EFFECTS OF BLADE TIP DESIGN REVISIONS ON AIRBORNE NOISE OF AN AXIAL FAN

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SUMMARY

Military axial fans are designed to offer high durability and high performance; hence they have increased noise levels. However, they are expected to have lower noise levels to enhance comfort in human-occupied areas and to ensure operational discretion. Sound power level of the sample fan is measured as 86.3 dB(A). Fan speed reduction and design revisions has been considered to prevent airborne noise. Design revisions of the fan blades has been performed which includes notched trailing edge and bevelled blade tip design variations. In this study, analysis and tests results of both aerodynamic and acoustics of the fan are shared to present the effect of the fan speed reduction and design revisions on the performance and sound power level of the fan.

INTRODUCTION

Military axial fans are mostly used in aerospace and defence industry due to the fact that they are specifically designed pursuant to military standards. Military standards requires axial fans to pass such as sand and dust, durability and EMI&EMC tests. Another point to consider is that axial fans shall supply high performance, since they are generally used in HVAC systems of aircrafts and military vehicles. HVAC systems are generally used for air conditioning in human-occupied areas such as cockpit and for cooling the equipment inside such as electronic devices that generate high amount of heat. Furthermore, they are required to have low noise for the purpose of maintaining operating discretion and improving comfort in places occupied by people.

The aim of the study is to reduce the noise level of a military axial fan that works at 6000 rpm. The main source is determined as airflow induced noise according to results of acoustic measurement, since noise level peaks occur at blade passing frequency of the fan. Thus, rework design that may improve aeroacoustics features of the fan is considered to reduce the noise level.

Different solution methods and model designs that have been studied in the past to prevent and improve air flow-induced noise in axial fans have been investigated in the literature. By examining wing designs in the literature, knowledge was created for future studies. Novakovic et al.[1] studied nine different blade models on an axial fan based on previous studies in literature. In these model studies, modifications were made on the wing, at the hood end of the wing and at the wing edge, and the effect of this modification on the aerodynamic and acoustic properties of the fan was shown with test results and compared with the main model. It was observed that the sound level decreased in all changes except for the modification in which a fin was added to the wing and the modification in which a ring was added to the end of the hood. Among the fans that were improved, the aerodynamic performance of the fans that only had flaps added to the wing tip and deep teeth added to the leading edge of the wing did not decrease. Qingyi et al.[2] conducted a study on improvement of the design of the trailing edge of an axial fan blade. The trailing edge of the axial fan is flat, and it is designed to be radial in three different radii in order to reduce the airborne noise level of the fan. In this study, sound pressure levels at blade passing frequency (BPF) of the fan is mentioned in order to compare airborne noise reduction of prototypes. Acoustic tests have shown that blade designs with radial trailing edges reduce the sound level by considering the first and second harmonics of its BPF.

In this study, notched trailing edge and bevelled blade tip design variations are designed to apply rework on the sample fans. Acoustic and aerodynamic performance of the fan are compared both numerically and experimentally.

DESIGN STUDY

The sample fan is a five-blade axial fan that rotates at 6000 rpm with 28 V. Hub diameter and shroud diameter of the fan are 75 mm and 146 mm respectively. The model of the fan is shown in Figure 1.

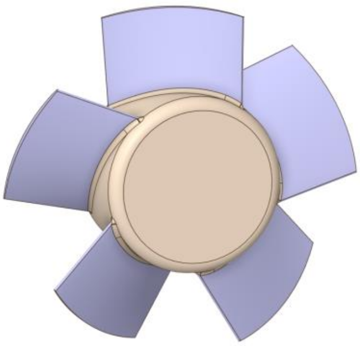


Figure 1: Model of the sample fan

The sample fan can supply up to 460 CFM (781.5 m^3/h) volumetric flow rate at open air as shown in its performance curve that given in its datasheet shown in Figure 2. Performance curve of the fan is determined by performance curve tests according to AMCA 210-2007. Performance tests are explained in Aerodynamic Tests section.

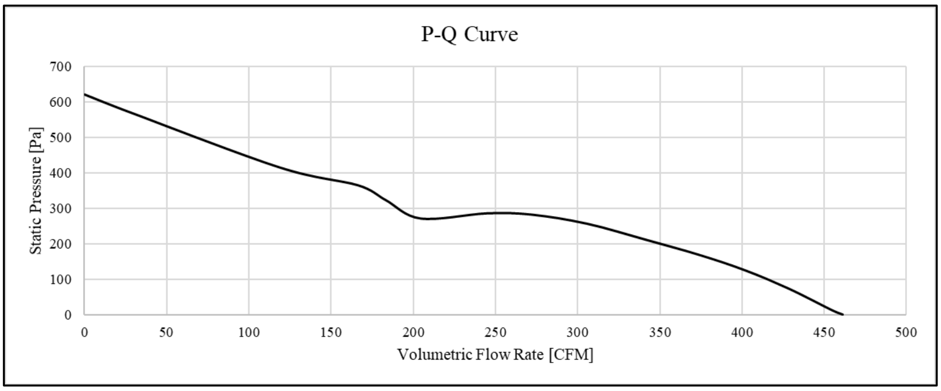


Figure 2: Performance curve of the fan

The total sound power level of the fan is measured as 86.3 dB(A). Besides, sound pressure level is measured at 3-feet (0.91 m) at the inlet of the fan in order to determine the noise level of the fan, since it is the noise level value given in the datasheet. Frequency spectrum of the sound pressure level is given in Figure 3. Frequency spectrum is determined by using Fast Fourier Transform (FFT) of the acoustic measurement in fully anechoic room that complies with ISO 3744-2010. Peaks on the frequency spectrum are checked with the aim of determining the main source of the noise, and it is observed that peaks occur at 500 Hz and its harmonics. The blade passing frequency of the fan is calculated as 500 Hz as given in Equation 1. That shows that the main noise source of the fan is airborne noise.

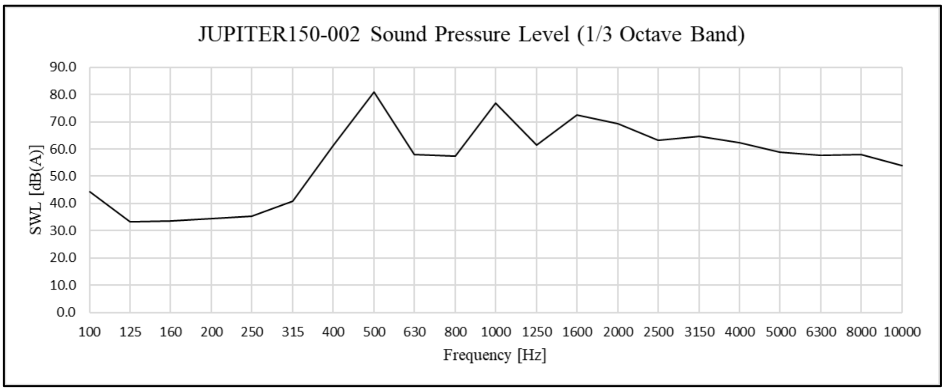


Figure 3: Sound pressure level of the sample fan at 0.91 m

$$\mathrm{BPF}_{\mathrm{Sample}} = \frac{6000 \cdot 5}{60} = 500 \text{ Hz} \tag{1}$$

Two new models of fan blades are designed to lower airborne noise level by reducing vortexes at the tip of the blade as the result of literature research. Rework design are considered and prioritized to keep performance curve as reducing the noise, and additionally, to get production process fast and easier. Thus, two new fans are designed directly on the same blade model of the sample fan. Revised designs of the fan are given in Figure 4, which blades have notched trailing edge (A) and bevelled tip added on notched trailing edge (B).

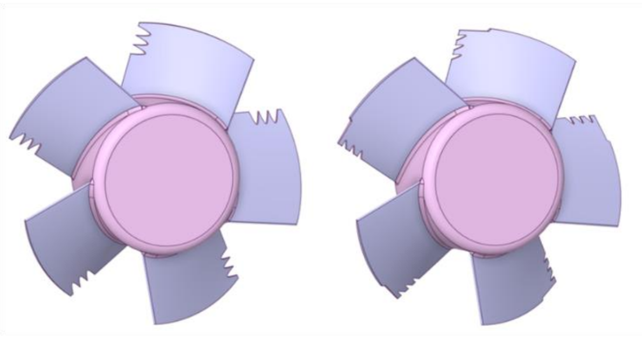


Figure 4: Revised blade models

PERFORMANCE AND ACOUSTIC ANALYSIS

Analysis of sample fan and revised models are conducted at steady state using shear stress transport on CFX. Mass flow at inlet and static pressure at outlet of the fan are defined under normal conditions. Aerodynamic analyses are performed at operating points which are above stall region of the sample fan which is in 250-460 CFM (424.8-781.5 m^3/h). Twenty harmonics of blade passing frequency is considered to calculate total sound power level in order to determine the frequency range up to 10 kHz, so that, results can be compared to the acoustics tests.

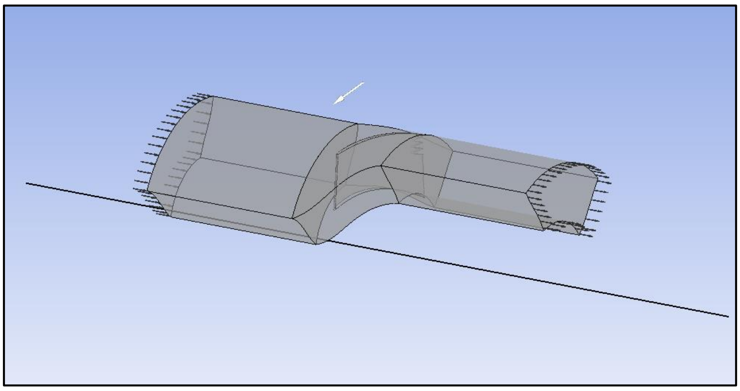


Figure 5: Flow domain

Performance curves of the sample fan and revised design are shown in Figure 6. Average static pressure at outlet of the fan is considered as performance criterion to compare three fans in determined flow rate region. It is noted that the sample fan has higher performance at analysis result than its performance curve on datasheet, yet overall characteristic of the curve is resulted similar. Overall performance in operating region of Model A and Model B are observed to be lower with average of %3 and %16 than the sample fan respectively.

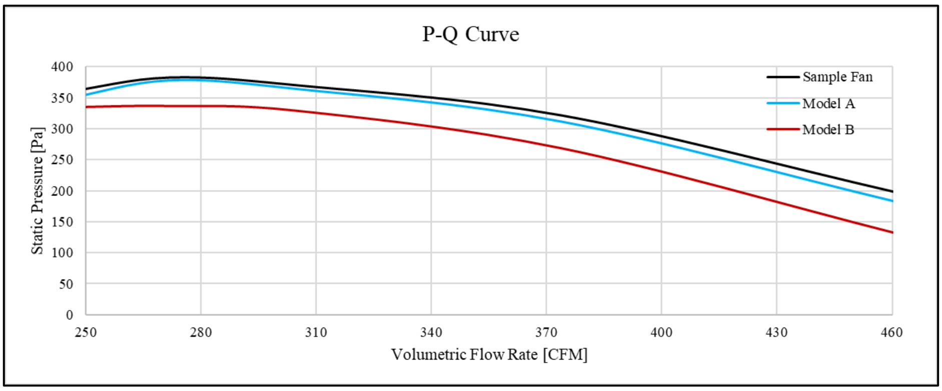


Figure 6: Performance Results of Analyses

Sound power levels and sound pressure levels at 0.91 m of three fans are given in Table 1. Total sound power level of twenty harmonics of the sample fan is turned out to be 84.3 dB. Design revisions on Model A decreases the sound power level by 0.7 dB with marginal performance loss. The sound power level of Model B is 3.1 dB lower than the sample fan, however, its performance curve is considerably lower.

Table 1: Sound Level Results of Analyses

Model	**Sound Power Level [dB]**	**Sound Pressure Level [dB]**
Sample	84.3	74.1
A	83.6	73.4
B	81.2	71.0

PERFORMANCE AND ACOUSTIC TESTS

Aerodynamic Tests

Performance tests of the fans are conducted on a test set-up that is designed according to AMCA 210-2007 that is showed in Figure 7 and Figure 8. Fan is mounted on the inlet of the test set-up at point 1. Static pressure value is measured at point 2 right after the inlet. Volumetric flow rate is calculated by using pressure difference at nozzles on point 3. Air exits the test set-up at point 4 where a blower is placed to set different pressure points in order to determine the performance curve.

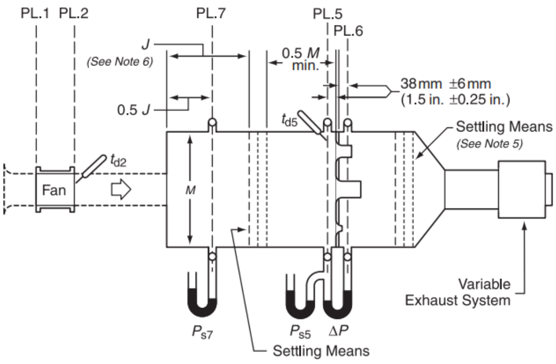


Figure 7: Outlet chamber Setup - Multiple Nozzles In Chamber (AMCA210-007)

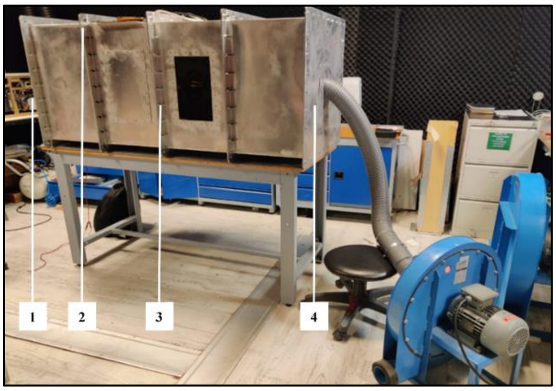


Figure 8: Set-up of performance tests

The performance of the fans are determined by conducting test on their operating regions. The sample fan is also tested with revised models in order to prevent any inconvenience caused by external effects. It is important to note that the stall region of the fans is kept exceptional and not tested, since it is not an optimal operational condition.

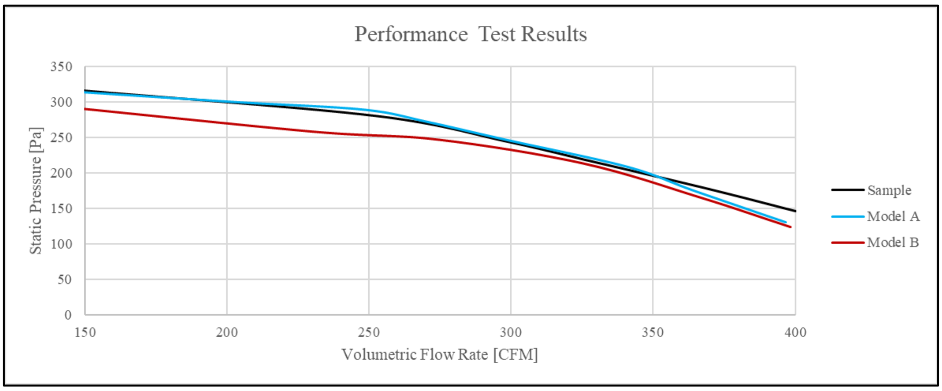


Figure 9: Performance comparison of fans

Comparison of the performance of the fans are determined by comparing static pressure at the same flow rate. It is observed that Model A has 2% performance loss at overall curve where Model B has 7% performance loss in Figure 9. Performance of Model A and Model B are getting closer as volumetric flow rate increases.

Acoustic Tests

Acoustic tests of the fans are conducted in a fully anechoic room according to ISO 3744-2010. Test set-up contains 11 microphones which are 10 microphones for measurement of sound power level and one microphone for measurement of sound pressure level at 3-feet (0.91 m) distance. Ten microphones are located spherically around the fan and the radius of the semi-sphere is 2 m as shown in Figure 10. The eleventh microphone is located at the inlet (suction side) of the fan. Fan is fixed on a tripod and placed in the middle of the anechoic room. Acoustic measurements are conducted for 60 seconds for each fan. In this study, sound pressure levels of the fans are considered to observe the noise reduction on blade passing frequencies. However, sound power levels are also mentioned to compare overall noise levels. Both sound pressure level and sound power level results are given with A-weighted frequency filter.

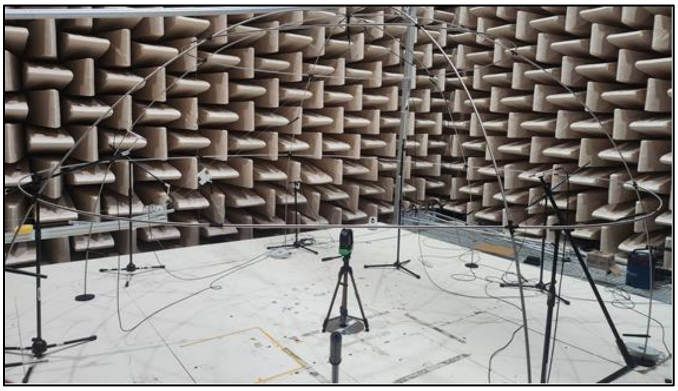


Figure 10: Test set-up of acoustic measurements

Frequency spectrum of sound pressure level of fans are shown in Figure 11. It is observed that sound pressure level of revised design models are lower at blade passing frequency and its harmonics. Especially, decrease in the sound pressure levels of Model A and Model B reaches up to 1.8 dB(A) and 2 dB(A) in the third harmonics respectively.

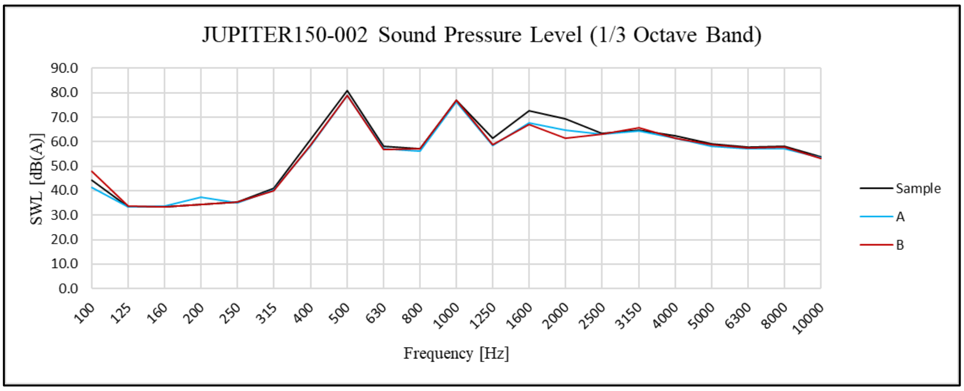
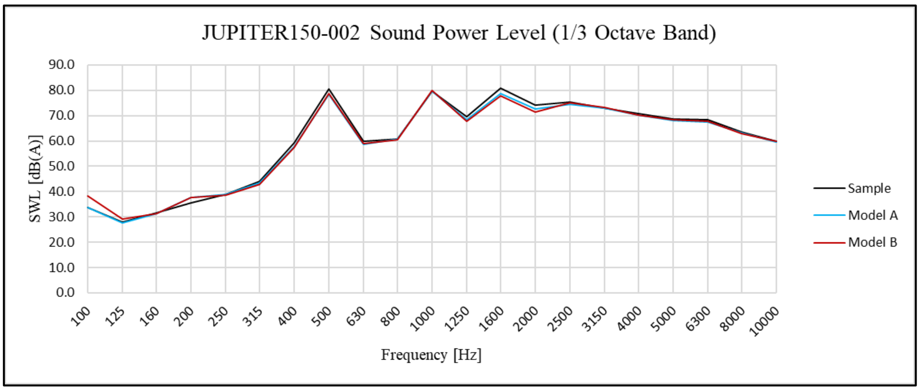


Figure 11: Sound pressure level comparison of fans

Frequency spectrum and overall total of sound power level is given in . The overall sound power level of Model A and Model B are both 85.1 dB(A) which is 1.2 dB lower than the sample fan. Additionally, sound power level decrease is distinct on the third harmonic of the blade passing frequency.



CONCLUSION AND FUTURE WORK

According to aerodynamic analyses, Model B has the lowest sound power level, however, Model B is expected to have lower performance than both the sample fan and Model A. Model A and Model B have similar results of both aerodynamic and acoustic tests. That may be mentioned that bevelled tip and notched edge designs have similar effects on the aerodynamic features of the axial fan. Contrary to analysis results, the reduction in sound power level of both Model A and Model B has the same as 1.2 dB(A) as given in Table 2. Even though Model A and Model B have acceptable loss in performance according to test results, the reduction in noise level is not sufficient to consider.

Table 2: Comparison of Sound Power Level between Tests and Analyses

	Sound Power Level [dB(A)]	
Model	**Test Result**	**Analysis Result**
Sample	86.3	84.3
A	85.1	83.6
B	85.1	81.2

In the future work, a new fan design shall be created to have lower sound power level at present performance level. Number of blades can be increased to reduce the speed of fan, so that, sound power level due to high speed may be decreased and blade passing frequency is shifted. New blade tip design and swept blade design can be worked on the blade number increased fan. Notched edge and bevelled tip designs that are studied in this paper can also be applied on the new fan to maximize the reduction in sound power level.

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