situation, the maximum value is 63.90 pa, and in the ideal axial intake situation the maximum value is 42.40 pa. The minimum value appears in the edge area of the blade, the minimum value under the coupling condition is -90.29pa, and the minimum value under the ideal axial intake condition is -121.99 pa (all of them are relative to atmospheric pressure).

One of the important indicators to measure fan performance is the static pressure rise at the inlet and outlet side of it. Therefore, two observation surfaces are established at the same position in two simulation models. In coupling case, one is set between the rotor end wall and fan hub leading edge, the other is set in the axial outlet position. In ideal axial intake situation, they are set in the same geometric position, as figure 5 shows. The average static pressure on the observation surfaces at 3000 rpm are shown in Table 2. It can be seen that at 3000 rpm, the static pressure rise in ideal axial intake situation is higher than that in coupling situation, which proves that the axial fan performance is better in this situation.

|                      | Inlet observation surface/pa | Outlet observation surface/pa | Static pressure rise/pa |
|----------------------|-------------------------------|-------------------------------|--------------------------|
| Coupling situation   | -15.979                       | 0                             | 15.979                   |
| Ideal axial intake   | -19.310                       | -0.028                        | 19.282                   |
| situation            |                               |                               |                          |
Figure 5  observation surfaces in two simulation models

Figure 6  Static pressure rise in two conditions at different speeds
Figure 6 shows the curves of average static pressure rise between fan observation surfaces at different rotating speeds in coupling situation and ideal axial intake situation. As is shown in the figure, at different rotating speeds, the average static pressure rise in ideal axial intake situation is always higher than that in coupling situation, which means the overall performance of the axial fan in ideal axial intake situation is always better. Under the same rotate speed and mass flow rate, the static pressure rise between fan observation surfaces in coupling situation is about 18.24% less than that in ideal axial intake situation.

4.2. Analysis of axial fan performance difference in two situations

As is shown in 4.1, the static pressure rise calculated in coupling situation, no matter near the axial fan or between the selected observation surfaces, is always smaller than that in the ideal axial intake situation, which indicates that the performance of the fan is better in ideal axial intake situation. In this part, combining with the specific internal flow field, the analysis of the phenomenon is given.

It can be seen from Figure 7 that compared with ideal axial intake situation, due to the more complex internal geometric structure, there are more interference terms for air flow in coupling situation, and the air is more turbulent when it goes through the fan blades. The vortex occurs, causing the backflow near the hub, which could explain the higher static pressure minimum on fan surface in coupling situation compared with that in ideal axial intake situation. The tip leakage flow makes the air congested at the tip of the blades, causing the highest static pressure. In ideal axial intake situation, the air flow near the fan is more uniform, there is no vortex, and the tip leakage flow range is also smaller, which makes the static pressure rise higher than that in coupling situation.

Figure 7 Flow details of the flow field near the fan

Figure 8 static pressure contours of fan inlet observation surface
It can be seen from Figure 8 and Figure 9 that in coupling situation, the air passes through the narrow air gap and the radial channels, then reaches the fan inlet observation surface. Because of the air viscosity and end wall influence, the direction of airflow is changed, and it leads to backflow between rotor and fan, as marked in Figure 9. The occurrence of backflow causes the static pressure on the intake side of axial fan to be higher. On the exhaust side, both of the cases are in open-type atmospheric pressure environment, so the static pressure on the outlet side is very similar to each other. To sum up, the final phenomenon is that the static pressure rise between observation surfaces in coupling situation is smaller than that in ideal axial intake situation, and the performance loss of the axial fan in coupling situation is higher than that in ideal axial intake situation.

5. Conclusion
The research conducts the simulation of the axial fan in motor-fan coupling situation and ideal axial intake situation, and obtains the following results:

(1) For a 4.5kw aviation motor, the performance characteristics of the axial fan in coupling situation and ideal axial intake situation are analyzed quantitatively, under the same rotate speed and mass flow rate, the static pressure rise in coupling situation is about 18.24% less than that in ideal axial intake situation;

(2) The main reason for the performance loss of axial fan in coupling situation is the change of air inlet condition. In coupling situation, the air ducts are air gap between stator and rotor and axial air channels in rotor, which is greatly different from that in ideal axial intake situation. The complex air inlet condition leads to the nonuniformity of airflow, which causes the large-scale tip leakage flow and vortex, finally results in the performance loss of the axial fan compared with ideal design situation;

(3) To improve the performance of the axial fan, better air inlet condition should be the main concern, such as designing the air intake duct and stator blades.
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