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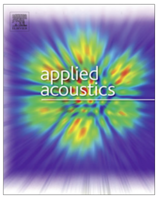

Noise source analysis for two identical small axial-flow fans in series under operating condition

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ABSTRACT

The noise signature of two identical small axial-flow cooling fans in series, under the operating condition of 120 Pa back pressure to simulate its usual working condition, is analyzed and the BPF analysis method is used to decompose the total noise into various noise source components. Acoustic directivity measurements are conducted for two different inlet flow conditions: free/unobstructed inlet and partial admission by several kinds of flat plates all blocking 30% inlet area. The inlet obstacle increases the broadband noise and the tonal noise of the upstream fan while it has little effect on the tonal noise of the downstream fan. In addition, the tonal component from the downstream fan dominates over that from the upstream fan for unobstructed inlet while the dominance by the downstream fan is reversed for partial admission. Furthermore, the aerodynamic and acoustic effects of a flow straightener placed between the two fans and in front of the upstream fan in an attempt to relieve the adverse effect of the inlet flow distortion are studied as well. The flow straightener between the two fans plays an important role in straightening the non-axial flows from the upstream rotor before impinging upon the downstream rotor. The broadband noise in the case with partial admission is reduced by 3.5 dB by the flow straightener in front of the upstream fan although the tonal noise radiated by the upstream fan is not relieved effectively.

1. Introduction

Fan noise is always an important topic in applications ranging from small cooling fans for computers, transport vehicles and machinery, and building ventilation fans, to large compressors and turbo-engine fans in aircraft. Usually single fan is enough in applications such as computer cooling and building ventilation. However, two or more fans are needed in some special working conditions. In addition, configuration of multiple stages is very common in fans, compressors, and turbines of aero-engines as well. Multiple fan operation includes parallel and series operation. Fig. 1 shows the comparison of P-Q curves among single fan, two fans in parallel and in series. Parallel operation is the situation that two or more fans are set up side by side. It can be seen the air flow rate Q is increased when using two fans in parallel and the flow is nearly doubled when there is no resistance in the system. However, it can also be noticed that the static pressure rise ΔP of the fan set is not changed. Therefore, the parallel operation applies to situations where more air flow is needed and the system resistance is low. For series operation (two or more fans in series), the static pressure of the fan series is almost doubled. However, the maximum flow rate is not increased. Series operation can be considered when the resistance of the system is high because single fan is not able to deliver adequate air flow for cooling. Higher static pressure is needed to overcome the resistance of the system. When the system impedance or load (denoted by the dotted curve in Fig. 1) is assumed as a typical condition based on actual use, the intersection points with the P-Q curves are the practical working condition of the fans in the system.

No matter for single fan or for two/multiple fans in series, the radiated noise contains both broadband (random) and tonal (discrete) components. Basically, broadband noise means noises which are not phase-locked with blade rotation. Mechanisms of broadband noise may include the following. First, there is flow turbulence at the rotor inlet (which may be from ingested atmospheric turbulence [1]). It creates unsteady forces on blades regardless of the blade rotation. Similarly, flow turbulence in the wake extending from the blade trailing edge is also not dependent on blade rotation. On the blade surface, boundary layers are naturally unstable and a wave called Tollmien Schlitchting wave, or TS wave for short, develops and convects with the mean flow towards the

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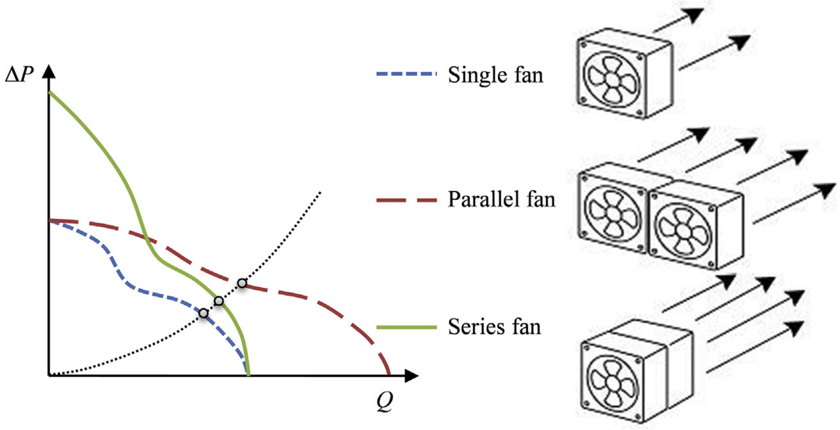

Fig. 1. The P-Q curve comparison among single fan, two fans in parallel and in series.

trailing edge. When the waves are terminated by the trailing edge (TE), some of the wave energy is scattered into sound energy and the noise thus generated is called trailing edge noise [2,3].

For discrete noise, there are also a number of potential mechanisms. The relative importance of each type very much depends on the specific application. Gutin [4] was one of the pioneers in propeller noise research in 1930 s. The steady flow loading noise on rotating blades, called Gutin noise (including thickness noise) is normally insignificant or even almost completely negligible for small axial-flow cooling fans with slowly moving fan blades. Much more potent is the interaction between a rotor and stationary structure like downstream stator blades or motor struts found in cooling fans. The general qualities and mechanism of rotor-stator interaction noise related to the upstream wake or velocity defects were described by Blake [5]. Lu et al. [6] focused on the fundamental aerodynamic mechanism of rotor-strut interaction for a computer cooling fan by the numerical simulation method and several interesting and new findings were pointed out although they were obtained from the specific fan used in their study and their generality remained to be proved. Another important noise source is the inlet flow distortion. A distorted or nonuniform inlet flow may be caused by the four sharp edges of the incomplete bellmouth cut by the square outer frame, thus leading to a four-lobe distortion pattern, or by some obstacles in front of the fan inlet. The former is an unreasonable design commonly noticed in most small cooling fan products [7,8]. The latter will be studied in the current study after simplifying it to be a flat plate blocking part of the inlet flow passage. Other causes of pressure fluctuation which may be controlled by the blade rotation include tip leakage vortex [9,10] and vortex shedding from struts and blades [11]. The tip leakage vortex may hit and interact with adjacent blades or the downstream blade row. These events create noise in a far more efficient manner than Gutin noise.

For single fan, the total noise can be decomposed into the contributions made by the tonal and broadband components. However, for the current studied case of two fans in series, both the tonal and broadband noise components can be further attributed to either upstream or downstream rotors. The following several issues may be key and hot concerns for researchers, scholars and engineers in the field of two- and multi-stage fan noise control. (1) Which fan of the double series fan contributes more noise, the upstream or the downstream one? (2) Which noise source component accounts for the largest part, the tonal noise or the broadband noise? (3) What is the difference between the results when the fan is operated with free (unobstructed) inlet and distorted inlet? The answers of those questions would definitely be very useful and helpful for industry applications such as in designing a quiet two-stage or even multiple-stage fan and adopting an appropriate method to reduce noise. The noise source analysis results of two identical small axial-flow cooling fans in series in free space (zero system resistance) are discussed in our previous study [12]. Another interesting issue is if there exists any difference between the results when the fan is operated under free space and its usual working condition (a specific back pressure). Therefore, in the current study, the noise measurement of this two-stage fan is performed under the typical operating condition of back pressure being 120 Pa, in consideration of the fact that the aerodynamic environment of a cooling fan inside a computer or other electronic instruments does present extra sources of noise which is not encountered in free space.

2. Experimental methodology

2.1. The tested fan

Fig. 2 shows the front and back views of the tested fan. The fan consists of 7 upstream rotor blades ($B = 7$) and 11 downstream stators behind the rotor to change the flow direction, support the motor assembly and connect the outer square frame. The hub radius, tip radius and axial chord of the rotor blades are 31.5, 56.8 and 20 mm respectively. The inner diameter of the circular flow passage is 116 mm, thus the tip clearance for the rotor blades is 1.2 mm.

2.2. The sound-absorbing fan test rig

The P-Q curve, also called characteristic curve, is used to evaluate the aerodynamic performance of fans. It is typically a curve of the air volume flow rate Q versus static pressure rise ΔP_s or total pressure rise ΔP_t. The fan test rig shown in our previous study [13] is built according to ANSI/AMCA Standard 210 [14], one of standards which establish a uniform method of laboratory testing to measure the aerodynamic performance of fans. In order to realize both functions of aerodynamic and acoustic performance measurement, a sound-absorbing fan test rig, indicated in Fig. 3(a), is built based on the fan test rig for pure aerodynamic performance measurement in [13]. The sound-absorbing fan test rig is used to realize both functions of adjusting back pressure and absorbing the additional noise radiated by the test rig as far as possible. The whole duct, 116 mm in inner diameter D, is made of perforated panel with 2 mm in aperture diameter and 40%–50% in perforation