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Effect of Pre-Swirling Flow on Performance and Flow Fields in Semi-Opened Axial Fan

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Abstract

In this study, we tried to improve the performance by giving a pre-swirling flow to the radial inflow that occurred in the semi-opened axial fan. In addition, the flow fields of rotor outlet were clarified experimentally, and the effect of pre-swirling flow was considered. The experiment was carried out using a performance test wind tunnel with a square cross section of 880 mm. Three types of casings were prepared, in which the blade tip protruded 0%, 20%, and 40% of the meridional chord length. They were called R25, R15, and R05, respectively, in the casing bellmouth model code. Guide blades for generating a pre-swirling flow were installed on the vertical wall surface of the casing. In addition, a vertical wall was installed 60% upstream of the meridional chord length as an obstacle to prevent axial inflow. The velocity fields of the rotor outlet were measured using a hot-wire anemometer. From the results, the pre-swirling flow did not significantly affect the fan performance. When there was no obstacles wall upstream, there was a partial increase in efficiency, but the difference was not so large. When there was an obstacle wall upstream, the efficiency increased overall in the case of R15, but in the case of R05, the efficiency increased only in the low flow rate region, and conversely decreased in the high flow rate region. By observing the blade outlet flow fields when the performance was improved, it was confirmed that the influence of the tip leakage vortex was weakened.

Keywords

Axial Fan, Semi-Opened, Narrow Space, Pre-Swirling Flow, Fan Performance

1. Introduction

Small and low-pressure axial flow fans are widely used for ventilation, air blowing, and cooling because they have a simple structure and can generate a relatively large flowrate. Especially in recent years, the demand for cooling fans has been increasing to cope with the increase in heat generation accompanying the high performance of electronic devices. However, ducts cannot be installed upstream and downstream of the fans due to the space constraints where those fans are used. Therefore, such a cooling fan has a half-ducted type in which only the rotor blades are covered with a casing.

A half-ducted axial flow fan differs from a ducted one, which is often used for industrial purposes, because there is a radial inflow at the fan inlet, so a complex flow field with a strongly three-dimensional flow is formed at the fan inlet, the performance is lower than that of the ducted type. Therefore, various studies have been conducted to improve the performance of the half-ducted type fan. Many of those studies are related to noise, which is one of fan performances. For example, Liu *et al.* [1] tried to reduce noise by installing porous material in the casing that covers the rotor. This study showed that suppression of tip leakage vortices has a great effect on noise reduction. Obayashi *et al.* [2] clarified the noise source of a small axial flow fan by numerical simulation. They showed three possible noise sources for small axial flow fans: those were fluctuating flow on the blade surface, complex flow near the inlet hub, and fluctuating tip leakage flow occurring in the blade tip clearance. Since the relationship between noise reduction and aerodynamic performance (fan efficiency) is basically a trade-off, lower noise usually leads to lower efficiency. Yo *et al.* [3] attempted to improve performance while reducing noise by using a multi-objective optimization program. As a result, 4 dB noise reduction was achieved while improving efficiency by 5%. In addition, these half-ducted axial flow fans are often installed in narrow spaces, and it is not easy to predict their performance in such environments. Fukuda *et al.* [4] clarified how the performance of the fan changes when there is an obstacle upstream of the fan by CFD. However, these studies have not paid attention to radial inflow, and no attempt has been made to improve fan performance by experimentally controlling radial inflow.

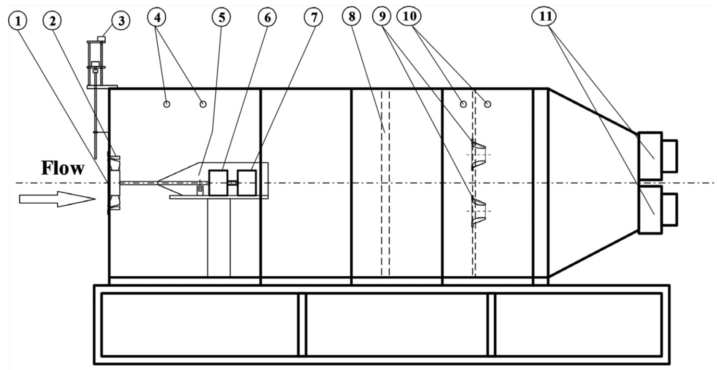
The authors have conducted research on the idea that a semi-opened axial flow fan with a part of the blade tip protruding from the casing can maintain its performance even in a narrow space with obstacles around it. As a result, it was shown that it is possible to reduce the rate of performance degradation, although it is not possible to completely prevent performance degradation [5] [6].

In this study, we try to further improve the performance by giving a pre-swirling flow to the radial inflow that occurs in the semi-opened axial fan. In addition, the flow field of rotor outlet will be clarified experimentally, and the effect of pre-swirling flow will be considered.

2. Experimental Apparatus and Procedures

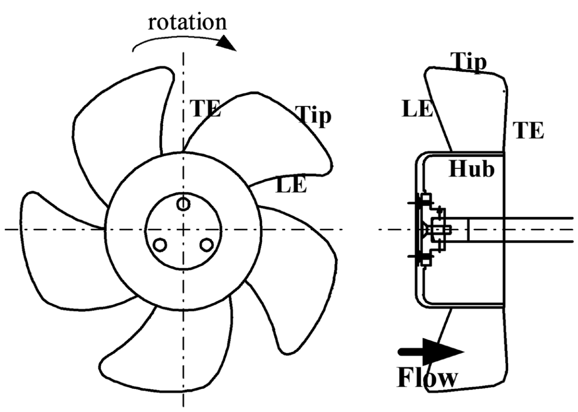
The experiment was carried out using a performance test wind tunnel with a square cross section of 880 mm. **Figure 1** shows the schematic view of test rig and its component list. The flow direction is left to right in **Figure 1**. As the test rig didn't have the throttle to regulate the flowrate, the flowrate was set up by changing the power of booster fan. At the fan test, the pressure-rise in the chamber box, the shaft power and the pressure difference at nozzle section were measured for each flowrate condition. The rotor blade location at hotwire survey was detected by use of photo sensor mounted on motor shaft. Figure 2 shows the outline of the test rotor. The rotor has 5 blades, its tip diameter is approximately 180mm, and the hub-to-tip ratio is 0.5. The rotating direction is clockwise from the front view direction.

Three types of bellmouth were prepared, in which the blade tip protrudes 0%, 20%, and 40% of the meridional chord length. They are called R25, R15, and R05,



1	Test rotor	7	Main motor
2	Casing	8	Gauge screen
3	Hotwire traverse	9	Nozzles
4	Prssure taps	10	Pressure taps
5	Photo sensor	11	Booster fan
6	Torque meter		

Figure 1. Schematic view of test tunnel.



Blade geometry

Blade number	5
Tip dia. at LE	0.18018 [mm]
Hub dia.	0.090 [mm]
Hub-to-tip ratio	0.5

Figure 2. Outlines of test rotor.

respectively, in the casing bellmouth model code. The 0% casing is a type in which the blade does not protrude. Tip clearance at casing region is 1 mm constant. Guide blades for generating a pre-swirling flow were installed on the vertical wall surface of the casing. The height of the guide blade was adjusted so that the tip was at the same position as the tip of the blade leading edge. In addition, a vertical wall was installed 60% upstream of the meridional chord length as an obstacle to prevent axial inflow. The mounting angle of the guide vane was set to 8˚ based on preliminary experiments.

The velocity fields of the rotor outlet were measured using a hot-wire anemometer. The hot-wire probe used is a single I-type probe, and its installation directions are two directions, that is, normal and parallel to the meridional plane. How-wire traverse line is shown in Figure 3. Its line is set at 14 mm downstream of rotor, and 19 measurement stations put on the survey line. The data measured at each measurement station were phase-locked and averaged using the blade rotation phase. These data were displayed as iso-velocity maps on a plane defined by the blade phase (two pitches) on the horizontal axis (circumferential direction) and the measurement radial position on the vertical axis.

The rotor rotating speed is 3000 min^{-1} at constant. The test Reynolds number based on blade tip speed and blade chord length at blade tip is 1.32×10^5.

3. Results and Discussions

3.1. Fan Characteristics

Figure 4 shows the effect of bellmouth size and guide vanes. Horizontal axis is flowrate coefficient and vertical axis is efficiency. Solid lines are the case without guide vane and dotted lines are the case with guide vanes.

In Figure 4, the maximum efficiency decreases as the bell mouth size decreases. From this result, we can understand the following. As the bell-mouth size

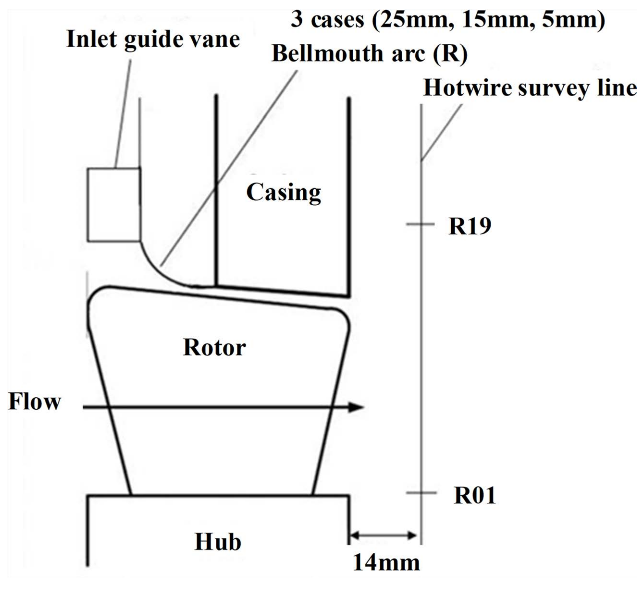


Figure 3. Layout sketch of test section (guide vane, bellmouth & casing).

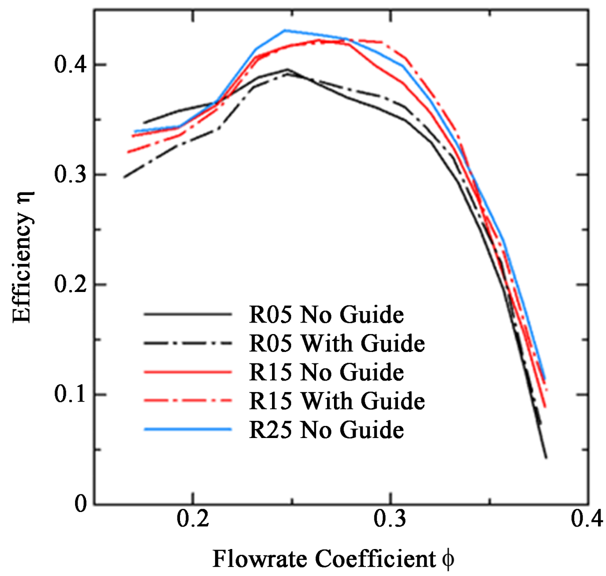


Figure 4. Efficiency distributions of test fan for each bellmouth size.

becomes smaller, the blade tip protrusion increases and the radial inflow through the blade tip increases. The interference between the radial and axial inflows increased at the blade leading edge near blade tip and the loss increased, resulting in a decrease in efficiency. A detailed observation of the results confirms the effect of the guide vane on the high flow-rate region in the case of R15. At the high flowrate region, the efficiency is partially higher than that of R25. On the other hand, in the low flowrate region, the efficiency becomes lower when there is a guide vane. From these results, it is considered that the effect of the guide differs depending on the inflow flowrate, and that there is an optimum guide installation angle depending on the flow range where performance improvement is desired.

Figure 5 shows the effect of obstacle on efficiency. The distance between fan and obstacle is 30 mm constant, the bellmouth size is 15 mm (R15), and the angle of guide vanes is 8 degrees form radial line. The left is in case of without guide vanes and the right is with guide vanes. It was found that the influence of obstacles was large, and the efficiency was greatly reduced regardless of the presence or absence of guide vanes. Examining the effect of the guide vanes under the same conditions, that is, with an obstacle, it appears that the efficiency drop can be slightly suppressed with the guide. In the case of R05, the efficiency increased only in the low flow rate region, and conversely decreased in the high flow rate region (No drawing issued). The effect is smaller than when there are no obstacles, and this result shows that the optimal installation angle of the guide vanes is changing when there are obstacles.

3.2. Velocity Fields at Fan Outlet

Figures 6-8 show contour maps of the velocities measured by the hot wire. The measured data are phase-locked averaged using the rotor blade phase and

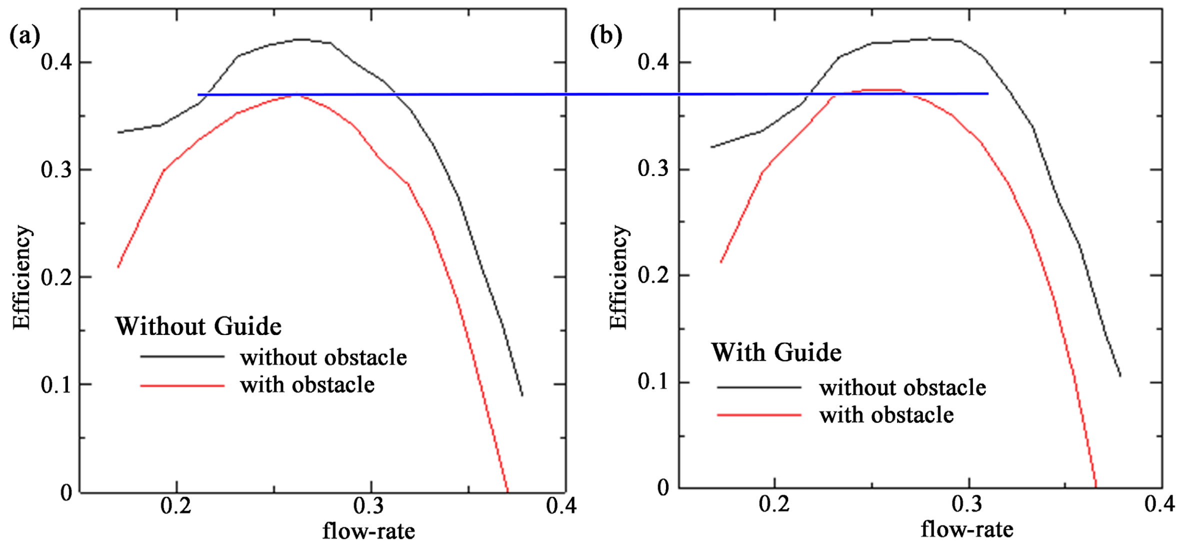


Figure 5. Effect of obstacle on efficiency in case of R15. (a) Without guide vanes; (b) With guide vanes.

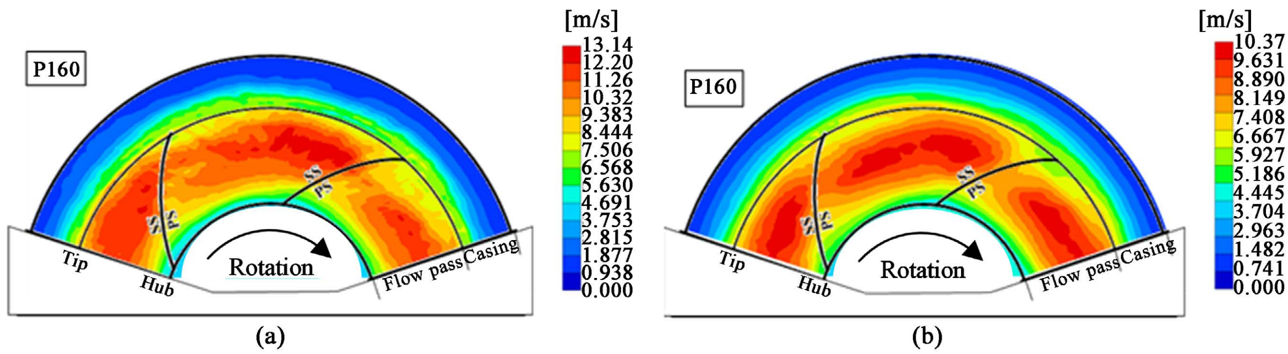


Figure 6. Contour maps of axial-radial resultant velocity fan outlet in case of R15 without obstacle. (a) Without guide vanes; (b) With guide vanes.

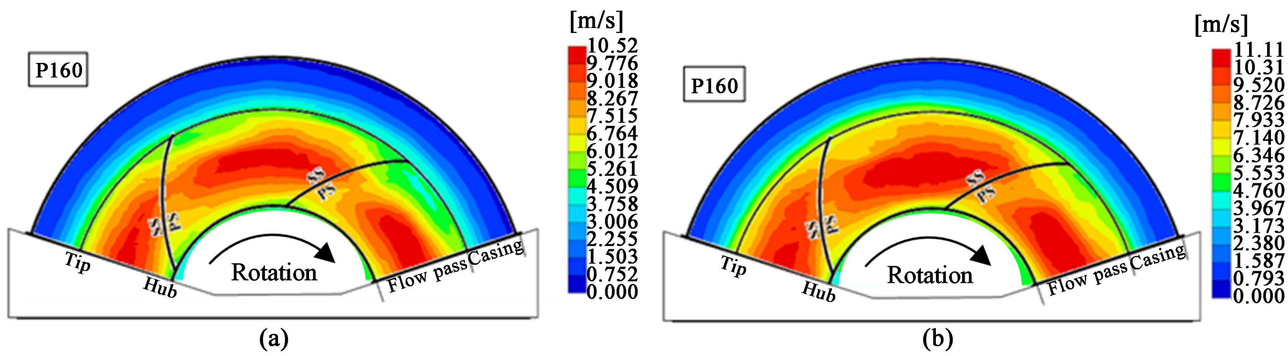


Figure 7. Contour maps of axial-radial resultant velocity at fan outlet in case of R15 with obstacle. (a) Without guide vanes; (b) With guide vanes.

displayed on a fan-shaped plane defined by the blade pitch (2 pitches for circumferential direction, 5 pitches for full circumference) and the measurement radius position for radial direction. Figure 6 shows the contour map of axial-radial resultant velocity, Var, at fan outlet in case of R15 bellmouth without obstacle. The left is without guide vanes and the right is with a guide vanes. The

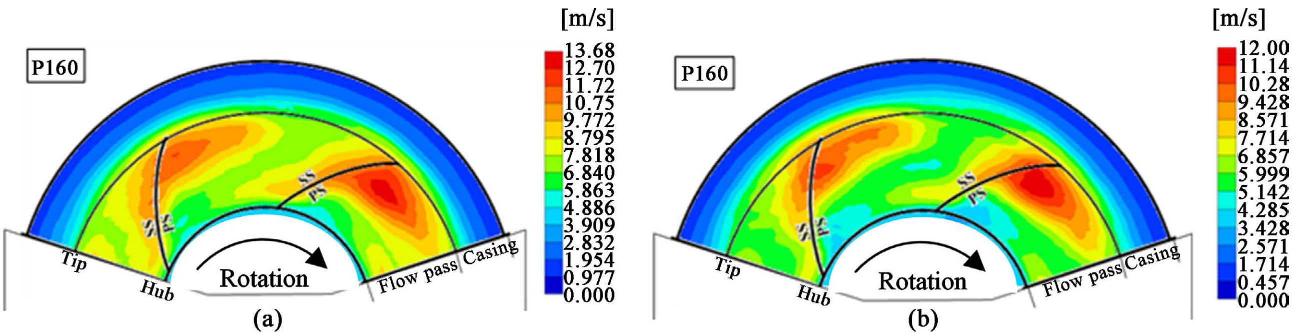


Figure 8. Contour maps of tangential-radial resultant velocity at fan outlet in case of R15 with obstacle. (a) Without guide vanes; (b) With guide vanes.

flowrate measured is near the best efficiency point (BEP). **Figure 7** is the same contour map, but the results are obtained when there is an obstacle upstream of the fan. In both cases, the range shown in the figure is two pitches of the blade, the inner small arc indicates the hub, and the arc in the figure indicates the tip location, respectively. The solid line connecting the arcs of the hub and tip indicates the blade trailing edge, and the symbols PS and SS mean "Pressure Surface" and "Suction Surface", respectively. The rotor rotating direction is clockwise as shown in the figure. The velocity magnitude is represented by a color distribution and its legend is on the right side of each figure.

From **Figure 6**, it can be confirmed that the flow spreads radially to the outer casing region of the blade tip. In addition, a low velocity region is confirmed near the hub in both cases. These results show that the flow field at the fan exit shifts radially outward when there is no obstacle. A similar tendency was also shown by a previous study by Shiomi *et al.* [5]. This is because the ducted fan does not spread radially outward due to the duct wall, while the semi-opened type does not have such restrictions and the flow at fan outlet spreads radially outward due to centrifugal force. Looking at the flow inside the blade passage, in both the right and left figures of **Figure 6**, a region where the velocity is partially reduced is observed mainly on the PS side of the blade tip. When there is no guide, the rate of decrease in velocity is small but distributed over a wide range. On the other hand, when there is a guide, the rate of decrease in velocity is large but concentrated in a relatively small range.

The results of **Figure 7**, which has obstacles upstream, show the same tendency as **Figure 6**. Comparing the results in **Figure 6** and **Figure 7** in detail, both the spread to the outside of the tip and the spread of the low-velocity region near the hub are small, indicating that the flow field does not spread outward so much. This is because the presence of an obstacle upstream strengthens the radial inflow and pushes the flow field radially inward. Regarding the low speed region existing on the PS side near the blade tip, both the spread and the velocity reduction are larger when there is an obstacle, and the influence of the obstacle can be confirmed. However, by installing guide vanes, this area was reduced, and the velocity reduction was suppressed.

Figure 8 shows the contour map of tangential-radial resultant velocity, Vtr, at fan outlet in case of R15 bellmouth with obstacle. The view of the figure is the same as **Figure 6** and **Figure 7**. Looking at the velocity distribution, there is a concentrated area of high velocity from the mid-span to the tip on the blade PS side. Generally, there is a small gap between the rotor blade tip and the casing. If there is a pressure difference between both blade surfaces across this gap, a flow occurs through this gap from the high pressure side (Pressure Surface, PS) to the low pressure side (Suction Surface, SS). This flow is called the "tip leakage flow". When the tip leakage flow interferes with the main flow and rolls up, a vortex is formed inside the blade passage. This vortex is called a "tip leakage vortex". A typical velocity distribution exhibited by the tip leakage vortex at the fan outlet flow field is that the axial velocity is smaller than the surroundings and the circumferential velocity is higher than the surroundings. Combined with the results of the Var distribution, it is thought that the blade tip leakage vortex exists here. However, due to the size of the spread of the distribution, it is possible that the vortex has already encountered with the pressure surface of the adjacent blade and collapsed in the inter-blade passage. However, no significant difference can be confirmed even if the comparison is made with or without the guide.

4. Conclusions

The authors tried to improve fan performance by installing guide vanes that give pre-swirling flow to a small semi-opened axial flow fan. In addition, we tried to clarify the effect of the guide vane when this fan is installed in a narrow space from the state of the fan outlet flow field.

When there were no obstacles upstream, the performance was improved by setting the mounting angle of the guide vane to 8˚. However, in the presence of obstacles, the improvement effect was smaller than in the absence of obstacles. This is probably because the optimal mounting angle of the guide vane changes when there are no obstacles.

We are continuing to study whether the guide vanes have similar effects in a narrower space, that is, in a space where the influence of radial inflow is stronger. As for the flow field, all of the velocities measured this time were synthetic velocities that included a radial velocity component, so measurements are currently being carried out to clarify the complete three-dimensional flow field (axial, radial, and circumferential).

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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