CROSS-FLOW COOLING FAN APPLIED ON NOTEBOOK COMPUTERS

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Abstract
This study intends to construct a cross-flow cooling fan for meeting the thermal task of laptop computers by utilizing an integrated scheme, which consists of design, mockup manufacture, and experimental verification. First of all, several blades of airfoil and circular-arc sections are generated by means of the aerodynamic analysis. Next, housing geometry is determined based on the outcomes of previous researches under the Notebook’s space limitation. Moreover, a comprehensive parametric study on fan geometry is performed to realize the influences caused by those variations. The parameters considered here include blade number, blade shape, tongue gap, throat gap, fan outlet area, and drilling holes on the housing. To fabricate the mark-ups for experimental verification, the designed fans are expressed in the CAD/CAM format for the CNC mill. Thereafter, a set of relations correlating the volume-flow-rate, static pressure, and noise of this cross-flow fan is executed with the aids of AMCA and semi-anechoic chambers. From experimental results, both the airfoil and circular-arc blades yield a superior performance than that generated from a traditional centrifugal fan. While the noise level is kept roughly at the same level, compared to the best blower available in the current market, a significant 24% flow-rate increase and a 21% static-pressure gain are observed. In summary, this study provides a systematic scheme for a cross-flow fan design to fulfill the thermal requirement of Notebook computer.

1 Introduction
The demand for notebook computers is growing nowadays. Over the years, the technology for manufacturing chips has improved greatly. At this moment, engineers have achieved the success in integrating multiple functions into a single computer chip. With this technology, the CPU is capable of processing more data within a given period of time and the CPU performance is therefore regarded as higher. However, this capability is directly related to its heat generation. The larger the amount of data the CPU processes at a time, the greater the amount of heat it generates. Furthermore, the CPU life is shortened quickly if it usually works in high temperature. Thus, the cooling technology is the very important issue for computer industry. A good thermal solution can make a computer work in a stable and quiet situation.

A cooling fan with high static pressure is capable of effectively removing the heat energy generated from the system of high flow resistance. Therefore, the development of high-performance fan can effectively overcome the flow resistance due to system components. Hence, centrifugal fans with high static pressure are usually used in the notebook computers as shown in Fig. 1. But centrifugal fans with multi-
blades rotors generate high frequency noise and low airflow. For example, a centrifugal fan with $45 \times 45 \times 10 \text{ mm}^3$ size at 6,000 rpm generates about 3 CFM volume flow rate. The airflow rate is too low to bring out the system heat generation. Therefore, the $50 \times 50 \times 10 \text{ mm}^3$ and $70 \times 70 \times 10 \text{ mm}^3$ size of fans are applied to notebook computers. Although the bigger centrifugal fan can solve the thermal issue, the space in notebook becomes more limited.

In the other end, the flow inlet and outlet directions of axial-flow fans are at the same axis (Fig. 1), and it must have large free space in front of fan to avoid blockage effect [1]. However, the space using to set every component in notebook computer is limited. If the $60 \times 60 \times 10 \text{ mm}^3$ axial flow fan is put horizontally in the notebook computer, it must have another free space or its performance will decrease sharply. In addition, the maximum size of axial fans used in laptops is constrained by the thickness of laptops (25 mm). The static pressure and volume flow rate of $25 \times 25 \times 10 \text{ mm}^3$ axial fan operating at 12,000 rpm is about 7~8 mm-Aq and 2~2.5 CFM, respectively. The small airflow can not take out the heat generation of electrical components so the axial fan is not suitable to use in notebook computers.

In the cross-flow fan, the airflow passes twice through the blades, first inward and then outward, and both of flow inlet and outlet are parallel to the radius axis, as shown in Fig. 1. Base on this flow characteristic, cross flow fan does not need extra space in axis direction. The thickness of cross flow fan can be equal to the thickness of notebook computer. Therefore, for notebook computer using a centrifugal fan with 10 mm thickness, a cross flow fan with 15 mm thickness can be utilized to replace the centrifugal fan. The amount of airflow can increase 50%. Therefore, the cross-flow fan has a great potential as an effective cooling fan in solving the thermal challenge for the high-performance notebook computers.

This study intends to construct a cross-flow fan for meeting the thermal task of laptop computers. First of all, based on the results described in previous works [2-8], the housing and impeller of cross flow fan are designed under the geometric limitations for notebook computers. Regarding the mockup manufacture, with the input of casing and rotor geometry, the CNC milling route is programming by CAM software. All the prototypes of design fans are manufactured by a CNC machine to serve as tests, as had been done by Lin et al. [9] Later, a comprehensive parametric study on fan geometry is performed to realize the influences caused by those variations. The parameters considered here include blade number, blade shape, tongue gap, throat gap, fan outlet area, and drilling holes on the housing. Thereafter, a set of relations correlating the volume-flow-rate, static pressure, and noise of this cross-flow fan is executed with the aids of AMCA and semi-anechoic chambers. Hence, a systematic scheme for a cross-flow fan design is furnished here to fulfill the thermal requirement of Notebook computer.

2 Impeller Design

Centrifugal fans are mostly selected to be used as the cooling fan in notebook computers nowadays. Therefore, a large number of technical reports are related to the study of centrifugal fans. Since most of the research studies about cross-flow fan are related to air-conditioning systems and no technical report is about the reduction on cross-flow fan size, the goal of this work is to design a new cooling fan for notebook computers as well as the blade configuration suitable for miniature cross-flow fan. The text that follows will describe the flow characteristics of the cross-flow fan and also the flow conditions in it. After that, the approach to design the blade for miniature cross-flow fan will be addressed.

2.1 Flow Path of Cross-Flow Fan

As far as the blade angle is concerned, the impellers for cross-flow fan and centrifugal fans are similar, as shown in Figure 2. The greatest difference between them is the directions of air flowing into and out of the fans. The directions of the centrifugal fan air inlet and outlet are...
perpendicular while those of the cross-flow fan are on the same plane. Therefore, when designing the blades, it is necessary to put the air flow directions into consideration prior to fan installation. In the past, the design of blades in centrifugal fans requires that the leading edge of the rotor blade points at the center of the impeller. In other words, air enters at the leading edge of the blade and leaves at the trailing edge. For this reason, centrifugal fans are always accompanied with a high static pressure. On the other hand, since the air flow associated with cross-flow fan enters the impeller from the left and then leaves from the right, both edges of a blade in cross-flow fan are capable of leading to inflow and outflow.

2.2 Rotor Blade

This work employed NACA-4410 airfoil profile as the blade profile for cross-flow fan. To maintain the aerodynamic characteristics associated to the airfoil profile, this work reserved the half front portion of the airfoil profile and replaced the other half with a reflection of the half front portion. This profile is clearly depicted in Figure 3. With this modified profile, air flowing through the impeller in the cross-flow fan maintained the aerodynamics characteristics of the airfoil profile and preserved the fan performance regardless of the inflow from the left or the outflow to the right of the impeller.

3 Experimental Setups

The best way to establish the performance and noise characteristics of any cooling fan is by experimental testing. Experimental testing should be conducted on a setup that meets code requirements. The following subsections illustrate the setups used in this study.

3.1 Performance Measurement

Many renowned engineering societies and industry organizations throughout the world have published fan test codes. Among them, AMCA Standard 210-99 [10] is one the most widely used and accepted in the fan industry. This test code was developed by the Air Movement and Control Association (AMCA) and was documented in the publication entitled “laboratory methods of testing fans for aerodynamic performance rating”. All performance characteristics of fans in this study are carried out in an AMCA test chamber to yield reliable measurements.

The AMCA test chamber and instrument setup are schematically presented in Fig. 4. A fan discharge is mounted on the AMCA test chamber to simulate free-inlet and free-outlet conditions. Flow settling means are installed in the chamber to guarantee proper flow conditions for measurements. For a measuring plane located upstream of the settling means, the settling screen absorbs the kinetic energy of the upstream jet and allows the flow to undergo a normal expansion. For a measuring plane downstream of the settling screen, this screen ensures a substantially uniform flow ahead of the measuring plane. In addition, adding an auxiliary fan at the end of the test chamber controls the operating point of the fan. Therefore, with the aid of curve fitting technique, a complete fan performance, such as static-pressure/volume-flowrate curve, can be obtained by combining various measuring points over the entire operating range of the cross flow fan.

3.2 Noise Measurement

In this experiment, A weighted and 1/3-octave band sound pressure levels are measured using a RION NL-14 portable sound level meter (SLM) and analyzed using an AND AD-3524 FFT frequency analyzer. The sound pressure creates an analog electric signal in the SLM microphone. From SLM, this signal is then fed into the FFT analyzer to generate noise characteristics. For verification, the consistency and calibration of the above devices are checked by a piston phone (94 dB at 1000Hz) both before and after a set of measurements. CNS-8753 code [11] is employed to measure the noise levels at the two fan outlet positions as shown in Fig. 5. To further guarantee
meaningful measurements, the measurements are taken in a semi-anechoic chamber (Fig. 5) because it offers an appropriate test environment. The transmission decay is larger than 35 dBA. The noise level of the test sample must be 10 dBA lower than the noise level of the environment.

4 Experimental Program

The experimental procedure was divided into three parts. In the first part, all impeller parameters that might influence fan performance would be investigated so that a better design of fan could be achieved. This preliminary design would serve as the foundation for future investigation. In the second part, a hub would be inserted into the impeller for a compact fan size so that they could be placed more easily in a notebook computer. The objective of this part was to investigate the influence of hub parameters on the fan performance if a motor was installed in the impeller. Base on the results obtained in the first and second parts, the third part aimed to further improve the most critical parameters that influenced the fan performance and noise generation level. In this work, the blade shape, chord length, and throat clearance were varied for investigation. Fan mockups corresponding to each of these parameters were fabricated to experimentally evaluate influences on the fan performance and noise level.

4.1 Traditional Cross-Flow Rotor

To design a high performance cross-flow fan, the blades of the impeller were the first subject of study. Although the impellers of a cross-flow fan and a centrifugal fan were similar, the blades of the impeller were studied so that an excellent cross-flow fan could be produced. Since the sequence of blades the air flows pass and the directions of inflow and outflow are different between a cross-flow fan and a centrifugal fan, the characteristics of the flow field in the cross-flow fan was given the major attention in the design of blade. First of all, three types of blade number were considered, i.e., 19, 23, and 29. According to previous studies [3, 4], among the geometric parameters associated to a cross-flow fan, the throat clearance imposed the greatest influence. The throat clearance is the gap width between the impeller and the backplate. By varying the throat clearance and the most suitable blade number, the influence of the throat clearance on fan performance could be investigated.

4.2 Rotor with an Inner Motor

In the first part, there was no hub installed inside the impeller. The flow field was identical to that of a conventional cross-flow fan. In this section, a hub was installed in the impeller. If a motor is placed in the impeller, the overall volume of the fan decreases and it is therefore much easier to be installed in a notebook computer. However, it is expected that the available region for flow passage within the inner volume of cross-flow fan will decrease significantly as the hub is placed inside the impeller. This will definitely lead to the decrease in aerodynamic performance. However, the motors for the cross-flow fan available in the market were all placed outside of the impeller. In contrast, this work tried to place the motor (hub) inside the impeller, and then analyzed their overall influence on the fan. Two hubs of different dimensions were considered. The diameter and thickness of the first hub were 20 mm and 8 mm, respectively. Those of the second hub were 25 mm and 11 mm. It was hoped that the better hub dimension could be determined via experimental results.

4.3 Parametric Study for Performance Enhancement

In this section, some parameters mentioned in section 4.1, such as throat clearance, were investigated. By varying the cut-off clearance and blade shape, it was hoped that the fan performance could be increased. It has been reported that the cut-off clearance has a great influence on the fan performance and noise level generated [2]. Therefore, three different
cut-off clearances were examined to determine its optimum value. Moreover, the geometric configuration of the cut-off will also greatly affect the fan performance and particularly the noise generation. Because the flow velocity exited from the impeller increases dramatically at the vicinity of the cut-off, large amount of acoustic noise is generated due to the collision of air with the cut-off. To overcome this problem, this work proposes drilling holes on the cut-off so that the acoustic noise due to collision can be reduced. Reference [7] mentioned that, as air flows into the center of an impeller, a swirling flow condition is very likely to occur in the center of the impeller because the impeller is hollow and thus a stagnant flow condition may take place. Apparently, the installation of a hub in the impeller can improve the flow condition in the impeller center.

In the previous two sections, the shape of the blade was based on an airfoil cross-section. In the light of reference [8], flat plates were adopted here as the blades. The experiments performed on these blades aimed to investigate the shape of the blades on the fan performance and noise generation. Furthermore, blades with different chord length were fabricated to study the influence of chord length on fan performance and noise. According to reference [12], the chord length of blades is a major factor that affects the fan performance and noise generation. Two chord lengths considered in this study was 5 mm and 7.5 mm.

5 Experimental Results

For the same comparison basis, the rotating speed of test fan at maximum airflow rate is operating at 6000 rpm. All the fan performance and noise characteristics are measured in AMCA 210-99 test chamber and semi anechoic chamber, respectively. As stated in previous section, this experiment is divided into three parts. In the first part, the blade number and throat clearance of the traditional cross flow fan would be investigated. Note that there is no motor (or hub) located inside the impeller of traditional fan. In the second part, a hub will be inserted into the impeller for obtaining a compact fan size. The objective of this part was to study the influence of hub parameters on the fan performance if a motor was installed in the impeller. Base on the results obtained in the first and second parts, the third part aimed to further improve the most critical parameters that influenced the fan performance and noise generation level. In this work, the blade shape, chord length, and throat clearance were varied for investigation. Fan mockups corresponding to each of these parameters were fabricated to experimentally evaluate influences on the fan performance and noise level.

5.1 Traditional Cross-Flow Rotor

Three blade numbers of impeller, i.e. 19, 23, and 29, are considered here. Figure 6 shows the fan performances under different blade numbers when the fan rotates at 6000 rpm. Apparently, both of static pressure and volume flow rate of the fan with 23-blade are the best among these three cases. The energy transfer from blades to air is closely relative to blade number. The fewer the blade number of the impeller is, the less the amount of energy transfer. On the other hand, the contact area between blades and air is proportional to blade number. Hence, the performance for the case with 23 blades is better than that of 19-blade fan. However, when the blade number increases further to 29, the flow path becomes narrow. Thus, the airflow is hard to move while the blade number increases too much.

Throat clearance is the other important parameters for cross-flow fan. Three clearances, 5 mm, 7 mm, and 9 mm, are considered in this study. The cross flow fan with 7 mm throat clearance yields a better static-pressure and airflow rate than the others as shown in Fig. 7. This trend is reasonable for an increasing throat clearance since the entrance area becomes larger, which makes the static pressure drop sharply.

5.2 Rotor with an Inner Motor

As indicated in section 5.1, the static pressure and volume flow rate of cross flow fan
can reach the similar output for the centrifugal fan. However, there is no hub installed inside the impeller. The motor of cross flow fan is placed outside the bottom plate of casing. If a motor is placed in the impeller, the overall size of the fan decreases and it is therefore much easier to be installed in a notebook computer. Hence, in this section, a hub was installed in the impeller. Two hubs of different dimensions, \( \phi 20 \times 8 \text{ mm} \) and \( \phi 25 \times 11 \text{ mm} \), were considered.

Figure 8 shows the performance curves of different hub dimensions. The hub would block part of the flow path. When the hub is built in the impeller, experimental results indicate that the volume flow rate decreases 29.7%~43.6%. Obviously, the installed hub will affect the volume flow rate of cross flow fan significantly. Also, the static pressure decays by the installed hub. The larger the hub size is, the worse the performance of the cross flow fan. Furthermore, there is a vortex structure existed in the flow field of the impeller without hub. When the hub is installed in the impeller, the vortex structure is destroyed and thus the noise generation is reduced.

5.3 Parametric Study for Performance Enhancement

In the previous two subsections, the performances of the cross flow fan with and without a hub are discussed. To enhance the performance of cross flow fan with a hub, the values of some parameters need to be examined again. Therefore, the throat clearance, cut-off clearance, and blade shape are considered in this subsection.

Figure 9 shows the static pressure and volume flow rate of cross flow fan increase 1.77% and 7.65% respectively, while the throat clearance enlarges from 7 mm to 9 mm. Although the throat clearance slightly affects the performance, the result indicated in Section 5.1 shows there is a big difference between the impellers with hub and without hub. (see Fig. 7) After carefully comparing Fig. 7 and Fig 9, when the hub is installed in the impeller, the static pressure raises 27% while the volume flow rate reduces 18%.

In Fig. 10, when the cut-off clearance reduces from 4 mm to 1 mm, the static pressure and the volume flow rate increases are 18% and 49%. Hence, the performance of cross flow fan is proportional to the cut-off clearance. The less the cut-off clearance is, the greater the variations of velocity gradient due to the air impacting on the cut-off. Also, the noise generation is raised by the decrease of cut-off clearance. Although smaller cut-off clearance can increase the performance, it also generates high noise level.

Figure 11 shows the performance curves for four blade shapes (Airfoil 5, Airfoil 7.5, Plate5, and Plate 7.5). These four performance curves are compared with a traditional centrifugal fan (sample fan). Every designed cross flow fan shows better volume flow rate than sample fan as shown in Fig. 11. The volume flow rate of the impeller with Plate 5 blade shape is 24% higher than that of the sample fan. In general, the flat plate can generate more volume flow rate and airfoil cross-section can result in higher static pressure.

Regarding the noise generation, the shorter the chord length is, the lower the noise produces as shown in figure 12. Clearly, the noise level of 7.5 mm chord length is about 2.5 dBA higher than 5 mm. However, the noises of designed fans are higher than the sample fan. Note that mockups always have trouble in the assembly of the cross flow fan parts. Also, different design of manufacture will cause the bad assemble. When the fan rotates at high speed, the vibration noise will be easily generated if the structure is not strong enough. This is the reason that the noise generation of reference fans is lower than the mockups. In brief, the experimental outcomes indicate that the flow characteristics and high volume flow rate of the cross flow fan are suitable to be applied in notebook computers.

6 Conclusions

Since the air inlet and outlet of a cross-flow fan are on the same plane, its installation in a notebook computer does not require a large space for air inflow. Hence, this work, based on
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the flow characteristics and high flow rate associated with cross-flow fan, has successfully developed a new design of cooling fan suitable for notebook computer. By varying the geometric parameters of the cross-flow fan, the static pressure of the cross-flow fan increases and therefore improves the fan performance. As far as the thermal management of a notebook computer is concerned, it is found that a fan with flat-plate blade whose chord length was 5 mm was the most suitable to produce high flow rate. Its maximum flow rate was 24% greater than that of the reference centrifugal fan. If the static pressure was under consideration, a fan with airfoil blade with chord length of 7.5 mm was the best choice for its static pressure was 21% greater than that of the reference fan. On the other hand, if it is desirable to design a fan that produces low noise level, the fan with flat-plate blade whose chord length is 5 mm performs reasonably well. Based on the experiment, its flow rate increased tremendously but its noise level only increased by 3 dBA. Even so, it is possible that the noise generation can be further controlled and reduced if the fan is under mass production. Therefore, the control of noise generation is considerably satisfactory.

References


(a) Axial-flow fan
Fig. 1. Sketch of the airflow direction for three types of cooling fans in laptop computers

(a) Without the top plate

(b) Centrifugal fan

(c) Cross-flow fan

Fig. 2. Fan Mockups

(b) With the top plate

Fig. 3. Schematics of the Blade Design

Fig. 4. Sketch of AMCA test chamber and instrument setup

Fig. 5. Schematics for the positions of noise measurement
Fig. 6. The performance curves for different blade numbers

Fig. 7. The performance curves for different throat clearance

Fig. 8. Performance curves for different hubs

Fig. 9. The performance curves for different throat clearances (with hub)

Fig. 10. The performance curves for different cut-off clearances (with hub)

Fig. 11. The performance curves for different blade shapes and chord lengths
Fig. 12. The noise generations for various blade shapes and chord lengths