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Application of a Flow Optimizer in a Limited Space to Increase Series Fan Performance

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***Abstract*—The performance increase of cooling for a 1U SunFire 4100 server through the introduction of multiple flow optimizers is investigated in this article. We found that the power consumption of cooling fans could be decreased by 17–33% depending on operating conditions. The use of flow optimizers was found to reduce noise produced by cooling fans by at least 5.3 dB(A). We also discuss the use of the increased performance to increase thermal head room by increasing the flow rate of cooling air by 6.5–20.4%.**

In addition, we found that a primary fan used with an exit stator allowed the overall fan module length to be reduced without a loss in performance. Reducing the length allowed the flow optimizers to fit into the standard 56-mm space previously occupied by the original series fans. CFD analysis was performed to better understand the effect of this stator on airflow.

***Keywords*—Series fans, flow optimizer**

Introduction

The increasing density and power of components within 1U servers has escalated cooling demands. This presents a particular challenge when upgrading processors because there are many other design restrictions such as cabinet layout, the position of other components, and so forth. In many cases, it may seem intuitive to add fans in series with the existing fans for enhanced performance and redundancy; however, this is an inefficient solution due to the nonideal characteristics of the airflow as it enters the secondary fan. Space limitations dictate that the secondary fan must be placed in close proximity to the existing or primary fan. Unfortunately this means that swirl introduced by the primary fan is still present at the entrance to the secondary fan because the close positioning does not allow sufficient space for the swirl to dissipate.

Previous studies [1, 2] have investigated how the introduction of a diffuser element between two close-stacked series fans could increase their performance significantly. Our investigation found that the performance gap, shown in Fig. 1, was critical to the overall performance of the module. However, space limitations may necessitate a shorter than optimal spacing. This was the case for the SunFire 4100 server manufactured by Sun Microsystems (Santa Clara, CA).

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To facilitate an upgrade in the CPU power for the SunFire 4100 server, the flow rate provided by their cooling fans had to be increased. Preferably, any upgrade to the current cooling system should fit in the same space as the existing fans. The use of the flow optimizer depicted in Fig. 1 offered a solution, however, the fans' performance was expected to be suboptimal due to the space limitations. This would reduce the thermal head room they could provide. The performance limitation was overcome through the introduction of primary fans with exit stators.

Although the current study focuses on the SunFire 4100 server that is 1U (44.5 mm) in height, the need to increase flow rates for cooling without increasing the fan footprint is present throughout the computer industry. This need has lead to the development of larger flow modules with 172-mm, and 120-mm fans for use in larger computer servers and fan trays.

This article describes the flow rate and acoustic and thermal tests conducted to determine the performance gains resulting from the use of flow optimizers in the SunFire 4100 server. We discuss the details of the computational fluid dynamics (CFD) analysis that was conducted to investigate the effect of the primary fan exit stator. An investigation of the application of flow-optimization technology to the SunFire server will increase our understanding of this technology so that it can be optimized for other commercial applications.

Experimental Procedure

Flow Bench Testing

A standard flow bench, based on the work of Gerald Recktenwald [3] was used to test the performance of the two different TFB0412EHN fans [4], manufactured by Delta Electonics (Kuei-shan, Taiwan) so that actual performance could be compared with the manufacturer's stated performance (see Fig. 2). Once it was confirmed that actual performance fell within the stated tolerance limits, the theoretical two-series fan limit for these fans was determined by adding the two performance curves together in a series or vertical sense (see Fig. 3).

Next, the actual or current SunFire 4100 results were obtained by using a test bracket to hold the same two Delta TFB0412EHN fans in series on the flow bench. The test bracket was designed to simulate the geometry of the sheet metal holding each pair of fans in place in a SunFire 4100 server, as shown in Fig. 4. Specifically, the bracket provided coaxial alignment and a 24-mm spacing between the two

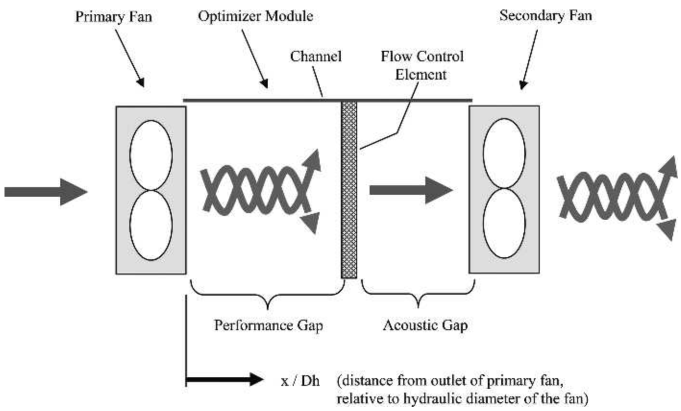

Fig. 1. The general layout of an optimizer module.

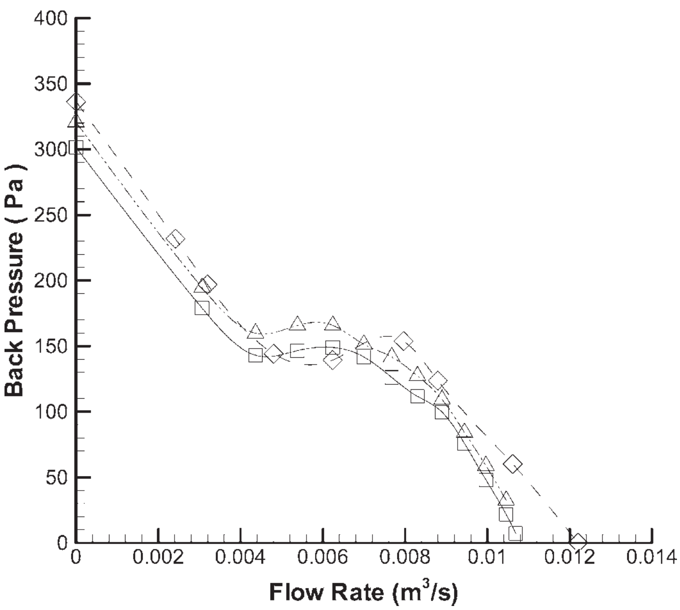

Fig. 2. Single fan test results vs. manufacturer's data. *Diamonds* represent manufacturer's data for TFB0412EHN; *squares* represent primary fan; *triangles* represent secondary fan.

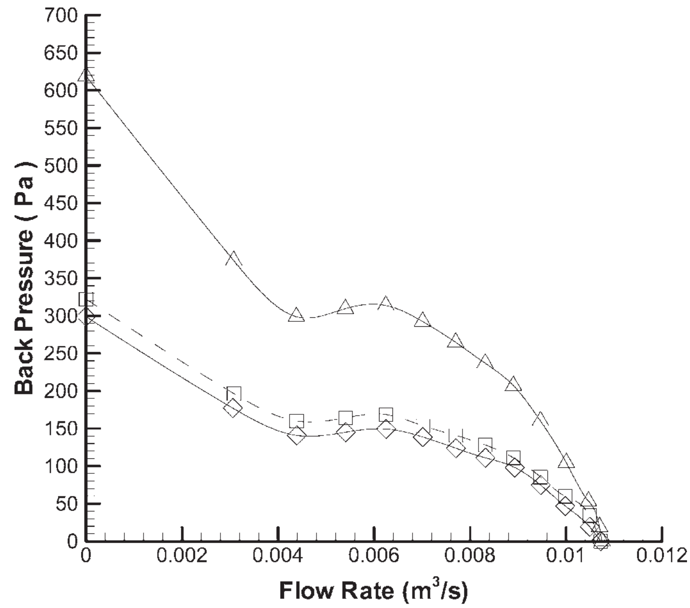

Fig. 3. Single fan results and theoretical two-fan limit. *Diamonds* represent primary TFB fan; *squares* represent secondary TFB fan; and *triangles* represent theoretical limit.

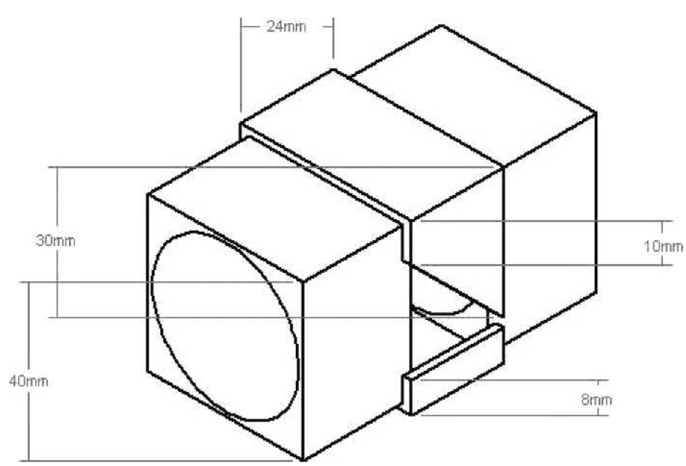

Fig. 4. SunFire 4100 test bracket.

fans. However, the test bracket did not have the side openings present in the actual SunFire 4100 sheet metal shown in Fig. 4 and therefore provided better flow control than the actual product installation. Hence, the test data are considered to be conservative and are likely to overstate the actual SunFire 4100 fan performance.

The purpose of this second series of tests was to determine the current level of performance and to compare this performance with the theoretical two-fan limit for the underlying Delta TFB0412EHN fans. Not surprisingly, the current level of performance fell below the theoretical two-fan limit, as shown in Fig. 5. Acoustic noise (SPL, dBA) and power consumption were also monitored across the operating range to establish a baseline for these parameters, allowing for a comparison with the optimized design.

The single cluster data (i.e., the performance data for a single pair of Delta TFB0412EHN fans mounted in the test bracket), was then used to determine the theoretical output of six such pairs of fans in parallel, as installed in the SunFire 4100 server. Generally this may be calculated by multiplying the single pair airflow in cubic feet per minute (CFM) by a factor of six for any given static pressure. The calculated overall performance for the 12 × Delta TFB0412EHN fans, as they are currently configured in the SunFire 4100 server, is provided in Fig. 6.

Finally, the test bracket was replaced by a flow optimizer and the same two fans were retested in this optimized configuration. In this case, the performance curve lies above the theoretical two-fan limit and over the normal operating range, as seen in Fig. 5. Again, the acoustic, RPM, and power data were monitored along with the flow rate and back pressure.

The performance of six such flow optimizers configured in parallel was then determined using the method outlined above. It is clear that the optimized performance exceeds current

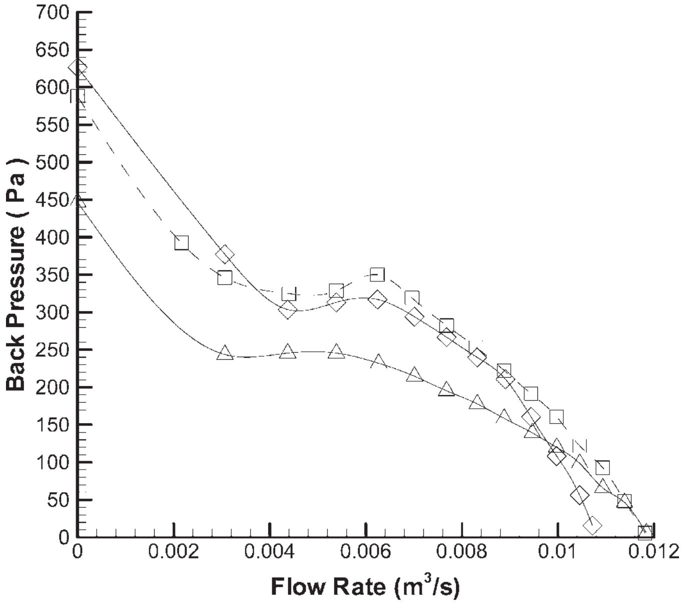

Fig. 5. Current and optimized performance relative to theoretical limit (2 fans). *Diamonds* represent theoretical limit; *squares* represent Optimizer; and *triangles* represent SunFire 4100 actual.

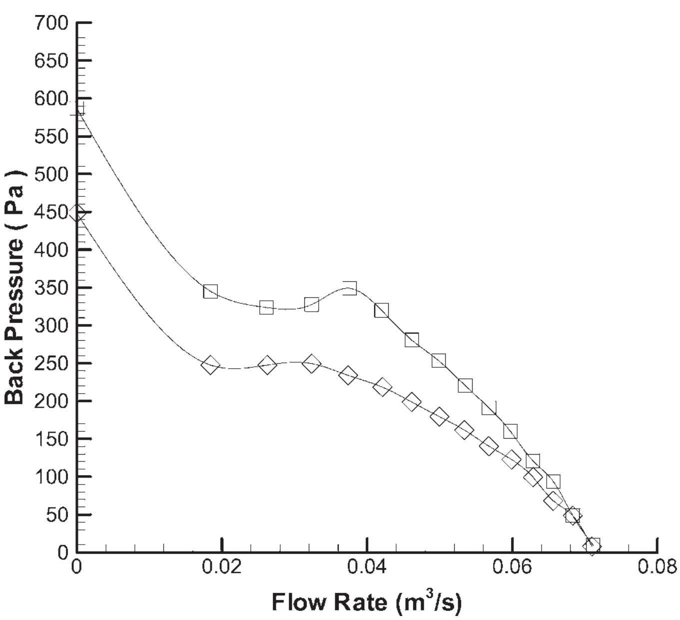

Fig. 6. Total current and optimized performance (12 fans). *Diamonds* represent SunFire 4100 actual; *squares* represent Optimizer.

performance for all back pressures as depicted in Fig. 6. Importantly, these performance gains may be achieved by simply installing a flow optimizer between each pair of fans within the SunFire 4100 server. All other cabinet specific dimensions, including the space between the fans, remain the same.

Acoustic Measurements

The noise level of the current and optimized configurations were measured using the standard Delta procedure [4], adapted to suit the laboratory conditions and available equipment. The

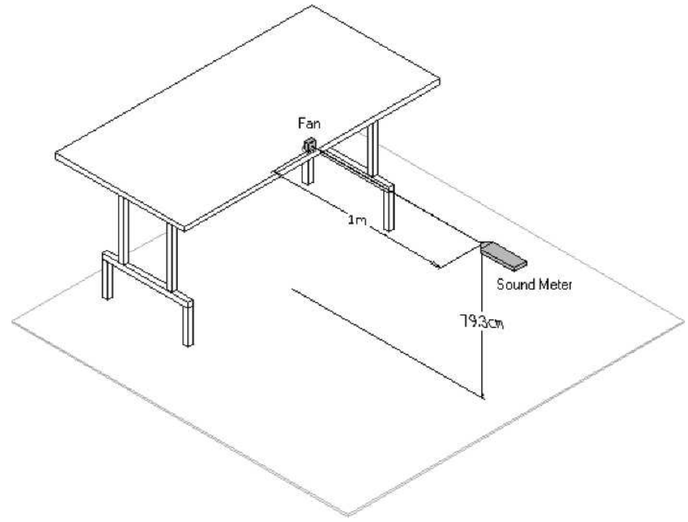

Fig. 7. Experimental setup for noise measurements.

laboratory was modified to ensure that background noise did not exceed 15 dB(A). The fans and microphone were placed on separate stands, at a distance of 1 m apart, with the fans mounted on foam insulation to dampen any vibrations that may have been passed to the stand. The experimental layout can be seen in Fig. 7. The sound meter used was an Extech Instruments model 407727 [5].

Temperature Measurements

Thermal testing was done on a SunFire 4100 with two AMD 254 processors. During the testing the CPUs were loaded to 100% usage and allowed to reach a steady state temperature. Typical rack mount conditions were simulated by covering the top and bottom of the server with one-quarter inch of Styrofoam and restricting the airflow into the server. The styrofoam insulated the server, reducing heat loss and restricting airflow through holes in the top and bottom of the server. The airflow into the server at the inlet was restricted by blocking off the bottom two-thirds of the inlet grill. Under these conditions the fans speeds in the current configuration approached maximum RPM while controlled by the service processor.

Two different types of tests were performed with the fans installed in the SunFire 4100. During the first type, the fan speeds were controlled by the central processors. The central processor's control algorithm adjusted the fan speeds to keep the temperatures of the CPUs constant. The result of installing the flow optimizers under these test conditions was a drop in the average fan speed by approximately 13%, as seen in Table I. The second type of test used the service controller to manually set the fan pulse width modulation of the control signal sent to the fans. This allowed the power supplied to the fans to be fixed while allowing the temperatures of the CPUs to vary.

The CPU temperatures were measured using the processors' built-in temperature sensors. Once steady state was reached and the temperatures were recorded, the flow optimizers were installed between all six pairs of fans and the test was repeated.

Table I
Average Fan Speed at 100% CPU Usage

Setup	Ambient (°C)	CPUO (°C)	CPU1 (°C)	Fan RPM
Current	24.6	49	52	13,300
Optimized	24.4	48	51	11,600

Table II
Current Operating Points (Representative)

Case	Flow Rate (m^3/s)	BP (Pa)
1	0.0092	149.5
2	0.0077	199.3
3	0.0054	249.1

The inlet air temperature, pressure, and humidity were monitored to ensure that the cooling air properties remained constant throughout the tests.

Analysis of Experimental Results

The test results provided two independent fan curves that were subsequently analyzed to determine benefits that could be realized after installing the flow optimizers. The analysis was based on the assumption that the operating points associated with the current configuration might reasonably lie between 150 and 250 Pa (0.6" and 1.0" H_2O), defining a range that could be represented by operating points at the limits and the midpoint (i.e., at 150, 200, and 250 Pa). The corresponding flow rate for each back pressure was then determined from the "current" performance curve labeled by "Sunfire 4100 Actual" in Fig. 5, and the resulting operating points were tabulated in Table II.

Each one of these operating points was combined with the origin (0 m^3/s, Pa) to determine a best fit parabolic curve. Although not 100% accurate, this approach did provide three representative system curves for the SunFire 4100 server, as shown in Fig. 8. The important criterion is that the representative system curves are accurate enough to allow for a comparison of the current and optimized configurations.

To ensure that the optimized setup operated at the same operating points as the current fan setup, the voltage supplied to the fans was reduced. Reducing the voltage also resulted in lower power consumption and noise. Table III shows that the optimized setup requires between 17 and 33% less power than the existing SunFire 4100 server setup, depending on the operating point.

Operating at a lower voltage also ensured that the fans in the optimized configuration had a lower operating RPM than the existing SunFire 4100 server setup. The lower operating RPM values correspond to lower noise levels with the optimized configuration being at least 5.3 dB(A) quieter than the current setup. The RPM and relative noise data for the existing SunFire configuration and the optimized configuration is shown in Table IV.

The optimized setup, when operating at 12 V, has the capacity to provide additional backpressure across the entire operating range. This additional capacity can be used to provide added component cooling. The three representative system curves shown in Fig. 8 were used to predict the incremental CFM that would be available when using the optimized configuration instead of the current configuration. The new (12 V) operating points can be determined by finding the intersection of the system curves with the optimizer-installed performance curve, as tabulated in Table V.

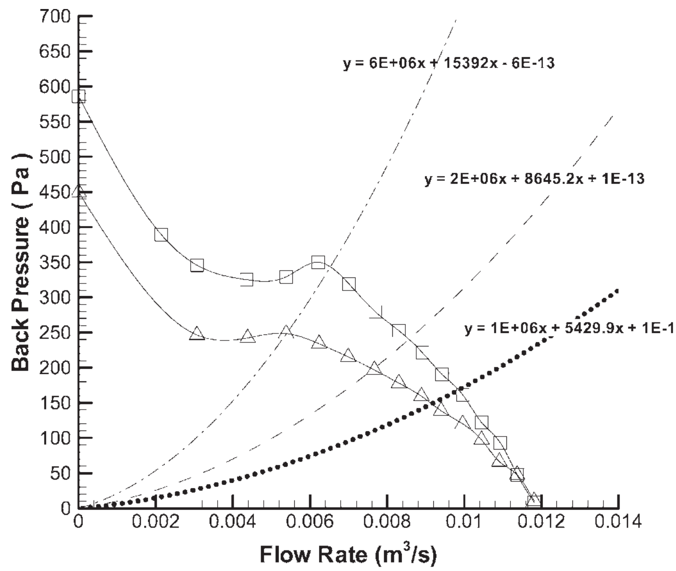

Fig. 8. Representative system curves for the SunFire 4100 server. *Triangles* represent SunFire 4100 actual; *squares* represent Optimizer; *interrupted line* = system curve 1; *dashed line* = system curve 2; and *dotted line* = system curve 3.

Table III
Power Consumption for Current and Optimized Configurations at Three Different Operating Points

Case	Setup	Flow rate (m^3/s)	BP (Pa)	Voltage (Volts)	Current (Amps)
1	Current	0.0092	149.5	12.00	1.60
	Optimized	0.0092	149.5	11.08	1.15
2	Current	0.0077	199.3	12.00	1.16
	Optimized	0.0077	196.8	10.56	1.09
3	Current	0.0054	249.1	12.00	1.13
	Optimized	0.0054	246.6	9.80	0.98

Table IV
RPM and Noise Data for Current and Optimized Configurations at Three Different Operating Points

Case	Setup	RPM Primary	RPM Secondary	Noise dB(A)
1	Current	15315	17645	76.88
	Optimized	14463	14683	71.56
2	Current	15353	17578	76.76
	Optimized	13957	14175	70.47
3	Current	15388	18158	77.89
	Optimized	13540	13712	69.52

Table V
Maximum Airflow (at 12 V) and Corresponding Noise Level for Three Different System Curves

System Curve	Setup	Flow rate (m^3/s)	BP (Pa)	Noise dB(A)
1	Current	0.0092	149.5	76.88
	Optimized	0.0098	168.0	73.53
2	Current	0.0077	199.3	76.76
	Optimized	0.0085	234.9	73.59
3	Current	0.0054	249.1	77.89
	Optimized	0.0065	340.0	74.21

Table V shows that the optimized configuration could provide up to 20.4, 10.4, and 6.5% more flow rate for systems 1, 2, and 3, respectively. Even at the highest flow rate (system 1) the optimized setup still produced less noise than the original setup (Table V). Obviously, the added cooling that could be achieved with this increased flow rate is dependant on component placement and the characteristics of the heat sinks. However, added cooling definitely offers the potential for enhanced system performance, either by increasing the clock speed of the existing CPUs or through acquisition of upgraded CPUs.

Alternatively the increased thermal headroom could be used to decrease fan RPM when the optimized configuration is used with existing CPUs. For example, when flow optimizer modules were installed in the SunFire 4100 server with two AMD 254 CPUs running at 100% usage, the average fan speed dropped by 1700 RPM (Table I). It is important to note that a lower fan speed substantially reduces noise levels, requires less power, and extends the expected life of the twelve fans in this configuration.

To better quantify the additional cooling potential provided by the use of optimizer modules, more in-system testing was conducted. Setting pulse width modulation (PWM) to 100% for the SunFire 4100 server fans, while the server was running at 100%, resulted in a decrease in fan RPM and a decrease in CPU temperature for both optimized and original configurations. The optimized configuration produced a greater temperature drop at a lower RPM than the original configuration. These results are shown in Table VI.

However, the decrease in temperature for the optimized configuration was expected to be greater than the results shown in Table VI based on the results from the flow bench testing. We believed that the reason for the underperformance of the optimizer modules is the presence of a flow restriction between the primary and secondary fans in the SunFire 4100 server. This rather large flow restriction was due to the power supply bus for the fan modules and was not present in the flow bench testing. This flow restriction affects the swirl dissipation within the space between the fans and changes the optimal diffuser design. Unfortunately, the placement of the bus was not known prior to the flow bench testing.

Although experimental results did show that the use of an optimizer module could be beneficial, they did not increase our understanding of why. To further investigate how the optimizer could increase performance while decreasing noise and power consumption, we conducted a CFD study.

Table VI
CPU Temperature with Fans at 100% PWM

Setup	Ambient (°C)	CPUO (°C)	CPU1 (°C)	Fan RPM
Current	24.8	47	49	16,080
Optimized	24.8	45	48	15,750

Numerical Analysis

In the present CFD study, the diffuser element was modeled mathematically as a porous media, the governing equations of which can be found, for example, in Reference [6]. The drag coefficient associated with the pressure drop across the diffuser element was estimated to be 0.09 [1] and was used in the present simulation.

In contrast to an earlier CFD study, in which a Delta AFB0412SHB fan (or AFB for brevity) was used, a Delta TFB0412EHN (or TFB for brevity) was used here instead. The TFB is a fan module of 28 mm thickness, in which the thickness of the fan is 15 mm, and the thickness of the stator is 13 mm. This is significantly different from the AFB, for which there is no stator.

The purpose of having both a rotor and stator in an axial-flow fan design is to ensure that (1) velocity direction relative to the rotor should be parallel to the rotor leading edge, and (2) the absolute velocity at trailing edge of the rotor should enter smoothly the next row of stator blades [7]. The same principle applies to the design of the TFB fan. However, the main interest here is to estimate the amount of swirl introduced into the flow field behind a fan with and without a stator.

The earlier study [1] suggests that less swirl results in better performance for the secondary fan. Using the turbomachinery Euler equation (see [7]), one can estimate the ratio of area-averaged secondary kinetic energy (SKE, defined as $\frac{1}{2}U_\theta^2$, where U_θ is the circumferential velocity) at the exit of an axial fan with and without a stator as

$$\frac{\text{SKE}_{\text{with stator}}}{\text{SKE}_{\text{without stator}}} = \left[\frac{\tan(\beta_1)/\tan(\beta_3)}{1-\tan(\beta_1)/\tan(\beta_2)}\right]^2 \quad (1)$$

where β_1, β_2, and β_3 are the blade angles at inlet of the fan, at the exit of the fan, and at the exit of the stator, respectively. They are estimated to be $\beta_1 \approx 40.5°$, $\beta_2 \approx 65°$, and $\beta_3 \approx 70°$.

For the TFB fan, the ratio of $\text{SKE}_{\text{withstator}}/\text{SKE}_{\text{without stator}} \approx 0.267$, suggesting that the inclusion of a stator significantly reduces the amount of swirl at the exit of the fan. However, questions remain regarding whether the performance of a secondary fan in a series fan configuration can be improved by simply introducing a stator alone.

To answer this question more specifically, the SunFire 4100 server configuration is used in the CFD simulation, in which the total distance between the exit of the primary fan and the entrance of the secondary fan is 20 mm. With reference to Fig. 1, a diffuser of 6 mm is also inserted between the primary and secondary fans, and positioned such that the performance gap is 12 mm and acoustic gap is 2 mm. The Reynolds number based on (i) the TFB fan diameter of 40 mm and (ii) the bulk velocity corresponding to a mid-range operating point of 199.3 Pa and 0.0077 m^3/s (with reference to Table II) is 46,500.

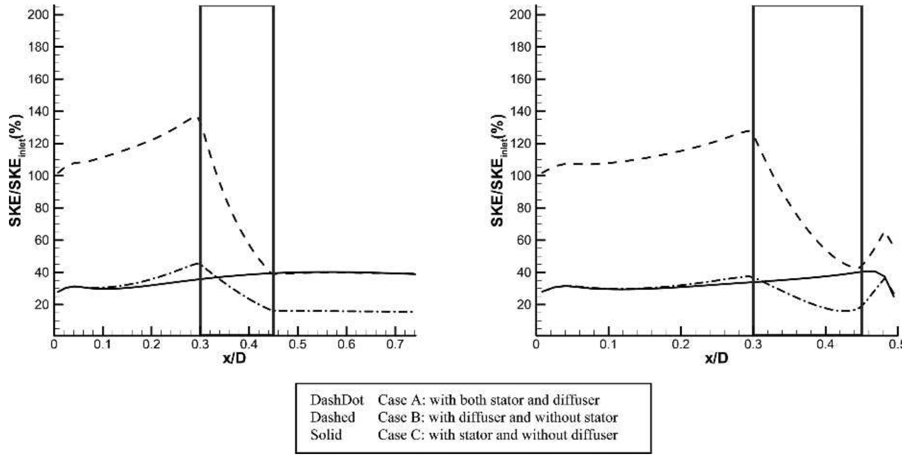

Fig. 9. Distribution of secondary kinetic energy (SKE) with primary fan only (*left*) and both primary and secondary fans (*right*). Case A: with both stator and diffuser (*interrupted line*); Case B: with diffuser and without stator (*dashed line*); and Case C: with stator and without diffuser (*solid line*).

All calculations presented below are performed with a CFD model STREAM [8] on a mesh of 60 × 50 × 50 nodes. The inlet condition for the CFD model is derived from the turbomachinery Euler equation. In the case of the TFB fan without a stator, the axial and circumferential velocity components are

$$U_x = \sqrt{r_o r_i}\tan(\beta_1), U_\theta = r\omega\left[1 - \frac{\tan(\beta_1)}{\tan(\beta_2)}\right], \quad (2)$$

whereas, in the case of the TFB fan with a stator (i.e., the original TFB fan design),

$$U_x = \sqrt{r_o r_i}\tan(\beta_1), U_\theta = r\omega\left[\frac{\tan(\beta_1)}{\tan(\beta_3)}\right]. \quad (3)$$

Here ω is the angular velocity of 15,000 RPM, $r_o = 0.0185$ m and $r_i = 0.012$ m. The predicted flow rate in the zero backpressure condition is 0.0124 m^3/s, which agrees with manufacturer's (Delta) data of 0.0123 m^3/s in the same condition.

To avoid explicitly simulating the secondary fan, which can be computationally expensive and requires detailed information about the blade profiles, the presence of the secondary fan is incorporated into the calculations by using the following simplified procedure. First, a fully developed flow condition at the outlet is assumed for all variables. The SKE distributions for 3 configurations, namely,

Case A: with both stator and diffuser,
Case B: with diffuser and without stator,
Case C: with stator and without diffuser,

are shown in Fig. 9. Note that the title "SKE_{inlet}" in the y-axis denotes SKE at the exit of the TFB fan without a stator, so that $SKE/SKE_{inlet} = 100\%$ at x/D = 0 for Case B, and $SKE/SKE_{inlet} \approx 26.7\%$ for Cases A and C in accordance with Eq. (1).

It is estimated from Fig. 9 (left subfigure) that $SKE/SKE_{inlet} \approx 40\%$ for Cases B and C, and $SKE/SKE_{inlet} \approx 16\%$ for Case A at x/D = 0.5 (or x = 20 mm, the inlet location for the secondary fan). This information allows us to assume the following Dirichlet boundary conditions for U_x at x/D = 0.5 to mimic the presence of the secondary fan based on the turbomachinery Euler equation:

$$U_x = \sqrt{r_o r_i}\tan(\beta_1), U_\theta = r\omega\left[1 - \frac{\tan(\beta_1)}{\tan(\beta_2)}\right]\sqrt{\frac{SKE_{x/D=0.5}}{SKE_{inlet}}}. \quad (4)$$

The side views of streamlines for Cases A–C are shown in Fig. 10. Note that the hub of the stator of the primary fan and the hub of the rotor of the secondary fan are indicated in the figure.

As observed from the top subfigure of Fig. 10, the recirculation zone is more or less confined between the hub of the stator and the diffuser element when both stator and diffuser are included in the calculation. With the diffuser only (middle subfigure of Fig. 10), the recirculation zone is extended into the diffuser element. Although SKE/SKE_{inlet} drops from 127–45% across the diffuser element as shown in Fig. 9 (left subfigure), the only way to further reduce the SKE ratio is to include an upstream stator such that $SKE/SKE_{inlet} \approx 20\%$ at the end of the diffuser. Note that a slight increase of SKE in the acoustic gap for Cases A and B is likely due to an impingement of flow on the downstream hub.

Again, based on the turbomachinery Euler equation, it is estimated that swirl can cause a flow to deviate from its design angle at the leading edge of the secondary fan by approximately 13.5° for both Cases B and C, and by approximately 8° for Case A (i.e., with both stator and diffuser). This explains why the performance of the optimized configuration, consisting of two TFB fans and a flow optimizer, is much better than the original series fan design in the SunFire 4100 server as observed previously in Fig. 5.

Reducing the Optimizer Module Length

A further design objective that became evident during the course of this work was to reduce the overall length of the flow optimizer, ideally to the extent that it could be inserted between two industry-standard fans while maintaining an overall configuration length of 56 mm. This would allow server manufacturers to achieve or even exceed the level of performance normally associated with counter rotating fans by using low-cost (and more readily available) axial fans.

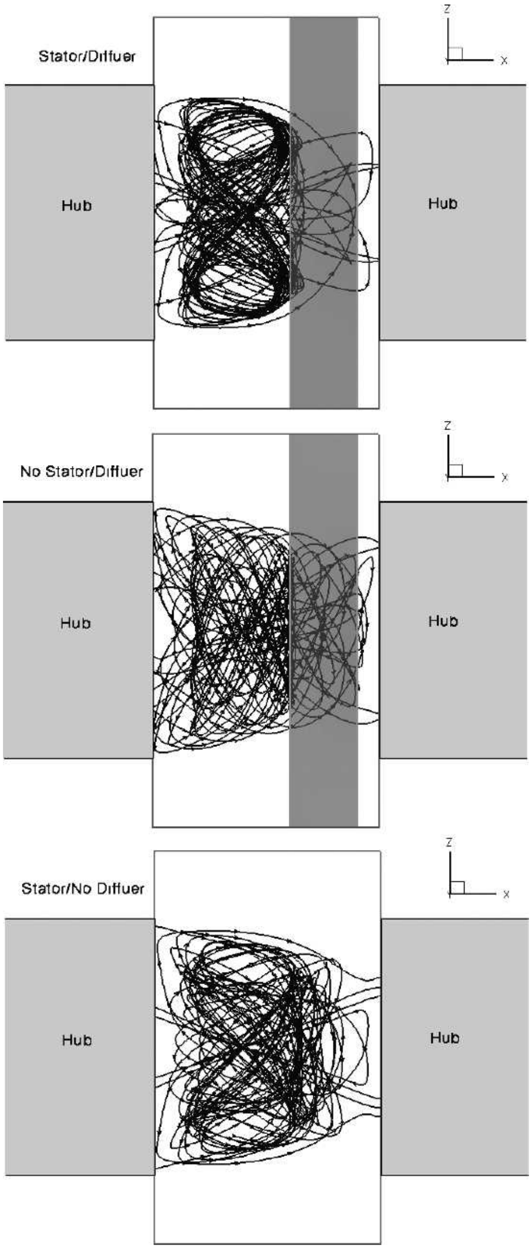

Fig. 10. 2D side views of streamlines for series fans with both stator and diffuser (*top*), with diffuser and without stator (*middle*), and with stator and without diffuser (*bottom*).

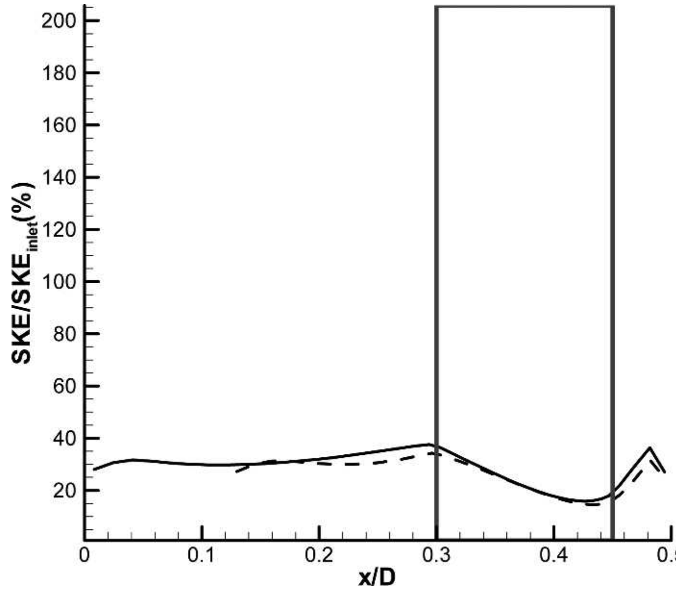

Fig. 11. Sensitivity of performance gap on the SKE ratio for a TFB fan with both stator and diffuser. *Solid line* = 12-mm performance gap; *dashed line* = 7-mm performance gap.

A more extensive examination of the SKE distribution in Fig. 9 reveals that the SKE ratio for Case A (with stator and diffuser) departs from Case C (with stator but without diffuser) at $x/D \approx 0.12$ and $x/D \approx 0.175$ in configurations where the secondary fan is absent (left subfigure) and present (right subfigure), respectively. This led to a hypothesis that the diffuser could in fact be repositioned closer to the primary fan without affecting the overall performance of the configuration. More specifically, it was determined that the distance between the diffuser and the primary fan could be reasonably reduced to $x/D = 0.175$ or 7 mm insofar as an optimized configuration does, in fact, include a secondary fan. Test results confirmed that performance remained consistent with the original configuration where the diffuser was positioned at $x/D = 0.3$ or 12 mm from the primary fan.

Further investigation was based on the observation that the SKE ratios for x/D 9 0.3 for Cases A and C shown in Fig. 9 (right subfigure) are very similar, and that they are close to a constant value of approximately 30%. We also observed from this figure that the SKE ratio increases slightly for Case A in the region $0.175 \leq x/D \leq 0.3$ as a result of flow deceleration due to the presence of the diffuser.

This behavior of SKE ratio in front of the diffuser is markedly different from what was reported in an earlier investigation [1] presented at iMAPS Boston, in November 2003, in which the 4710NL-04W-B50 (or B50 for brevity) fan manufactured by NMB Technologies (Chatworth CA) was used. In that case, the SKE ratio decayed monotonically between the exit of the primary fan and the diffuser. The major cause of this disparity is that the relative diameter of the hubs (i.e., the ratios of the hub and fan diameters) for the two fans was quite different. In the case of the B50 fan, the diameter of the hub is 0.375D. However, for the TFB fan, the diameter of the hub is 0.6D. Because a larger relative hub size can cause a more pronounced flow separation behind the primary fan, and because the nonaxial velocity components (in y and z directions, respectively) in the recirculation region also contribute to the SKE value, it is not surprising to see that the SKE ratio *does not decay* as expected, compared with a relative hub size that is much smaller. For this reason, it was believed that the performance gap can be further reduced in the case of the TFB fan without having too much of a negative effect on the performance of the optimizer module.

This suspicion is supported by the results shown in Fig. 11, in which the performance gap is reduced from 12 mm to 7 mm. As seen, little difference in SKE ratio is observed for both gaps. Note that in Fig. 11 the $x/D = 0$ and $x/D = 0.125$ represent the exit of the primary fan for 12 mm and 7 mm performance gaps, respectively.

The reduced distance of 7 mm between the primary fan and the diffuser is significant because it will allow the flow optimizer to be configured with industry-standard fans while maintaining an overall length of 56 mm, consistent with commercially available counter rotating modules. The following example provides further clarification:

Primary Fan (Delta TFB0412EHN) 28 mm
Reduced Performance Gap 7
Diffuser 6
Secondary Fan (Delta AFB0412SHB) 15
Overall Length 56 mm

Summary & Conclusions

Test results confirmed that installing a flow optimizer in between the pairs of Delta TFB0412EHN fans currently installed in a SunFire 4100 server will substantially improve cooling performance. The multiple-flow optimizers allowed the current operating point to be achieved, with the same two AMD 254 CPUs, while reducing fan speed by approximately 13%. This substantially reduced the acoustic noise, required less power, and extended the expected life of the fans. Alternatively, the increased thermal headroom could have been used to reduce the operating temperature of existing CPUs or facilitate an upgrade to higher performance CPUs without requiring any further modifications to the server design.

A CFD analysis confirmed the observed results and suggested that the length of the optimizer module could be shortened while providing the same level of performance enhancement when used with Delta TFB0412EHN fans, or other fans having a rotor and a stator. Further testing with a 13-mm optimizer module confirmed the predicted results.

The availability of a 13-mm flow optimizer meant that the flow optimizer could fit in the standard (40 × 40 × 56 mm) spaces providing excellent series fan performance without the expense associated with counter-rotating fans. In this case, the test configuration included a Delta TFB0412EHN (28 mm), a "short" flow optimizer (13 mm), and a Delta AFB041SHB fan (15 mm) for a total length of 56 mm. However, similar configurations are possible with industry-standard fans available from a variety of different manufacturers.

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