Performance of Fans and Blowers
in Thermal Management

With the increase in power dissipation of components, there is a need for more air flow before resorting to liquid cooling. The increase in air flow demand and the price of energy have placed greater attention on the efficiency of air delivery systems. For example, the IT industry has already surpassed the aviation industry in annual energy consumption and it is estimated to double over the next three years. Approximately 50% of this energy is used for cooling purposes [1].

The most common types of air delivery systems in thermal management are axial fans and blowers. Now the question is how efficient these are and how much they differ for different sizes. The efficiency of a fan can be defined as follows:

$$\varepsilon = \frac{P_{fan} G_{fan}}{\varepsilon_{motor} V_{motor} I_{motor}}$$

Where,

P_{fan} = fan pressure drop (pa)
G = Volumetric flow rate (m^3/s)
ε = Fan efficiency
ε_{motor} = Electrical efficiency of the motor
V_{motro} = Voltage to the motor
I_{motor} = Current to the motor

The electrical efficiency can be estimated approximately as 70%.

The commercial fans provide their performance as a function of flow rate and pressure drop. One such curve is shown in Figure 1.

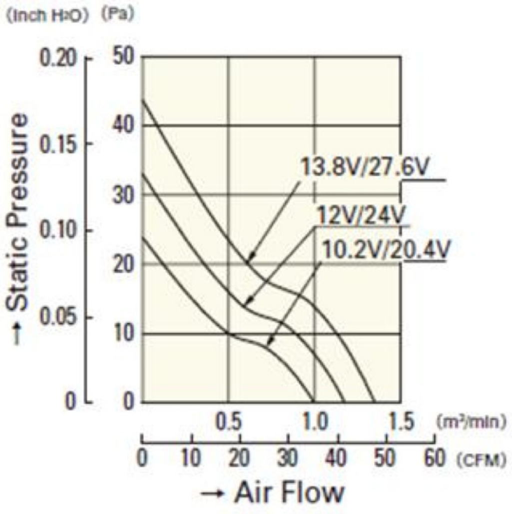

Figure 1- Performance Curve of a Commercial Fan [2]

These performance curves can be approximated as a line.

$$P = \frac{-P_{max}}{G_{max}} G + P_{max}$$

Where P_{max} and G_{max} are maximum pressure and volumetric flow rates, respectively. The maximum efficiency of the fan is where the product P_{fan} G_{fan} is maximum. Considering the product as below:

$$P \times G = \frac{-P_{max}}{G_{max}} G^2 + G P_{max}$$

$$\frac{d(P\times G)}{dG}=0 \text{ This yields } (P\times G)_{max}=\frac{G_{max}P_{max}}{4}$$

This point corresponds to the midpoint on the line with the corresponding maximum efficiency of

$$\varepsilon_{max}=\frac{P_{max}G_{max}}{4\varepsilon_{motor}V_{motor}I_{motor}}$$

Let’s look at some commercial fans and blowers and see what their efficiencies are. It is assumed that the product of voltage and current stays nearly the same for all loads. Table 1 shows some of these commercial fans with their respective size, thickness, voltage, current, volumetric flow rate, pressure and efficiency.

Type	Size(mm)	Thickness (mm)	P_{max}(pa)	V_{max}(m^3/min)	V(volts)	I(Amps)	Efficiency (%)
Blower	76	30	98	0.31	12	0.27	5.6
Blower	76	30	151.9	0.36	12	0.37	7.3
Blower	76	30	58.8	0.25	12	0.14	5.2
Blower	76	30	98	0.31	24	0.14	5.4
Blower	76	30	151.9	0.36	24	0.17	8.0
Blower	76	30	58.8	0.25	24	0.1	3.6
Blower	97	33	410	1.04	12	0.9	23.5
blower	97	33	760	1.34	12	1.8	28.1
Blower	97	33	490	1.11	12	1.1	24.5
blower	97	33	610	1.22	12	1.4	26.4
Blower	97	33	410	1.04	24	0.45	23.5
blower	97	33	760	1.34	24	0.83	30.4
Blower	97	33	490	1.11	24	0.55	24.5
blower	97	33	610	1.22	24	0.7	26.4
Blower	120	32	175.4	0.78	12	0.6	11.3
Blower	120	32	109.8	0.61	12	0.32	10.4
Blower	120	32	175.4	0.78	24	0.3	11.3
Blower	120	32	109.8	0.61	24	0.16	10.4
Blower	160	40	313.6	1.62	12	1.3	19.4
Axial fan	40	15	192	0.36	12	0.17	20.2
Axial fan	40	28	143	0.38	12	0.28	9.6
Axial fan	80	25	80.4	1.5	12	0.38	15.7
Axial fan	100	25	708	2.03	48	0.36	49.5
Axial fan	133	91	395	6.39	48	0.55	56.9
Axial fan	140	38	98	4.5	12	0.73	30.0
Axial fan	140	51	130	5.9	12	1.25	30.4
Axial fan	172	51	1000	15.46	48	2.91	65.9
Axial fan	175	69	360	9	48	0.65	61.8

Table 1- Typical Commercial Fan and Blower Efficiencies

The table shows that the efficiencies range from 3.6% to 65%. For small fans, the efficiency is very low, gradually increasing for bigger fans. For example, for 40x40x28 mm, the efficiency is about 9.6%. For typical servers in data centers, the fan size is about 172x172x51 mm, with efficiency of about 66%. For smaller fans, one can see that the energy lost is huge. For example, a 1-U system, using a 40x40x28 mm fan, has an efficiency of only 9.6%. This means that 90% of the energy input is lost, contributing to the cost of energy for cooling the electronics. Even for larger fans, an efficiency of 66% is low. The above efficiencies are based on the assumption of maximum efficiency, which is almost at the midpoint of the P-Q curve. In practice, the operating point may shift far away from the optimum point at the middle. For example, if you look at figure 1:

P_{max} = 45 pa
G_{max} = 1.35 m^3/min
P = -45/1.35G+ 45

Now assume the operating point is at the left hand side of the optimum point, at G = 0.3 m^3/min, P_{fan} = 35 pa

$$\varepsilon = \frac{P_{fan} G_{fan}}{\varepsilon_{motor} V_{motor} I_{motor}} = \frac{35 \times 0.3}{\varepsilon_{motor} V_{motor} I_{motor}} = \frac{10.5}{\varepsilon_{motor} V_{motor} I_{motor}}$$

$$\varepsilon_{max} = \frac{P_{max} G_{max}}{4\varepsilon_{motor} V_{motor} I_{motor}} = \frac{45 \times 1.35}{4\varepsilon_{motor} V_{motor} I_{motor}} = \frac{15.2}{\varepsilon_{motor} V_{motor} I_{motor}}$$

Comparing the maximum efficiency with the real efficiency, we can see that there is almost a 50% drop. In most applications for servers with increasing number of components, the pressure drop is most likely to be higher than that of the optimum point, so a 50% drop of the maximum efficiency would yield about 30-40% efficiency. The smaller fans have a much worse efficiency than the larger fans.

The situation gets worse for blowers, as can be seen from Table 1. In general, blowers are less efficient than fans. Figure 2 shows the theoretical characteristic and efficiency curve for an axial fan[3]. Point C is the design point, which corresponds to maximum efficiency. By moving to the right hand side of point C, the flow increases and the pressure decreases, but the efficiency drops very fast. To the left of point c, the situation is reversed and the efficiency drops very rapidly, too. If there is too much resistance on the fan to move the operating point close to around point D, the fan blades stall, resulting in discontinuity of the characteristic curve which causes instability of the fan.

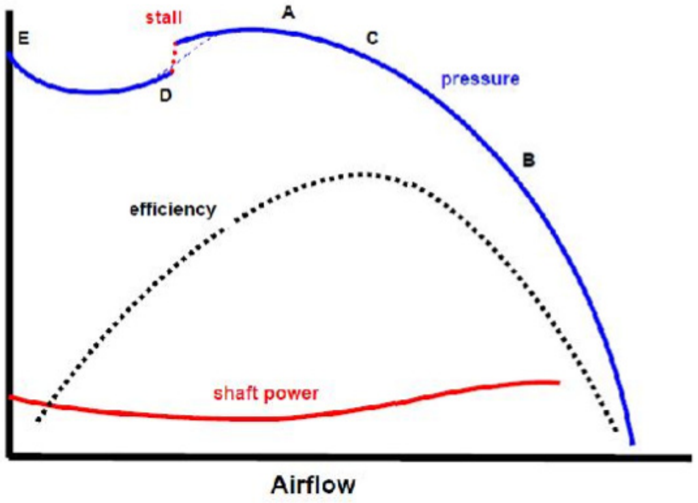

Figure 8. Loss Coefficient as a Function of Percent Blockage Area for a Fan [3]

To the left of point D, due to severe flow restriction, the boundary layers break away from the blades and centrifugal action occurs, producing recirculation around the blades. In practice, there are two losses in axial fans [3]. The recoverable losses that are associated with the vortices and rotational components leaving the fan. These losses can be minimized by operating at the design point and by utilizing guide vanes. As we depart from the design point, however, the swirling will build up.

The non recoverable losses are associated with friction at the bearing, drag on the casing, supporting rods, the casing and the blades. These losses are converted to heat, which is input to the system. Fans have been traditionally been used in cooling devices and will be used for the foreseeable future, since their implementation is the easiest. As the world becomes more concerned about energy uses and efficiencies of the systems, it is imperative that the designer takes into account all the factors that influence the performance of the fan. For example, in a data center with thousands of fans running, it is not difficult to see the benefit of improving the fan efficiencies which lead to huge financial gains and reduction of energy usage.

References:

1. Koplow, J., "A Fundamentally New Approach to Air-Cooled Heat Exchangers", Sandia Report SAN2010-0258
2. www.sanyo-denki.com
3. McPherson, J., "Fans", www.mvsengineering.com