Minimizing Aerodynamic Losses in Laboratory Fume Exhaust Systems:
A Unique Fan Design—US Patent 8,758,101.

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ABSTRACT

Upblast laboratory exhaust fans perform three tasks: drawing contaminated air out of the fume exhaust ductwork system, partially diluting it with surrounding clean air, and ultimately exhausting the diluted mixture into a tall upward plume. Traditionally, an inline model of such a fan includes an impeller, a guide vane section, a nozzle, and a windband. The impeller transmits axial momentum and swirl to the exhausted contaminated air. After that, the airstream expansion through the guide vanes followed by its contraction through the nozzle causes aerodynamic losses that were not sufficiently addressed in the initial design. It is possible to minimize these losses by eliminating both the expansion and the contraction. The final design discusses a patented fan housing (U.S. patent: 8,758,101) that combines the nozzle and the guide vanes into a single row of hollow open-ended airfoil vanes. The final design results in consequential improvements in fan energy efficiency, clean air entrainment rate, ease of assembly, and motor cooling options.

BACKGROUND

All laboratory exhaust fans generally are designed to maintain low toxic concentrations at fan discharge to meet environmental regulations. Therefore, such fans perform three basic functions:

- Removing potentially deleterious air from occupied spaces through fume exhaust ductwork
- Mixing the contaminated effluent air with clean outdoor air
- Shooting the diluted mixture up into a high-momentum plume away from occupied areas.

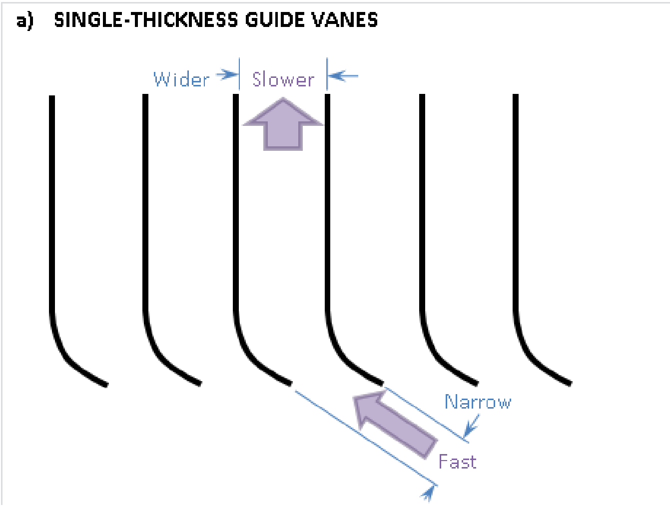
A rooftop laboratory exhaust fan that is typically equipped with a nozzle and a windband and can be tested in such a fashion that its outlet airflow is greater than its inlet airflow due to induced airflow is defined by AMCA test standard 260-13 as an “Induced Flow Fan,” among which the most commonly used are tubular inline mixed flow fans, and belt- and direct-drive. Traditionally, such fans are built on:

- Mixed-flow impellers to add axial momentum and swirl to the inlet air
- Single-thickness guide vanes to straighten the swirl
- Bifurcated design to cool and protect the motor and/or belt transmission
- Contraction nozzle for high-speed upblast discharge
- Windband for protecting the early stages of plume formation from crosswinds and the rooftop environment from potential contamination.

In addition, a windband may serve as a means to quantify induction or entrainment in a repeatable fashion when tested per AMCA standard 260-13. The author respectfully disagrees with the widespread opinion that a windband serves as a means to provide induction or entrainment of clean atmospheric air into the plume. While some windband designs do enhance induction by creating differential pressure around the nozzle, any upblast fan always induces some surrounding air into its jet. Induction of air into a bare jet was noted in turbulent jet theory (Abramovich, 1960) and verified experimentally in the Twin City Fan & Blower research lab.

Even without a windband, the laboratory exhaust fan design remains quite complex. Such a complex design results in a number of unnecessary momentum and energy losses, especially at high airflow rates. The single-thickness straightening vane section acts as a diffuser, which effectively reduces the discharge speed of air immediately past the impeller (see Figure 1a). Then, the contraction nozzle downstream from the vane section accelerates the air. Bifurcations and/or belt tubes also result in contractions and expansions. Any contraction or expansion imposes air-momentum loss, quantified as fan velocity pressure loss. To minimize losses and improve efficiency and functional fit, Twin City Fan invented TurboVanes™.

Figure 1: Stages of TurboVane™ Design.



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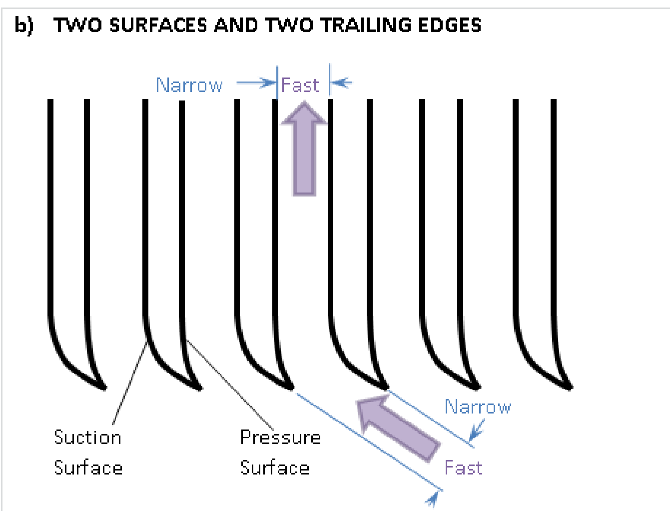

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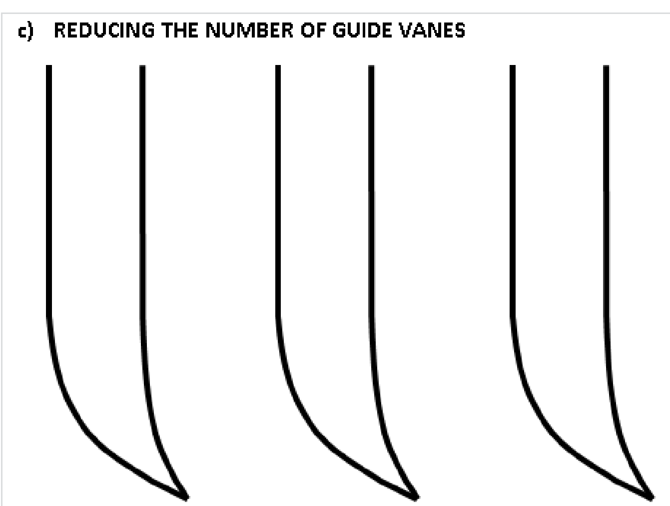

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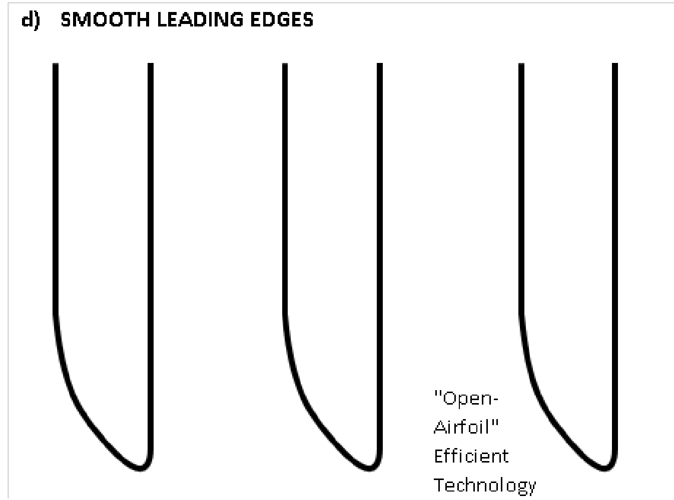

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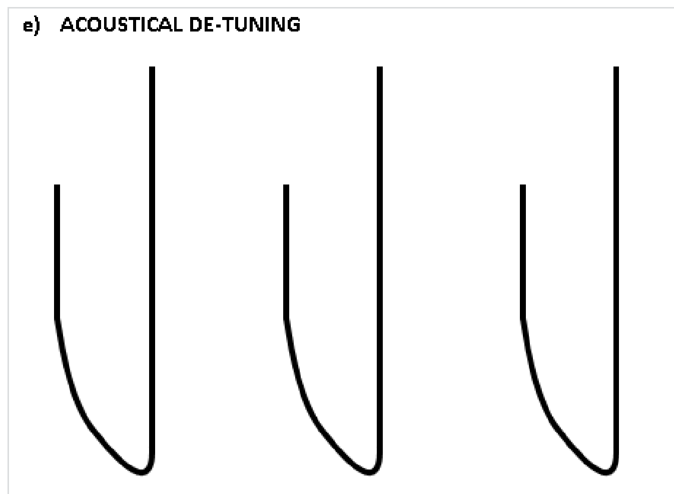

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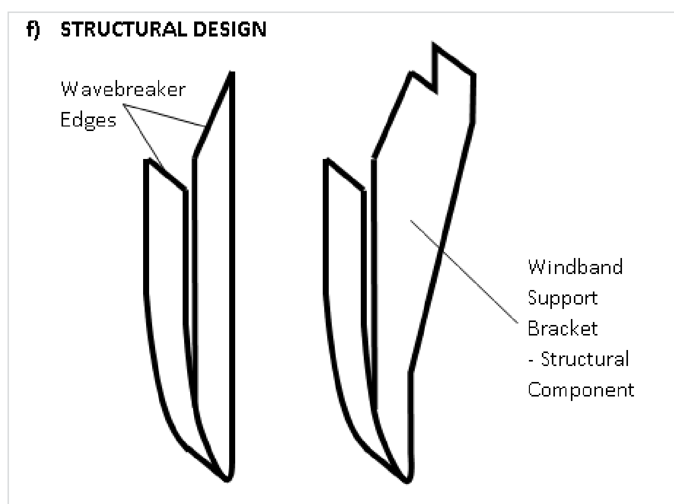

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PATENTED TURBOVANE™ TECHNOLOGY

To improve performance of the guide vane section, it would be logical to add some thickness to the vanes, thus preventing the airstream from slowing down, as shown in Figure 1b. However, merely doubling the number of surfaces and trailing edges would complicate the layout and effectively double the amount of material, forming, and welding operations necessary to make the vanes. Given feasibility of various layouts, it was determined that to maintain the same air performance, the sufficient number of double-surface vanes should be less than the original number of single-surface vanes. However, the vanes must be longer, as shown in Figure 1c. In this figure, sharp leading edges may severely limit the optimum performance range to a very short portion of a fan curve because they are “tuned” for a fixed swirl angle of air discharging from the impeller. Structurally, sharper corners would be more difficult to align for welding, and, once welded, they may serve as stress risers. Also, once installed, sharp edges may accumulate rainwater, thus leading to premature corrosion. Another, less-obvious shortcoming of the Figure 1c design is that the suction surface has a different curvature from that of the pressure surface, which implies the need for extra tooling.

To resolve the aforementioned issues, Twin City Fan rounded up the leading edges (similar to airfoil technology) and made the pressure surfaces straight, as shown in Figure 1d. This design change dramatically improved air performance, and hence it was patented, trademarked as TurboVanes™, and used as a basis for a new product line “TVIFE”: TurboVane™ Induced Flow Fume Exhaust Fan—Direct Drive.

The advantage of bluff leading edges is that they can adjust to various swirl angles thus making the fan very efficient throughout a wider range of system resistance points.

To improve the acoustic performance, we made suction surfaces shorter than pressure surfaces as shown in Figure 1e. This asymmetric vane design did not affect air performance, slightly increased entrainment, and significantly reduced tonal prominence of fan sound. However, shortening only one surface of the vane limited flexibility of the motor-cylinder geometry, which should be kept adjustable to accommodate various outlet areas, as will be discussed later. To retain the flexibility of the motor-cylinder design while providing sufficient structural rigidity, Twin City Fan also shortened the pressure surfaces, but only on the inner motor-cylinder side as shown in Figure 1f. In this figure, the flat pressure surfaces are structurally designed to handle weights of the motor and the impeller, vibrations, and thrust load. Furthermore, these surfaces were extended outward to serve as windband support brackets, thus improving overall rigidity while reducing the number of parts and the amount of welding. Another essential feature that makes this design simple and robust is Arrangement 4 direct drive where motor cooling uses clean outdoor air drawn through TurboVanes™.

The overall fan design and application example of TVIFE is shown in Figure 2.

Figure 2: TVIFE Application Example.

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TURBOVANE™ OPTIONS

In laboratory exhaust applications, it often is necessary to cover various combinations of inlet airflows and pressures, nozzle air velocities, and entrainment ratios with a given fan size. Historically, velocities of air discharging from a nozzle can be varied by offering multiple detachable nozzles with different outlet areas. TurboVane™ technology offers a unique nozzle by design. To maintain consistent language with the rest of the fume exhaust market and standards, and to differentiate from windband outlet area, the author will continue using the terms “nozzle” and “nozzle outlet area,” which, in this context, mean “the combined outlet area of segments between TurboVanes™,” as shaded in pink in Figure 3b. Twin City Fan investigated a number of options to vary this outlet area.

Figure 3 (a, b): Mixing Perimeter.

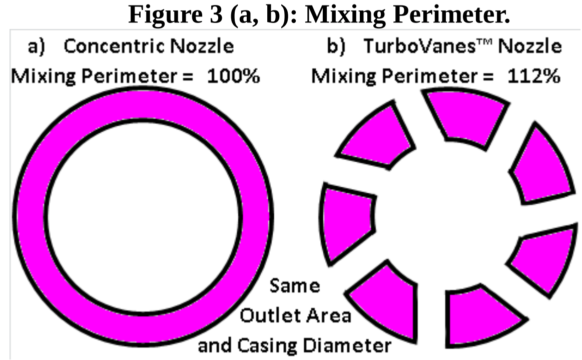

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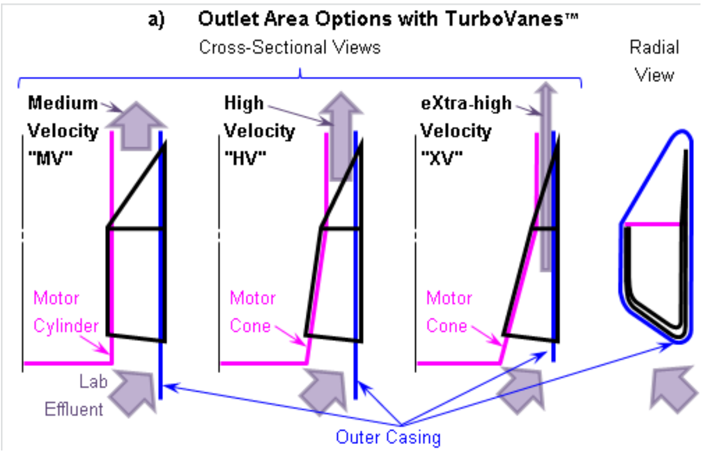
Figure 4 (a, b): TurboVane™ Options.



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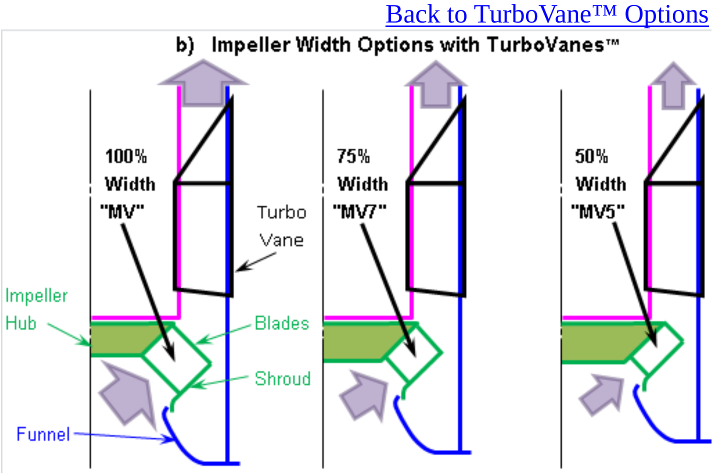

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Changing the vane geometry and the number of vanes is possible but limited by the motor-cylinder geometry and structure. Instead, it was decided to vary the motor-cylinder geometry itself. Figure 4a shows such variations. A straight motor cylinder provides the largest offered nozzle outlet area, which corresponds to medium velocity (MV) of air at the nozzle. When it is necessary to reduce the nozzle outlet area, the lower portion of the motor cylinder (along the span of TurboVanes™) is replaced with a conical surface. The top portion of the cylinder is kept cylindrical, increased in diameter, and extended to full length to protect the motor from hazardous fumes. Two discrete motor cones were offered, which result in high (HV) and extra-high (XV) velocity nozzles. Note that the vane cross section stays the same for all three nozzle outlet area options.

To satisfy various competitive regimes of required aerodynamic performances at the optimum motor load and efficiency, Twin City Fan found it necessary to offer three discrete mixed-flow impeller widths: 100%, 75%, and 50%, as shown in Figure 4b. Narrow-width impellers use larger hubs, shorter blades, and the same shroud (same outer tip diameter) as the full-width impeller. Therefore, each permutation of impeller width and nozzle outlet area carries its own distinct set of rating data tested per AMCA Standard 260-13.

CONCLUSIONS

Table 1 shows a sample comparison of these ratings against a few other products with best-matching air path geometries of inlet cone, impeller, nozzle, and windband. On competing belt-driven fans, belt losses were not included into horsepower ratings for the purpose of this comparison. Various critical-performance parameters were compared at the same fan inlet airflow and static pressure, which correspond to nozzle peak total efficiency point of operation of the Competition 1 Fan. According to these comparisons, TurboVane™ design outperforms single-thickness vanes in all aspects.

In particular, TurboVanes™ indicate better entrainment ratio at a given inlet total efficiency (see TExER column), which is often attributed to "additional air drawn through the vanes." Instead, perhaps, it would be more appropriate to say that mixing and entrainment are driven primarily by the regions where high- and low-speed airstreams are just starting to mix. Then, one may expect higher entrainment rates where mixing occurs over a larger perimeter, thus developing instability and turbulence over a larger volume. Figure 3 indicates that the mixing perimeter of TurboVanes™ is 12% larger than that of a conventional concentric nozzle. Thus, TVIFE offers the best combination of efficiency and entrainment ratio available in the market.

REFERENCES

Abramovich, G.N. "**Turbulent Jet Theory**", 1960, Gosudarstvennoe Izdatel'stvo Fiziko-Matematicheskoj Literatury, Moscow, USSR

Table 1: Performance Comparison. Back to Conclusions

Fan	Inlet	SP	RPM	BHP	Outlet	Inlet TE	Entrainment	TExER	Outlet LwA
Model	CFM	iwc		HP	CFM	%	Ratio, %	%	dBA
300MP TVIFE	**16600**	**2.7**	1,332	**12.79**	27,888	**79.2%**	168%	**133%**	**92**
COMPETITION 1			1,371	16.14	27,344	72.3%	165%	119%	92
COMPETITION 2			**1,050**	14.00	21,600	70.7%	130%	92%	93
COMPETITION 3			1,394	15.76	28,718	68.8%	173%	119%	94
COMPETITION 4			1,275	15.42	**32,204**	64.9%	**194%**	126%	96