Advanced Trailing Edge Blowing Concepts for Fan Noise Control

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DOI: 10.13111/2066-8201.2012.4.1.2

Abstract: *This study documents trailing edge blowing research performed to reduce rotor / stator interaction noise in turbofan engines. The existing technique of filling every velocity deficit requires a large amount of air and is therefore impractical. The purpose of this research is to investigate new blowing configurations in order to achieve noise reduction with lesser amounts of air. Using the new configurations air is not injected into every fan blade, but is instead varied circumferentially. For example, blowing air may be applied to alternating fan blades. This type of blowing configuration both reduces the amount of air used and changes the spectral shape of the tonal interaction noise. The original tones at the blade passing frequency and its harmonics are reduced and new tones are introduced between them. This change in the tonal spectral shape increases the performance of acoustic liners used in conjunction with trailing edge blowing.*

Key Words: *fan noise control, trailing edge blowing, rotor / stator interaction noise*

1. INTRODUCTION

This study documents trailing edge blowing research performed to reduce rotor / stator interaction noise in turbofan engines. The existing technique of filling every velocity deficit requires a large amount of air and is therefore impractical. The purpose of this research is to investigate new blowing configurations in order to achieve noise reduction with lesser amounts of air. Using the new configurations air is not injected into every fan blade, but is instead varied circumferentially. For example, blowing air may be applied to alternating fan blades. This type of blowing configuration both reduces the amount of air used and changes the spectral shape of the tonal interaction noise. The traditional method of reducing interaction noise, called "trailing edge blowing" (TEB), is outlined.

2. ADVANCED TRAILING EDGE BLOWING CONCEPT

The root cause of rotor / stator interaction noise is unsteadiness in the fluid reaching the stator vanes. These unsteady wake deficits are caused by losses incurred along fan blade surfaces. If no interaction noise control is attempted, every fan blade produces a wake and these wakes produce interaction noise tones at the blade passing frequency and harmonics.

This baseline configuration is illustrated in Figure 1. A fan with 16 blades is shown (3 blades have been removed for ease of visualization). The blue surface downstream of the blades represents fluid velocity; there is a ripple downstream of every blade trailing edge

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representing the wake due to that blade. The stators (not shown) would be further downstream.

The spectrum shows the interaction noise produced in this situation. Interaction tones are produced at the blade passing frequency and harmonics (1xBPF, 2xBPF, 3xBPF, etc.)

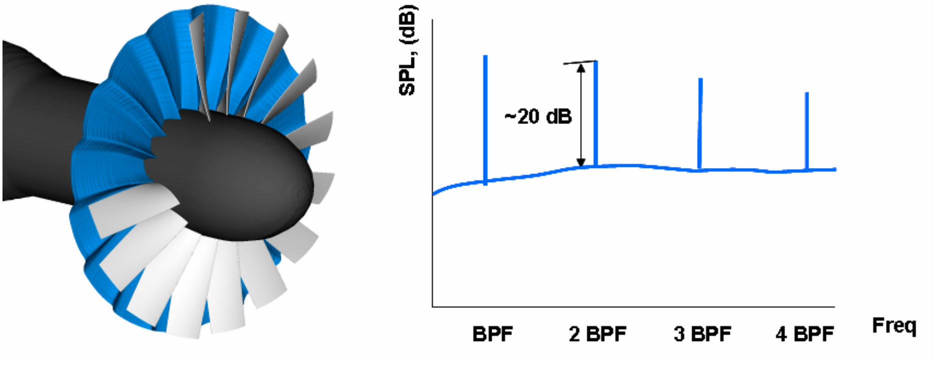

Fig. 1 Fan, wakes, and interaction noise with no tab [20]

The conventional application of trailing edge blowing requires a large amount of air because every wake deficit is filled. This configuration of TEB applied to every blade is shown in Figure 2, which shows the same fan as Figure 1 except that the wakes are greatly reduced.

With only small amounts of unsteadiness present in the velocity profile only small amounts of interaction noise are produced. The interaction tones are smaller than they were in the baseline configuration of Figure 2, and would be eliminated completely if the wakes were perfectly filled. Any remaining interaction noise is, however, present at the same frequencies and modes as it was with no blowing; only the magnitudes are reduced.

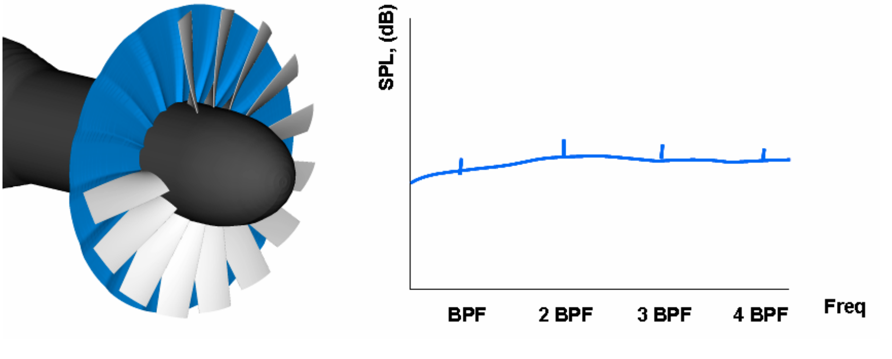

Fig. 2 Fan, Wakes, and Interaction Noise with Full TEB [20]

Advanced trailing edge blowing differs from conventional (full / every blade) trailing edge blowing because it does not attempt to fill every wake profile. This partial-blowing configuration results in an immediate savings of air.

Instead of injecting air on every blade to fill every wake deficit, the application of air is varied circumferentially to selectively fill wakes. This selective wake filling can be done in any number of different ways, but numerical predictions have identified two configurations in particular that are used in this research. The two configurations were chosen because they were predicted to give the best and the worst noise reductions, respectively. The first configuration predicted to give the most noise reduction is called “ATEB 1x1” and consists of injecting air into alternating fan blades. The second configuration predicted to give the worst noise reduction is called "ATEB 2x2" and consists of injecting air into alternating, adjacent fan blades. That is, air is injected into two adjacent blades, skipped on the next two, applied on the next two, etc. Both of these advanced layouts use air on exactly half of the fan blades present, and therefore theoretically should use half as much air as conventional TEB.

The ATEB 1x1 layout serves as an example in Figure 3. For this explanation, it is assumed that TEB perfectly fills any wake that it is applied to. Therefore, applying the ATEB **All Wakes Filled** 1x1 configurations is, acoustically speaking, equivalent to halving the number of fan blades. The shape on the interaction noise is changed accordingly. In this case (ATEB 1x1), the acoustic blade passing frequency is reduced to half of the physical blade passing frequency. The harmonics are therefore spaced more closely together. This behavior is demonstrated in Figure 3, which shows the effects of applying the ATEB 1x1 layout. The illustration of the fan shows how alternating wakes are filled. The spectrum shows a reduction in the original tones' power and the introduction of new tones at new interaction frequencies.

New interaction modes are present at the new interaction frequencies, but the modal structure at the "original" frequencies (1xBPF, 2xBPF, etc) is not changed by the application of ATEB. This has two implications. The first is that any tone that is cut off with no TEB or full TEB remains cut off when ATEB is applied. For example, fans are often designed to cut off the 1xBPF tone. This tone will remain cut off when ATEB is applied. The second implication is that ATEB should always decrease the original tones' power levels. This is because the modal structure is held constant at the original frequencies while there are fewer wakes present to drive noise generation.

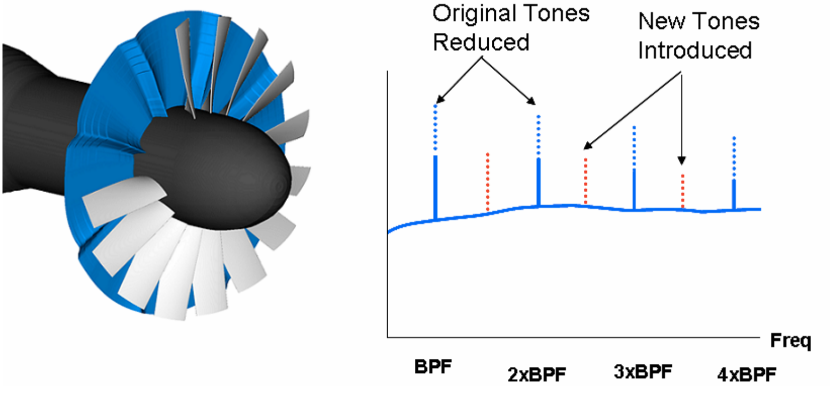

Fig. 3 Fan, Wakes, and Interaction Noise with ATEB 1x1 [20]

All of the ATEB layouts are by definition partial-blowing layouts, and as such they do not achieve as much source-level noise reduction as conventional TEB on every blade. Some of the velocity deficits are still present and therefore still produce some interaction noise.

This remaining noise is managed with acoustic liners. Acoustic liners used in turbofan engines typically have high resistances, and are most effective at attenuating broadband noise. The liner can be tuned to a specific tone at a specific engine power setting by designing the proper liner cavity depth and having a low resistance.

However, the liner becomes less effective for the other tones and power settings. Thus, the liner is designed to be effective over a broad frequency band by increasing the liner resistance. Rotor / stator interaction noise is tonal in nature, and the interaction noise resulting from a fan with no TEB or full TEB has tones only at the BPF and harmonics.

Liner performance on conventional interaction noise is poor because the noise is strongly tonal in nature but the liners are designed to attenuate broadband noise. When ATEB is used the spectral shape of the interaction noise is changed.

The sound energy is split into more tones spread out over more frequencies. In addition the distribution of power over radial modes may be changed even within a particular frequency.

The noise from a fan with ATEB is more “like” broadband noise. Therefore acoustic liner performance is expected to be improved.

A standard rotor produces interaction noise only at the BPF and harmonics, but an ATEB configured rotor produces more interaction tones. The ATEB interaction spectrum is a better fit for a high resistance liner's attenuation curve.

To summarize the concept, advanced trailing edge blowing leaves some of the wake deficits unfilled in order to use less air.

Because some of the deficits are left unfilled, less source level noise reduction is achieved with ATEB than is achieved with TEB. A second effect of ATEB is to modify the spectral shape of the tonal interaction noise.

The modified spectrum allows acoustic liners to perform better, making up for the lesser amount of source-level reduction. The end result is that similar overall noise reduction levels are achieved while using less air.

This hypothesis is investigated and demonstrated in this study.

The approach is used to find the optimum blowing rate for the TEB, ATEB 1x1, and ATEB 2x2 configurations.

The results are shown in Figure 4. (There are no experimental data for the full TEB layout with 28 vanes.) The ATEB 1x1 layout has its optimum blowing rate at 0.9% resulting in a reduction of 5 dB.

The ATEB 2x2 configurations performed especially poorly, with all of the blowing rates actually increasing the sound power. The lowest of these powers is achieved at a blowing rate of 0.8%, which increases the power by 0.8 dB. The reason for the power increase is discussed below.

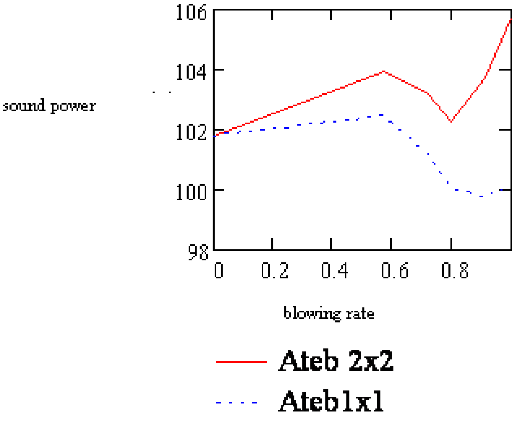

Fig. 4 Power vs. Blowing Rate for the Configurations [Inlet Duct, 28 Vanes]

The power due to the original and new tones can be seen in Figure 5. For the ATEB 1x1 configurations, the new tones' power is small at the lesser blowing rates and nearly equal to the original tones' power at the highest blowing rate of 1.0%. For the ATEB 2x2 configurations, the new tones' power is about the same as the original tones' at all of the blowing rates. This explains the poor performance of ATEB 2x2 according to the far-field data; the new tones contribute too much power for effective overall noise reduction to occur.

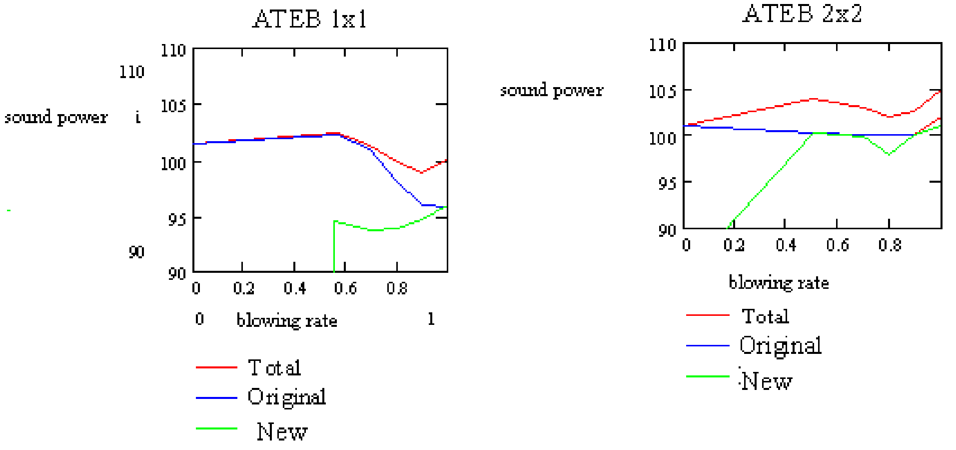

Fig. 5 Original and New Tones' Power for [Inlet Duct, 28 Vanes, ATEB 1x1, Hardwall] and [Inlet Duct, 28 Vanes, ATEB 2x2, Hardwall]

This section discusses configurations using the aft duct of the rig and 28 vanes. The optimum blowing rates are found using the same method as in the above sections, and shown in Figure 6.

The optimum blowing rate is 0.8% for both configurations, with ATEB 1x1 and ATEB 2x2 giving power reductions of 3.4 and 2.0 dB, respectively.

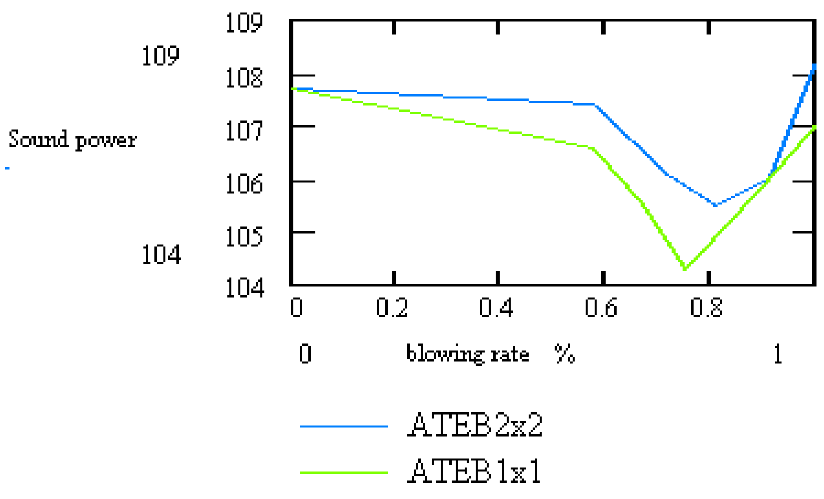

Fig. 6 Power vs. Blowing Rate for the Configurations [Aft Duct, 28 Vanes]

The power due to the original and new tones can be seen in Figure 7. For the ATEB 1x1 configurations, the new tones' power is small at the lesser blowing rates and greater than the Original tones' power at the high blowing rates.

For the ATEB 2x2 configurations, the new tones' power is about the same as the original tones' at all of the blowing rates measured. This explains why ATEB 1x1 gives more overall power reduction than ATEB 2x2; the later configuration's performance is more limited by the new tones.

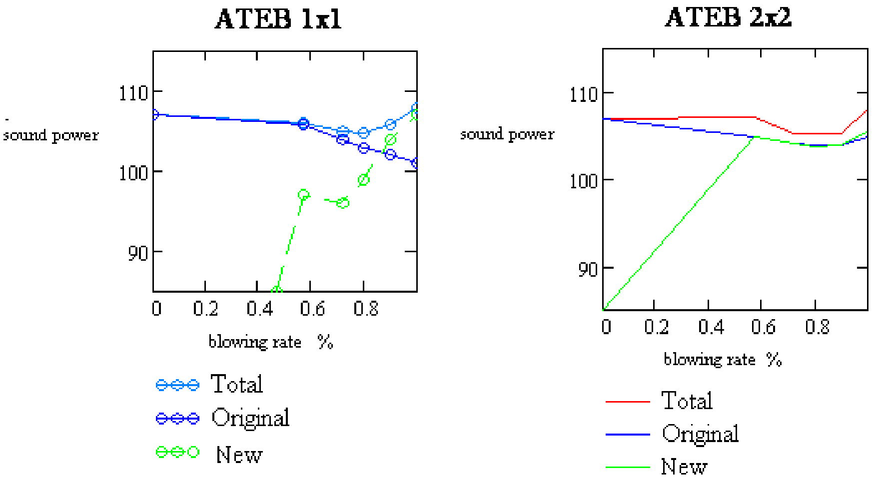

Fig. 7 Original and New Tones' Power for [Aft Duct, 28 Vanes, ATEB 1x1, Hardwall] and [Aft Duct, 28 Vanes, ATEB 2x2, Hardwall]

I have conducted a calculation in fluent: for an isolated profile, we have calculated the pressure coefficient, speed distribution and distribution of sound power levels (dB).

On the external border of the field of computing, has imposed the condition “light pressure field” that was imposed: - static pressure = 1 atm

Initial data:

- static temperature = 15 C
- Mach = 0.3
- flow direction, incidence -5 degrees
- turbulence intensity = 1%
- ratio of turbulent and molecular viscosity = 1

Grid has 121 500 nodes and 120 972 quadrilateral cells. Calculation area has been extended about 20 strings around aerodynamic profile. Turbulence model is SST k-omega Menter's.

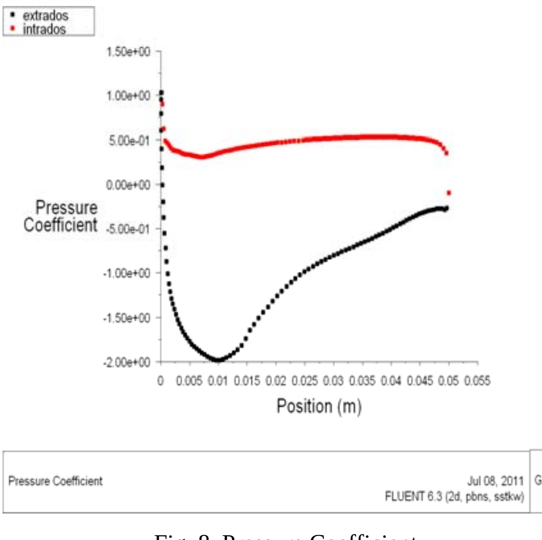

Fig. 8 Pressure Coefficient

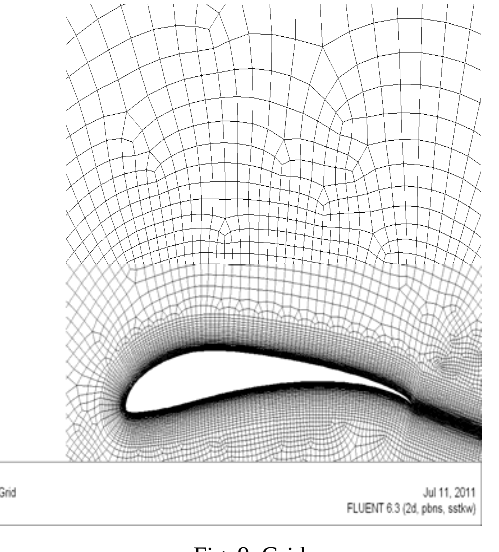

Fig. 9 Grid

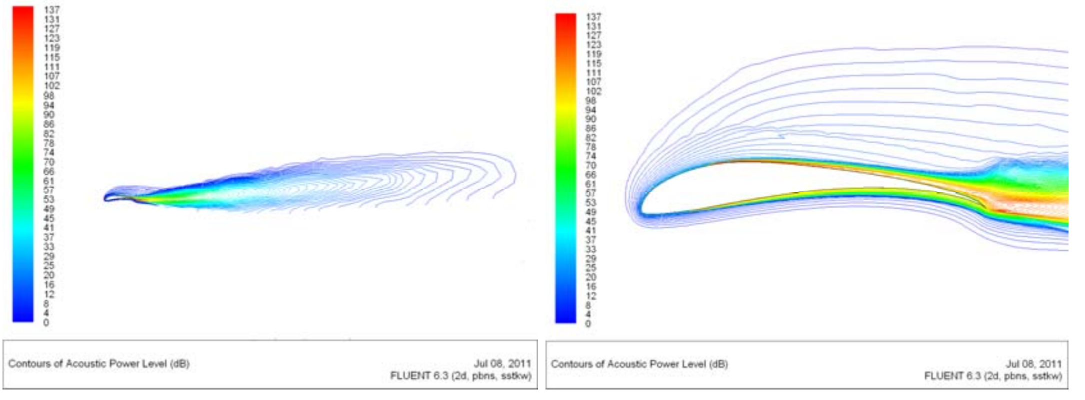

Fig. 10 Detail distribution of acoustic sources
We note that the noise level is highest at the trailing edge.

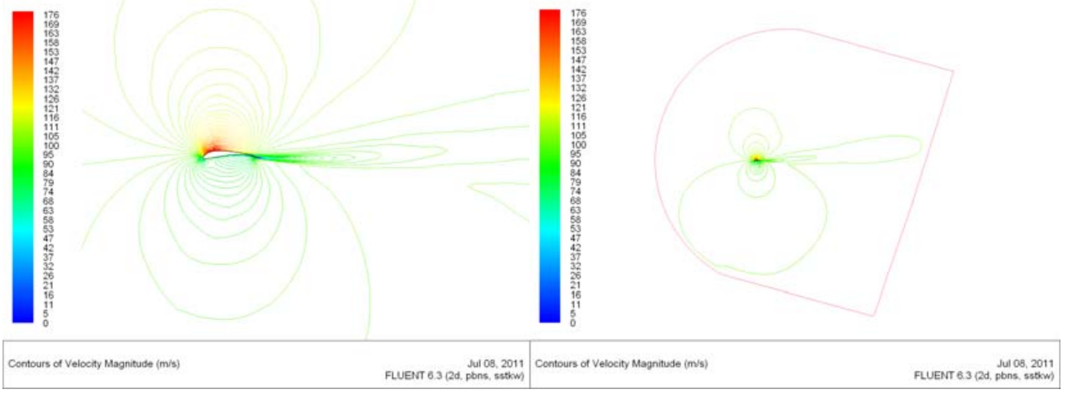

Fig. 11 Detail distribution of speed.

3. CONCLUSIONS

Trailing edge blowing (TEB) is a proven technique for reducing rotor / stator interaction noise, but is made impractical by the amount of air required. A new implementation of TEB was validated in this study. The concept "advanced trailing edge blowing" (ATEB) applies selective wake-filling to achieve noise reduction with less air used. This is possible because the modified spectral shape of interaction noise from advanced blowing layouts makes acoustic liners more effective. The interaction noise is spread over more frequencies and modes, behaving more like broadband noise and better matching liners' attenuation curves. This compensates for decreased source-level reduction due to leaving some wakes unfilled.

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