The influence of guide vane on the performance of an axial fan for air-assisted sprayer

Wei Xiao¹, Donghai Jin¹, ² * and Xingmin Gui¹, ²

¹ School of Energy and Power Engineering, Beihang University, Beijing, China
² Collaborative Innovation Center for Advanced Aero-Engine, Beijing, China

*Corresponding author e-mail: jdh@buaa.edu.cn

Abstract. For the axial fan used in air-assisted sprayer, it always requires a good outlet flow field. In addition to ensuring that the outlet flow field has sufficient dynamic pressure, it is also necessary to ensure that the outlet flow direction is close to the axial direction. In this paper, the influence of the profile load distribution and the solidity of the outlet guide vane on outlet flow field was studied with numerical simulation. The results indicates that increasing the solidity or using the fore-load distribution profile can effectively reduce the outlet flow angle, and result in increasing the spraying distance of the water droplet. This result can provide reference for the design of the guide vane for axial fan used in air-assisted sprayer.

1. Introduction

Because of the characteristics of environmental protection and economical, air-assisted sprayer is widely used for dust suppression, pesticide spraying and fire-fighting. Fig. 1 shows the structure of an air-assisted sprayer. The atomized water droplet, generated by the atomizing nozzle, would be transported to a required distance with the assist of the outlet wind filed pressurized by an axial fan.

As an energy conversion device, the performance of the axial fan will directly affect the quality of the sprayer. Transportation distance is an important parameter when evaluating the performance of a sprayer. At a certain shaft power, it is mainly determined by the efficiency of the fan and the quality of the outlet flow field. The axial fan needs to be well designed to reach the requirement of high efficiency and acceptable outlet flow field quality. Reducing flow loss is the key to improve the aerodynamic efficiency of an axial fan. The internal flow of the impeller is complex. In addition to loss induced by the boundary layer friction and blade wake, the secondary flow such as radial migration of the boundary layer and tip leakage flow, would also bring great loss [1, 2, 3]. What’s worse, the secondary flow in the guide vane passage is harmful to the quality of the outlet flow field, and would reduce the spraying distance of atomized water droplet.

For spraying fan, guide vane is used to turn the flow from the rotor back to axial direction, which is of great importance for achieving a required spraying distance. Solidity and geometry of the profile can affect the ability of the vanes to turn the airflow. Song S [4] carried out structural optimization and experimental research on guide vane of an orchard air-assisted sprayer, and discussed the influence of the number of blades on the flow in the guide vane. Zhengxiang Li [5] replaced the straight guide vane with circular guide vane when optimizing an air-assisted sprayer fan, CFD simulation showed that the flow state in the guide vane got improved. Chen Bo [6] used neural networks and genetic algorithms to
optimize the number and chord length of guide vane, resulting in significant improvements in both fan efficiency and spray distance. These studies are valuable for engineering application. However, the reasons for the improvement of performance was not clearly explained. This paper will discuss and analyze the influence of the guide vane on the performance of the fan, especially the influence on the outlet flow field.

Figure 1. Structure of air-assisted sprayer

2. Axial fan model
The axial fan of this study is a single stage fan designed for an air-assisted sprayer, consisting of a row of rotor blades (R) and a row of guide vane (S). The flow path is shown in Fig. 2 and the basic geometric parameters of the blades are shown in Table 1. The fan is designed to operate at 1450 rpm. The volume flow rate is 50000m3/h, and the total pressure rise is 900 Pa.

Figure 2. Flow path of the fan

Table 1. Geometric parameters of the fan

|                      | Rotor blade | Outlet guide Vane |
|----------------------|-------------|-------------------|
| Number of blade      | 13          | 8                 |
| Chord (hub/tip)      | 146 / 144 mm| 202 / 194 mm      |
| Stagger angle (hub/tip)| 31.7 / 67.2| -20.2 / -11.8     |

3. Computational Methodology
Three-dimensional numerical simulation has been widely used in turbomachinery and has been proved to be of acceptable accuracy [7]. In this paper, commercial software Numeca was used to conduct the three-dimensional numerical simulation analysis. The reliability of Numeca has been evaluated in Yang xi's work [8]. Computational domain includes the inlet section, the rotor blade passage, the guide vane passage and outlet section, as showed in Fig. 3. The blade row adopts the default O4H topology. The S-A turbulence model is selected for turbulence calculation. Y+ is lower than 10 on all walls in the operating points, which meets the model requirements. As for boundary condition, total pressure and temperature at standard atmospheric condition are set at inlet, and at the outlet, the average pressure is given. The walls are considered as no-slip adiabatic walls.
The mesh was encrypted for independence verification. As shown in Fig. 4, the pressure characteristic and efficiency characteristic are calculated with the total grid points around 0.85 million, 1.4 million, and 1.8 million respectively. For three different grid densities, the pressure rise characteristic are basically the same, and the efficiency characteristic increases as the grid density increases. As the number of grid points increases to about 1.4 million, the efficiency characteristic almost remains the same, so the paper adopts the mesh with 1.8 million grid points for all computations.

Figure 3. Computational domains

Figure 4. Independence verification for computational grid

4. Result and Discussion

4.1. The Influence of Blade Solidity
The solidity was changed by altering guide vane number respectively to 6, 8, 10, without changing the blade profile. In order to estimate to what extent the outlet airflow direction deviates from the axial direction, outlet flow angle is defined as the angle between the airflow tangential speed and the axial speed. A positive outlet airflow angle indicates that the flow has the circumferential velocity in the rotation direction, while a negative airflow angle indicates that circumferential velocity direction of the outlet flow is opposite to the rotation direction, or in other words, the airflow is overturned by guide vane.

Fig. 5 plots the distribution of the outlet airflow angle along the span at the design point. S6, S8, and S10 correspond to the calculation results of 6, 8, and 10 guide vanes, respectively. The result indicates that solidity has an obvious effect on the outlet airflow angle: as the guide vane number increase, the
outlet airflow angle decreases in the full span range, which means the outlet airflow direction approaches to the axial direction. It can be concluded that increasing the solidity is an effective way to improve the profile’s ability to turn the airflow to axial direction, without changing the profile geometry.

![Outlet flow angle](image1)

**Figure 5.** Outlet flow angle

![Total pressure loss coefficient](image2)

**Figure 6.** Total pressure loss coefficient

On the other hand, the solidity also has a significant effect on loss and thus affects the fan efficiency. Increasing the solidity would increase loss induced by friction and wake, while help suppress or weaken the secondary flow separation and reduce the secondary flow loss. Fig. 6 shows the characteristics of guide vane’s total pressure loss coefficient with different number of blade. In the large volume flow rate area, the flow in the guide vane passage is in good condition. The loss mainly came from friction and wake loss. As the stator solidity increase, the friction and wake loss increase, resulted in the increase of the total static pressure loss coefficient. While in the small flow rate area, the guide vane suffered large positive attack angle, and the loss is mainly caused by the secondary flow separation. Since the increase of solidity can suppress the separation, bigger solidity contributes to reduce the total pressure loss factor.

For this fan, at the design volume flow rate point (50000m$^3$/h), as the solidity increase, the flow angle decreases while the loss increases, and eventually reduces the efficiency of the axial fan. When choosing the solidity of guide vane, both loss and out flow angle should be taken into consideration. This is the reason why 8 guide vanes were chosen for this fan.

4.2. **The influence of blade profile load distribution**

In order to study the influence of the profile load distribution on the performance of the fan, two kinds of guide vane were designed. One used uniform load profile while the other used fore-load profile. All the profile had the same bending angle and solidity. Fig. 7 is the comparison of the load distribution. The blue curve represents a uniform load distribution, whose circulation is uniform decreased in the flow direction, while the red curve is the fore-loaded distribution, in which the load gradient near the trailing edge is reduced. The comparison of blade profile between two kinds of load distribution is shown in Fig. 8.

The distribution of outlet flow angle is displayed in Fig. 9. Compared to the uniform load vane, the fore-load blade significantly reduces the outlet flow angle in whole span. The average outlet flow angle decreases from 4.36 to 2.26 degree, while the total pressure rise coefficient remains almost unchanged, especially at the design point (50000m$^3$/h) as showed in Fig. 10. Since the flow direction gets closer to axial direction, the spray range would get increased.
5. Conclusion
In this paper, the influence of the guide vane on outlet flow of the spraying fan is numerically studied. The results are summarised as fellow:

1. Increasing the solidity can reduce the outlet flow angle and improve the guide vane’s capability of turning the flow.
2. The increase of solidity can affect the fan efficiency at the design point. Both guide vane loss and the outlet flow angle should be taken into account when selecting the number of blades.
3. For the same solidity and bending angle, using the fore-load profile can help reduce the outlet flow angle and make the outlet flow direction closer to the axial direction.

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