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# Active Control of Fan Noise: Feasibility Study

## Volume 4: Flyover System Noise Studies, Part 2

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## Summary

An extension of a prior study has been completed to examine the potential reduction of aircraft flyover noise by the method of active noise control (ANC). It is assumed that the ANC system will be designed such that it cancels discrete tones radiating from the engine fan inlet or fan exhaust duct, at least to the extent that they no longer protrude above the surrounding broadband noise levels.. Thus, without considering the engineering details of the ANC system design, tone levels are arbitrarily removed from the engine component noise spectrum and the flyover noise EPNL levels are compared with and without the presence of tones.

The study was conducted for a range of engine cycles, corresponding to fan pressure ratios of 1.3, 1.45, 1.6, and 1.75. This report is an extension of an effort reported previously in Reference 1. The major conclusions drawn from the prior study, which was restricted to fan pressure ratios of 1.45 and 1.75, are that, for a fan pressure ratio of 1.75, ANC of tones gives about the same suppression as acoustic treatment without ANC. For a fan pressure ratio of 1.45, ANC appears to offer less effectiveness than passive treatment.

In the present study, the other two fan pressure ratios are included in a more detailed examination of the benefits of the ANC suppression levels. The key results of this extended study are the following observations:

1. The maximum overall benefit obtained from suppression of BPF alone was 2.5 EPNdB at high fan speeds. The suppression benefit increases with increase in fan pressure ratio (FPR).
2. The maximum overall benefit obtained from suppression of the first three harmonics was 3 EPNdB at high speeds. Suppression benefit increases with increase in FPR.
3. At low FPR, only about 1.0 EPNdB maximum reduction was obtained. Suppression is primarily from reduction of BPF at high FPR values and from the combination of tones at low FPR.
4. The benefit from ANC is about the same as the benefit from passive treatment at fan pressure ratios of 1.75 and 1.60. At the two lower fan pressure ratios, the effectiveness of treatment is much greater than that of ANC.
5. No significant difference in ANC suppression behavior was found from the QCSEE engine database analysis compared to that of the $E^3$ engine database, for the FPR = 1.3 engine cycle.

The effects of ANC on EPNL noise reduction are difficult to generalize. It was found that the reduction obtained in any particular case depended upon the frequency of the tones and their shift with rpm, the amount of ANC suppression received by each tone (which depended on its protrusion from the background), and the NOY-value of the tone relative to the NOY-value of other tones and the peak broadband levels, because PNL is determined from the sum of the NOY-values.

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## 1. Introduction

The advent of ultra-high-bypass engines (UBE) with a thin, short outer nacelle structure will increase the importance of tones as contributors to the radiated noise levels, and make it more difficult to provide adequate passive acoustic treatment for their suppression. One possible means of overcoming this problem is the application of the principles of Active Noise Control (ANC), such that an array of electrically-driven secondary noise sources mounted on the fan inlet or exhaust duct walls are used to generate sound waves that physically cancel out the waves from the primary aeroacoustic fan source.

The primary objective of this study was to assess the feasibility of using wall-mounted secondary sources, in terms of both their ability to generate sufficient acoustic energy with practical weight and power restrictions, and their ability to couple with fan duct acoustic modes such that the far-field radiation is significantly reduced over a wide area. An aircraft flyover noise system study was conducted to determine the potential benefit that could be achieved by ANC suppression of dominant tones, assuming the concept can be physically realized. In other tasks, which are reported in separate volumes, an ANC actuator ring and control system were developed, fabricated, and demonstrated in the NASA Lewis 4-foot ANC fan.

The purpose of this study is to evaluate the potential impact of active noise control using flyover noise prediction methods and a set of assumptions of how the ANC system will operate. In particular, it is assumed that a practical ANC system can be designed to effectively reduce the tones of a turbofan engine at blade-passing-frequency (BPF) and all its harmonics to the surrounding broadband noise levels, for both the fan inlet and fan exhaust ducts.

With this assumption, a system noise study was conducted in the first phase of this program to assess the potential flyover noise reduction by ANC application to UBE engines of fan pressure ratio (FPR) equal to 1.75 and 1.45 (designated as S75 and S45), mounted on a 407 Klb twin-engine aircraft. The Energy Efficient Engine ($E^3$) engine database, with hardwall inlet and exhaust, was used for that analysis, as presented previously in Volume 1[1] of the Contractor Report. That assessment has now been extended by completing the following:

- Estimating system noise benefits of ANC applications on UBE engines with FPR equal to 1.6 and 1.3 (S60 and S30), also using the $E^3$ engine database.
- Conducting an in-depth examination of the ANC results for all four UBE engines.
- Making system noise predictions with ANC applied to the S30 engine using the Quiet Clean Short Haul Experimental Engine (QCSEE) database.

The results of the extension are summarized in this report (Volume 4).

## 2. Background and Program Objectives

### 2.1 Active Noise Control of Aircraft Engines

In its simplest form, the concept of active noise control can be considered as the provision of a secondary noise source that is located and controlled such that it radiates sound waves that interfere destructively with those generated by the primary sound source, for which noise suppression is desired. The sound suppression may occur over only a limited region of space, depending on the complexity of the sound field being controlled. The reader is referred to the previous report[1] for a more complete discussion of engine ANC and a perspective on prior research.

### 2.2 Objective and Approach of System Noise Studies

In a prior study carried out under NASA Contract NAS3-25269, Task 4, the noise characteristics of four single-rotation engines applied to a 407 Klb takeoff gross weight two-engine aircraft (representative of the Boeing 767) were studied.[2] Four different engine fan pressure ratios characterized the cycles of these engines, 1.3, 1.45, 1.6, and 1.75. The sideline, takeoff, cutback, and approach flight conditions were studied.

In this study, using results of Contract NAS3-25269 Task 4 as a basis, the benefits of active control of fan tone noise on the total noise (EPNL) of selected high bypass engine cycles were assessed. This study examines all engine cycle cases in more detail than the previous study. Aircraft flyover noise levels were compared for the untreated, hardwall engine configurations with no applied ANC, the hardwall engine configuration with ANC applied, and the treated engine configuration with no applied ANC. Applying ANC tone removal to the treated configurations was beyond the scope of this study.

For the low pressure ratio (FPR = 1.3) cycle, an additional study was made using the measured noise database of the QCSEE (Quiet Clean Short-Haul Engine)[3] engine as the basis for the noise prediction. The QCSEE engine was designed for a fan pressure ratio of 1.29, and therefore required less extrapolation of noise and cycle parameters to represent the 1.30 fan pressure ratio.

A key objective was to explain the suppression levels obtained in terms of the effects on EPNL of removing the engine tones from the radiated noise spectra. The relative contributions of forward versus aft radiated tone noise control were evaluated.

## 3. Potential Effect of Active Noise Control on Aircraft System Noise

### 3.1 Study Engine Selection

The scope of this program was designed to build upon results previously obtained in NASA Contract NAS3-25629, Task Order 4, in which aircraft system noise studies were conducted over a wide range of engine fan pressure ratio variation for single-rotation fan designs. This study had as its objective an examination of system noise sensitivity to fan pressure ratio for optimization of future Ultrahigh-Bypass Engine (UBE) cycle designs for low noise. (The information in this and the following section, which was also included in Volume 1, is repeated for the convenience of the reader.)

The foreseeable range of fan pressure ratios for advanced single-rotation UBE engines is from a low value of 1.3 to a high of 1.75. Four fan pressure ratio (FPR) values were chosen for the study; 1.3, 1.45, 1.6, and 1.75. The 1.75 FPR represents current state-of-the-art for high bypass ratio engines, while the 1.3 FPR is representative of proposed ultra-high bypass fan designs, and is the lowest value being currently considered, given limitations on fan diameter and installation penalties.

Below a fan pressure ratio of 1.5, speed incompatibilities between the fan and low pressure turbine dictate the need for a gear drive. For all engine cycles with FPR = 1.45 and higher, a mixed flow exhaust was employed to improve performance and reduce jet noise. The engines were sized to 61,500 lbs takeoff thrust, for a two-engine aircraft of 407,000 lb takeoff gross weight. The engine cycle and architecture represent year 2000+ technology level propulsion systems.

The noise component breakdowns for the engines used in this study were based on the $E^3$ (Energy Efficient Engine) database.[4,5] The $E^3$ engine database with the hardwall bellmouth inlet and the hardwall exhaust, although not used in Contract NAS3-25269, is used in this study to provide the hardwall baseline from which the tones can be removed. Table 1 compares engine cycle parameters for the baseline engine (based on $E^3$) to those for the fan pressure ratio variation engine cycles.

**Table 1. Engine Cycle Definition Based on $E^3$ Database for System Noise Studies**

| Parameter | Baseline $E^3$ | Study Configurations | | | |
|---|---|---|---|---|---|
| *FPR* | 1.62 | 1.75 | 1.60 | 1.45 | 1.30 |
| *BPR* | 5.8 | 5.94 | 7.75 | 9.81 | 15.75 |
| *OPR* | 38.5 | 55 | 55 | 55 | 55 |
| $T_{41max}$, °F | 2504 | 2800 | 2800 | 2800 | 2800 |
| *Flow* | Mixed | Mixed | Mixed | Mixed | Separated |
| *Fan Drive* | Direct | Direct | Direct | Geared | Geared |
| *Fan Inlet H/T Ratio* | 0.342 | 0.30 | 0.30 | 0.30 | 0.30 |
| *Fan Tip Diam, in* | 99.5 | 89 | 96 | 106 | 130 |

Engine data for the "reference" (1.62 FPR) cycle $E^3$ engine[4,5] were scaled and adjusted using a GEAE methodology to predict the component noise levels for the "target" engines of other fan pressure ratio cycles, per the methods in Reference 2. See Reference 1 for further details on noise component prediction methodology. Since fan pressure ratio was found to be an important correlation variable for ANC noise suppression, Figure 1, which shows fan blade passing frequency as a function of fan pressure ratio for all engine designs, is included for reference.

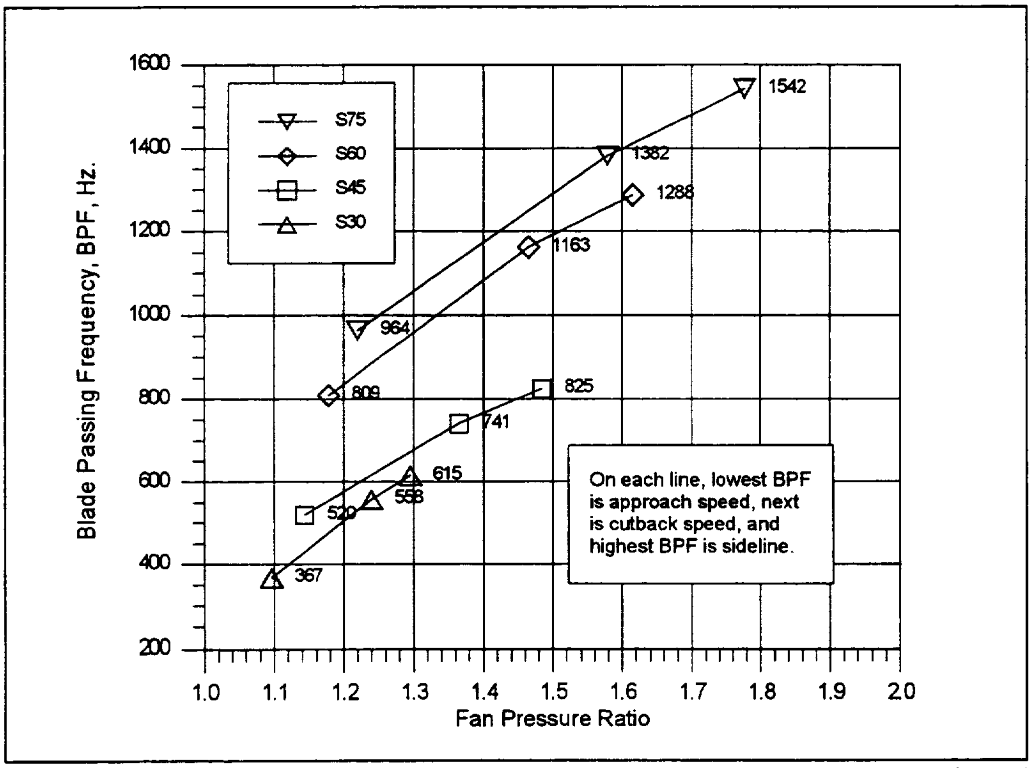


Figure 1 Fan blade passing frequency as a function of fan pressure ratio for all engine configurations at approach, cutback, and sideline.

### 3.2 Acoustic Prediction Methodology

Data for the $E^3$ engine inlet and exhaust radiated levels in hardwall were measured using the Integrated Core/Low Spool (ICLS) engine, as described in References 4 and 5. Background information for the QCSEE engine database can be found in Reference 3. The hardwall engine data were separated into the various engine noise components, including combustor, fan inlet, fan exhaust, and jet noise, using GEAE component noise decomposition methods. Engine cycle parameters, including engine station pressures and temperatures, component mass flows, and engine station flow velocities and Mach numbers, were obtained from cycle analysis. Engine geometric parameters, such as blade and vane numbers, axial spacing, and inlet and exhaust lengths, were given by the flowpath design.

The study engine noise components were obtained by scaling and correcting the component database to the desired study engine cycle conditions using GEAE in-house procedures. The spectra for the fan inlet and exhaust components were then modified by removing the effects of the fan tones. The modified noise components were then re-combined to forecast the study engine noise levels for the new engine cycle conditions.

The noise components were synthesized into flyover noise prediction levels using the GEAE flyover noise prediction program "FAST". The EPNL levels were calculated at sideline, takeoff, cutback, and approach flight conditions. The flight path parameters, altitude, Mach number, and engine thrust levels, were provided from the mission analysis for the subject aircraft.

Flyover noise levels for the treated configurations of the engines included in this study were already available from Contract NAS3-25629[2]. Noise level comparisons were made among the hardwall engine levels with no applied ANC, the hardwall levels with applied ANC, and the treated levels with no applied ANC. Applying ANC to the tones of the treated configurations was not within the scope of this study.

### 3.3 Effects of ANC Tone Removal on EPNL

The reader is referred to Volume 1[1] for a tabulation and charts showing the acoustic levels predicted for all configurations with no applied ANC, for sideline, takeoff, cutback, and approach conditions. The predictions provide the noise source component EPNL values for the combustor, fan exhaust, fan inlet, jet noise, and airframe. Table 2 below summarizes the maximum protrusion of the tones above broadband level for all engine cases, based on the $E^3$ engine database. These tone protrusions are the assumed ANC tone suppressions.

**Table 2 SPL tone protrusions in dB ($E^3$ engine database).**

| | | | Fan Inlet | | | | Fan Exhaust | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Engine | | Tone | S/L | T/O | C/B | APP | S/L | T/O | C/B | APP |
| | Freq, Hz. | BPF | 1542 | 1558 | 1382 | 964 | 1542 | 1558 | 1382 | 964 |
| S75 | Tone | BPF | 13.0 | 13.0 | 13.2 | 7.3 | 8.6 | 8.6 | 6.9 | 6.4 |
| | Protrusion | 2BPF | 5.6 | 5.6 | 6.7 | 4.5 | 4.3 | 4.3 | 6.0 | 2.2 |
| | dB | 3BPF | 2.8 | 2.8 | 4.4 | 2.9 | 2.3 | 2.3 | 6.2 | 0.0 |
| | Freq, Hz. | BPF | 1288 | 1298 | 1163 | 809 | 1288 | 1298 | 1163 | 809 |
| S60 | Tone | BPF | 13.9 | 13.9 | 13.2 | 11.5 | 7.9 | 7.9 | 7.0 | 12.5 |
| | Protrusion | 2BPF | 7.4 | 7.4 | 6.7 | 3.2 | 6.8 | 6.8 | 2.7 | 2.2 |
| | dB | 3BPF | 5.4 | 5.4 | 3.0 | 0.0 | 6.8 | 6.8 | 2.4 | 0.0 |
| | Freq, Hz. | BPF | 825 | 836 | 741 | 520 | 825 | 836 | 741 | 520 |
| S45 | Tone | BPF | 13.0 | 13.0 | 14.3 | 4.8 | 7.9 | 7.5 | 11.8 | 5.3 |
| | Protrusion | 2BPF | 4.5 | 4.8 | 5.1 | 0.0 | 5.2 | 6.5 | 2.4 | 0.0 |
| | dB | 3BPF | 7.9 | 7.2 | 4.8 | 13.8 | 7.5 | 8.1 | 1.0 | 0.0 |
| | Freq, Hz. | BPF | 615 | 620 | 558 | 367 | 615 | 620 | 558 | 367 |
| S30 | Tone | BPF | 12.3 | 12.5 | 7.7 | 3.6 | 9.8 | 9.8 | 11.2 | 7.7 |
| | Protrusion | 2BPF | 5.2 | 5.0 | 0.0 | 3.1 | 2.5 | 2.5 | 2.4 | 0.0 |
| | dB | 3BPF | 7.3 | 7.5 | 3.3 | 14.9 | 3.3 | 3.6 | 0.0 | 0.0 |

Since the QCSEE design fan pressure ratio is very close to 1.30, it was felt that this engine might provide a more representative basis for evaluation of the ANC effects. QCSEE hardwall database test points were identified that are reasonably close to the sideline, cutback and approach test conditions of the S30 application (FPR= 1.295, 1.24, 1.096; UTC=947, 859, 566 respectively). The tone protrusion predictions using the QCSEE engine database are given in Table 3.

**Table 3. SPL Tone protrusion in dB (QCSEE engine database).**

| S30 | Tone | Fan Inlet S/L | Fan Inlet C/B | Fan Inlet APP | Fan Exhaust S/L | Fan Exhaust C/B | Fan Exhaust APP |
|---|---|---|---|---|---|---|---|
| Freq, Hz. | BPF | 615 | 558 | 367 | 615 | 558 | 367 |
| Tone | BPF | 17.9 | 15.0 | 4.7 | 9.8 | 9.8 | 4.3 |
| Protrusion | 2BPF | 6.2 | 5.5 | 9.3 | 3.5 | 7.5 | 3.5 |
| dB | 3BPF | 0.0 | 3.8 | 5.9 | 0.4 | 1.3 | 3.0 |

This section will present the results of removing the tones on the flyover noise EPNL for all configurations, including the S45 and S75 cases analyzed previously. In the course of the study it was found that the tone protrusions of the sideline and takeoff rpm values of both engines were nearly identical (they have approximately the same power setting), so that the examination of the takeoff case was eliminated.

The values of the maximum tone protrusion were considered as an ANC reduction and applied at all angles, by subtracting them from the SPL in the third octave band that contained the harmonic. For each case, ten independent runs of the FAST program were made, in the following combinations:

Fan Inlet (FIN) only:

1) BPF only
2) 2BPF only
3) 3BPF only
4) BPF, 2BPF, and 3BPF

Fan Exhaust (FEX) only:

1) BPF only
2) 2BPF only
3) 3BPF only
4) BPF, 2BPF, and 3BPF

FIN and FEX combined:

1) BPF only
2) BPF, 2BPF, and 3BPF

The results of comparing the original hardwall engine levels presented previously to the levels calculated with the tones removed in the above combinations are summarized in Tables 4 through 7 for the S75, S60, S45, and S30 engines, respectively, for all flight conditions, in terms of EPNL benefit ($\Delta$EPNdB) due to removing the tones.

Table 4. ANC suppressions for S75 engine.

| | Sideline | | | Cutback | | | Approach | | |
|---|---|---|---|---|---|---|---|---|---|
| *ANC Applied* | *EPNL Benefit* | | | *EPNL Benefit* | | | *EPNL Benefit* | | |
| **Fan Inlet Only** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | 5.2 | | 0.3 | 5.9 | | 0.6 | 1.5 | | 0.6 |
| 2BPF | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.3 | | 0.1 |
| 3BPF | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.3 | | 0.1 |
| All BPFs | 5.6 | | 0.3 | 5.9 | | 0.6 | 2.0 | | 0.8 |
| **Fan Exhaust Only** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | | 2.9 | 1.6 | | 2.5 | 1.4 | | 0.6 | 0.3 |
| 2BPF | | 0.1 | 0.1 | | 0.1 | 0.0 | | 0.1 | 0.0 |
| 3BPF | | 0.0 | 0.0 | | 0.0 | 0.1 | | 0.0 | 0.0 |
| All BPFs | | 3.4 | 1.9 | | 2.6 | 1.4 | | 0.9 | 0.3 |
| **Fan Inlet & Exhaust** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | 5.1 | 2.9 | 2.1 | 5.9 | 2.5 | 2.6 | 1.5 | 0.6 | 0.8 |
| All BPFs | 5.5 | 3.4 | 2.5 | 6.1 | 2.6 | 2.7 | 2.0 | 0.9 | 1.0 |

| ***Passive*** | *EPNL Benefit* | | | *EPNL Benefit* | | | *EPNL Benefit* | | |
|---|---|---|---|---|---|---|---|---|---|
| ***Acoustic*** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| ***Treatment*** | 5.8 | 2.3 | 1.8 | 6.1 | 2.0 | 2.1 | 4.3 | 6.4 | 3.9 |

Table 5. ANC Suppressions for the S60 Engine.

| | Sideline | | | Cutback | | | Approach | | |
|---|---|---|---|---|---|---|---|---|---|
| *ANC Applied* | *EPNL Benefit* | | | *EPNL Benefit* | | | *EPNL Benefit* | | |
| **Fan Inlet Only** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | 5.5 | | 0.6 | 4.8 | | 0.8 | 1.2 | | 0.6 |
| 2BPF | 0.1 | | 0.0 | 0.1 | | 0.0 | 0.1 | | 0.0 |
| 3BPF | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 |
| All BPFs | 6.7 | | 0.7 | 5.6 | | 0.9 | 1.4 | | 0.6 |
| **Fan Exhaust Only** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | | 1.6 | 1.0 | | 1.4 | 0.9 | | 0.4 | 0.1 |
| 2BPF | | 0.5 | 0.3 | | 0.4 | 0.2 | | 0.5 | 0.0 |
| 3BPF | | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.0 | 0.0 |
| All BPFs | | 3.2 | 1.7 | | 2.0 | 1.2 | | 0.9 | 0.1 |
| **Fan Inlet & Exhaust** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | 5.6 | 1.6 | 1.8 | 4.8 | 1.4 | 1.7 | 1.2 | 0.4 | 0.7 |
| All BPFs | 6.8 | 3.2 | 2.8 | 5.6 | 2.0 | 2.4 | 1.4 | 0.9 | 0.7 |

| ***Passive*** | *EPNL Benefit* | | | *EPNL Benefit* | | | *EPNL Benefit* | | |
|---|---|---|---|---|---|---|---|---|---|
| ***Acoustic*** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| ***Treatment*** | 5.7 | 2.6 | 2.3 | 5.6 | 1.9 | 2.2 | 5.1 | 6.6 | 4.7 |

Table 6 ANC Suppressions for the S45 Engine.

| | Sideline | | | Cutback | | | Approach | | |
|---|---|---|---|---|---|---|---|---|---|
| *ANC Applied* | *EPNL Benefit* | | | *EPNL Benefit* | | | *EPNL Benefit* | | |
| **Fan Inlet Only** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | 2.8 | | 0.5 | 0.8 | | 0.1 | 0.1 | | 0.0 |
| 2BPF | 0.1 | | 0.0 | 0.1 | | 0.0 | 0.0 | | 0.0 |
| 3BPF | 0.3 | | 0.2 | 0.4 | | 0.1 | 3.5 | | 1.5 |
| All BPFs | 3.2 | | 0.6 | 1.4 | | 0.2 | 3.4 | | 1.6 |
| **Fan Exhaust Only** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | | 0.5 | 0.4 | | 0.6 | 0.4 | | 0.3 | 0.1 |
| 2BPF | | 0.2 | 0.1 | | 0.3 | 0.2 | | 0.0 | 0.0 |
| 3BPF | | 1.3 | 0.9 | | 0.3 | 0.1 | | 0.3 | 0.1 |
| All BPFs | | 3.4 | 2.1 | | 1.3 | 0.7 | | 0.5 | 0.1 |
| **Fan Inlet & Exhaust** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | 2.7 | 0.5 | 0.8 | 0.8 | 0.6 | 0.5 | 0.1 | 0.1 | 0.1 |
| All BPFs | 3.2 | 3.4 | 3.1 | 1.7 | 1.3 | 1.0 | 3.4 | 0.5 | 1.7 |

| *Passive* | *EPNL Benefit* | | | *EPNL Benefit* | | | *EPNL Benefit* | | |
|---|---|---|---|---|---|---|---|---|---|
| *Acoustic* | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| *Treatment* | 5.2 | 4.1 | 3.2 | 6.0 | 6.2 | 4.7 | 4.3 | 4.7 | 3.4 |

Table 7 ANC Suppressions for the S30 Engine Using $E^3$ Database.

| | Sideline | | | Cutback | | | Approach | | |
|---|---|---|---|---|---|---|---|---|---|
| *ANC Applied* | *EPNL Benefit* | | | *EPNL Benefit* | | | *EPNL Benefit* | | |
| **Fan Inlet Only** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | 0.3 | | 0.1 | 0.3 | | 0.1 | 0.1 | | 0.0 |
| 2BPF | 0.1 | | 0.0 | 0.0 | | 0.0 | 0.1 | | 0.0 |
| 3BPF | 2.5 | | 0.7 | 0.6 | | 0.2 | 2.5 | | 1.0 |
| All BPFs | 3.0 | | 0.9 | 0.9 | | 0.2 | 3.1 | | 1.1 |
| **Fan Exhaust Only** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | | 0.9 | 0.5 | | 0.9 | 0.8 | | 0.5 | 0.1 |
| 2BPF | | 0.3 | 0.1 | | 0.0 | 0.1 | | 0.0 | 0.0 |
| 3BPF | | 0.4 | 0.3 | | 0.0 | 0.0 | | 0.0 | 0.0 |
| All BPFs | | 2.3 | 1.2 | | 1.2 | 0.9 | | 0.5 | 0.1 |
| **Fan Inlet & Exhaust** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | 0.3 | 0.9 | 0.6 | 0.3 | 0.9 | 0.9 | 0.1 | 0.5 | 0.1 |
| All BPFs | 3.0 | 2.3 | 2.3 | 1.0 | 1.2 | 1.2 | 3.1 | 0.5 | 1.2 |

| *Passive* | *EPNL Benefit* | | | *EPNL Benefit* | | | *EPNL Benefit* | | |
|---|---|---|---|---|---|---|---|---|---|
| *Acoustic* | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| *Treatment* | 7.3 | 6.2 | 5.2 | 9.2 | 6.0 | 5.7 | 4.9 | 4.3 | 3.2 |

The comparison of the original hardwall engine levels to the levels calculated with the tones removed in the above combinations summarized in Table 7 for the S30 engine are based on the E3 engine database. The comparison for the S30 engine based on the QCSEE database is given in Table 8.

Table 8. ANC Suppressions for S30 Engine Using QCSEE Database.

| *ANC Applied* | *EPNL Benefit* | | | *EPNL Benefit* | | | *EPNL Benefit* | | |
|---|---|---|---|---|---|---|---|---|---|
| **Fan Inlet Only** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | 1.3 | | 0.2 | 0.8 | | 0.1 | 0.2 | | 0.0 |
| 2BPF | 1.7 | | 0.3 | 0.0 | | 0.0 | 0.3 | | 0.0 |
| 3BPF | 0.1 | | 0.0 | 0.0 | | 0.0 | 0.9 | | 0.0 |
| All BPFs | 3.4 | | 0.4 | 0.8 | | 0.1 | 1.0 | | 0.1 |
| **Fan Exhaust Only** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | | 1.4 | 1.1 | | 1.1 | 0.9 | | 0.2 | 0.1 |
| 2BPF | | 0.7 | 0.5 | | 0.5 | 0.4 | | 0.0 | 0.0 |
| 3BPF | | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.6 | 0.3 |
| All BPFs | | 2.0 | 1.6 | | 1.6 | 1.4 | | 0.9 | 0.4 |
| **Fan Inlet & Exhaust** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** |
| 1BPF | 1.5 | 1.4 | 1.3 | 0.8 | 1.1 | 1.0 | 0.2 | 0.2 | 0.1 |
| All BPFs | 3.9 | 2.0 | 2.0 | 0.9 | 1.6 | 1.5 | 1.3 | 0.9 | 0.4 |

The ANC benefit results are presented graphically in Figures 2 through 10, in terms of EPNL values. The bars represent EPNL levels in dB for various combinations of ANC applied to individual tones or combination of tones. For each group of five bars, the solid bar on the left is with no ANC applied. The next three bars are for ANC applied individually to each of the tones, BPF, 2BPF, and 3BPF. The bar on the right is for ANC applied to all three tones simultaneously. Variations of these combinations are as noted in the legends.

The first three charts are for the sideline operating condition. The first of the three sideline charts is for ANC applied to the inlet only. The second of the sideline charts is for ANC applied to the exhaust only. The third chart is for ANC applied to both inlet and exhaust simultaneously. This pattern of three charts is then repeated for cutback and approach conditions.

The results for each engine are presented in each chart as two grouped pairs of bar graphs. For instance in Figure 2 at sideline, the first group of five bars gives the inlet component noise levels with and without ANC for the S75 engine. The second group of five bars, denoted as SUM, gives the effect of applying ANC suppression to the inlet on the overall S75 engine noise (that is, suppressed inlet, unsuppressed exhaust). This same pattern of two groups of bar graphs is then repeated for the S60, S45, and S30 engines.

In Figure 3, the bar graphs are grouped the same way as for Figure 2, but now for the exhaust noise component. In Figure 4, the EPNL values for the fan inlet component and the fan exhaust component at sideline for each engine are repeated, but the values for the 2BPF and 3BPF ANC tone suppression have been omitted. The group of bars marked SUM in Figure 4 are for the overall engine EPNL values with ANC applied to both the inlet and exhaust simultaneously.

Figures 5 through 7 repeat the sequence for the cutback condition, and Figures 8 through 10 are for the approach condition. The results of the predictions will be discussed following the figures.

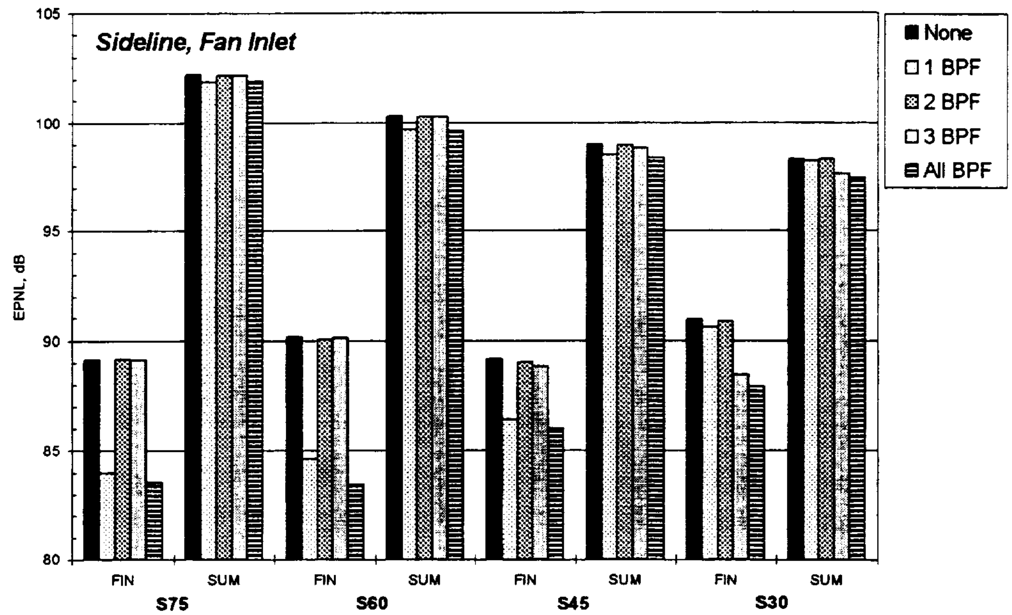


Figure 2. Effect of applying ANC to the fan inlet for all study engines for various tone combinations at sideline condition.

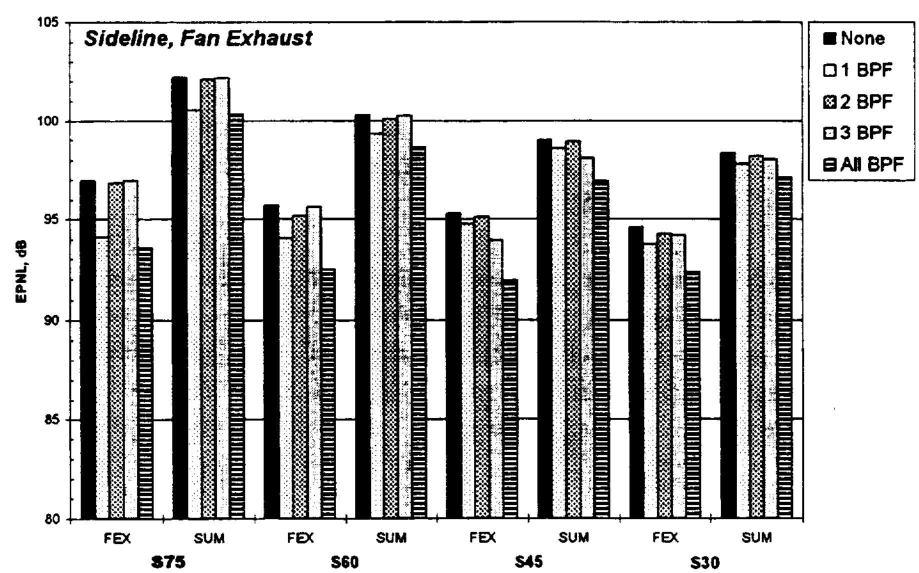


Figure 3. Effect of applying ANC to the fan exhaust for all study engines for various tone combinations at sideline condition.

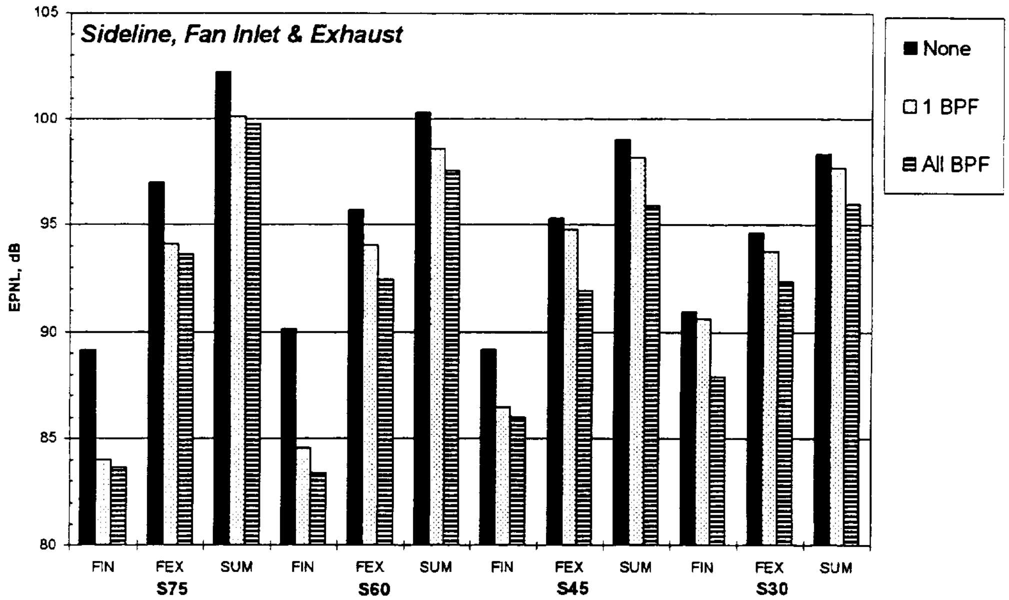


Figure 4. Effect of applying ANC to the fan inlet and exhaust for all study engines for various tone combinations at sideline condition.

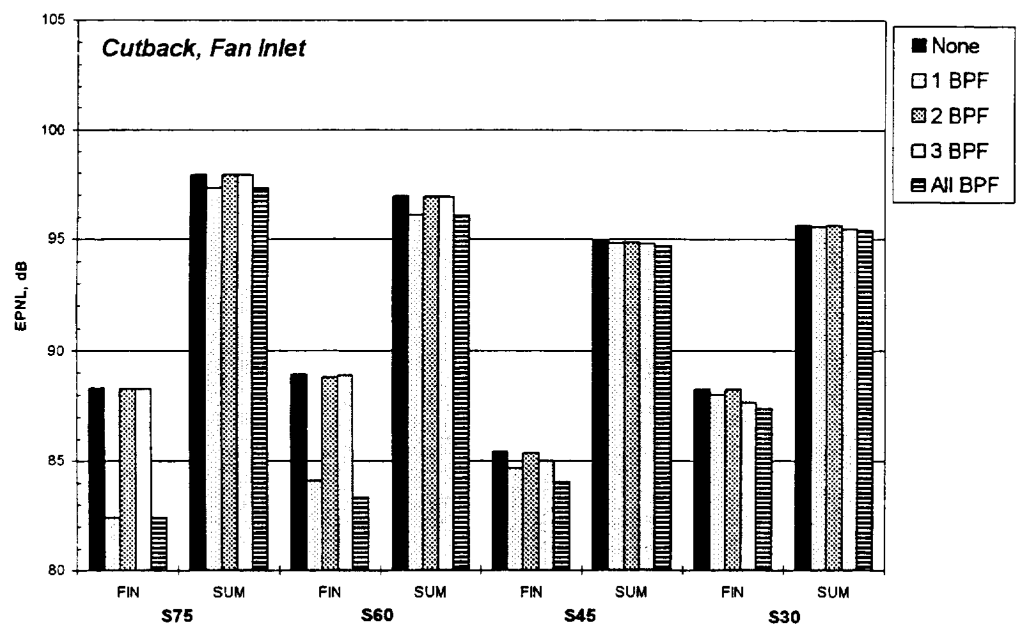


Figure 5. Effect of applying ANC to the fan inlet for all study engines for various tone combinations at cutback condition.

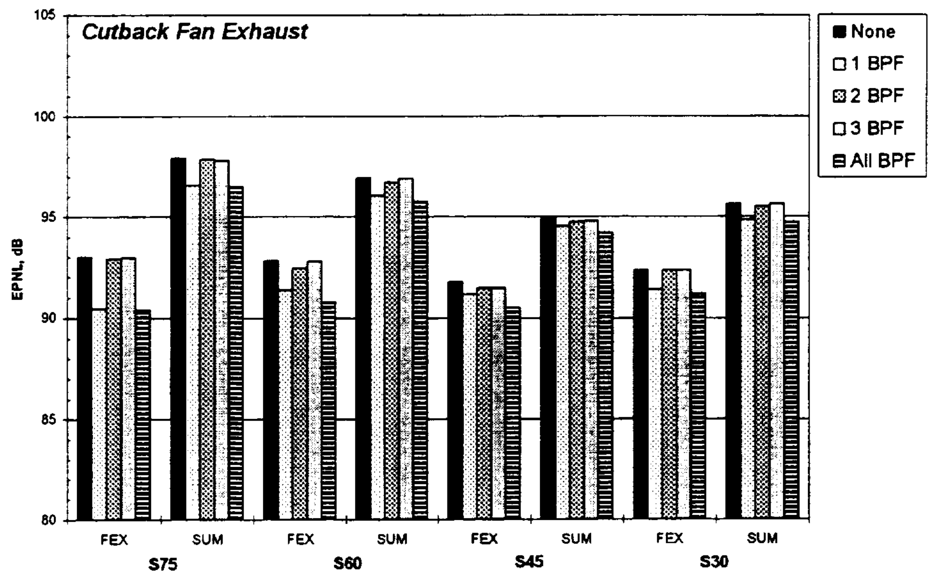


Figure 6. Effect of applying ANC to the fan exhaust for all study engines for various tone combinations at cutback condition.

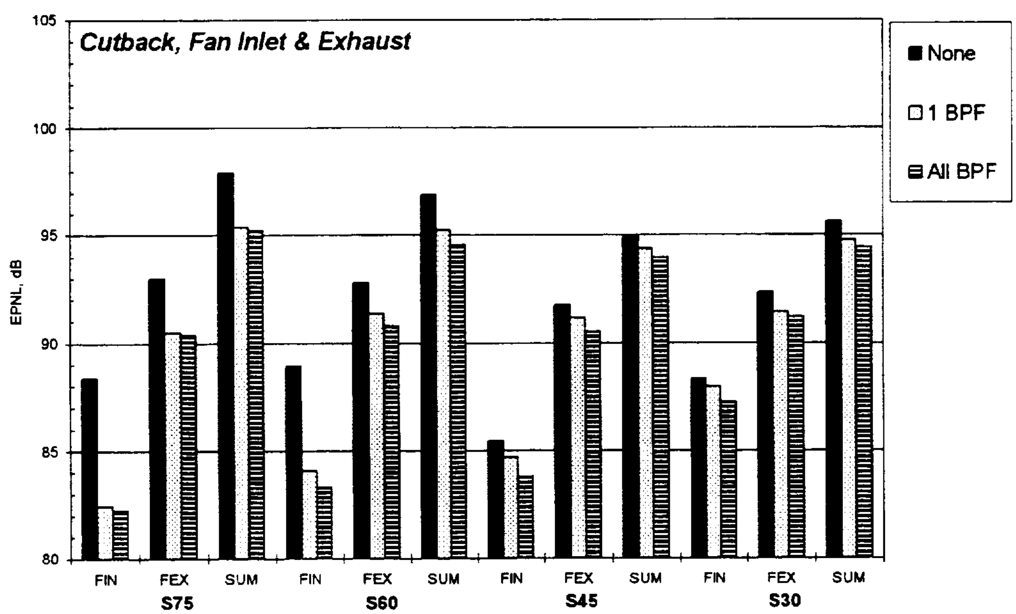


Figure 7. Effect of applying ANC to the fan inlet and exhaust for all study engines for various tone combinations at cutback condition.

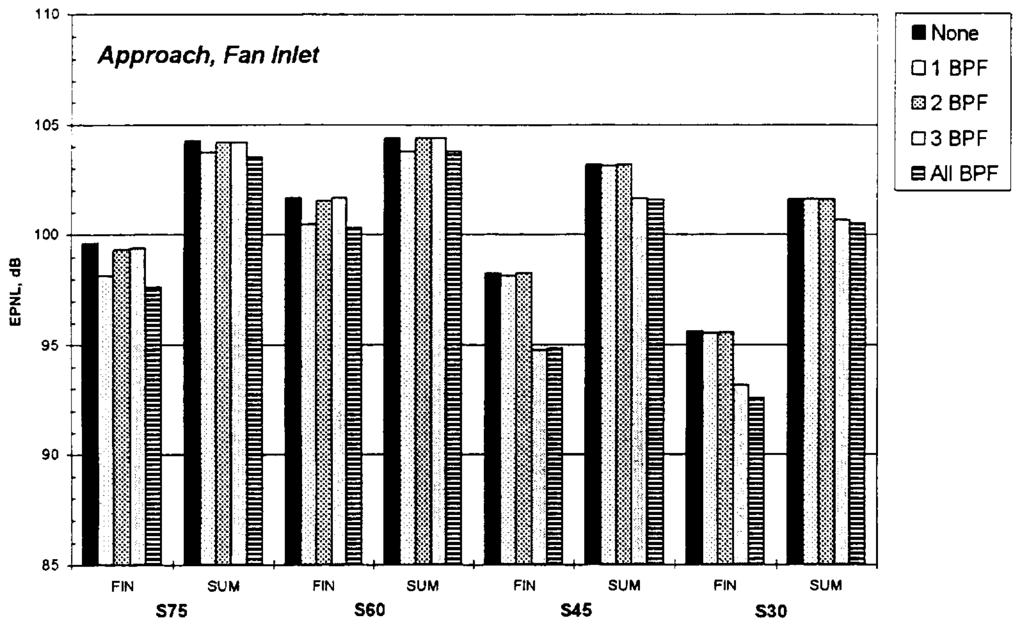


Figure 8. Effect of applying ANC to the fan inlet for all study engines for various tone combinations at approach condition.

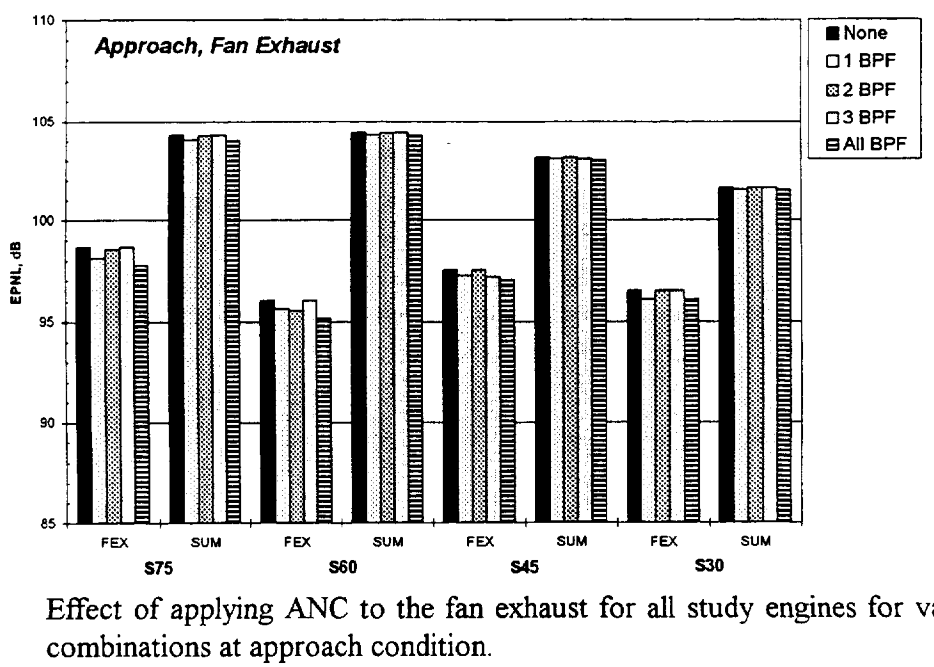


Figure 9. Effect of applying ANC to the fan exhaust for all study engines for various tone combinations at approach condition.

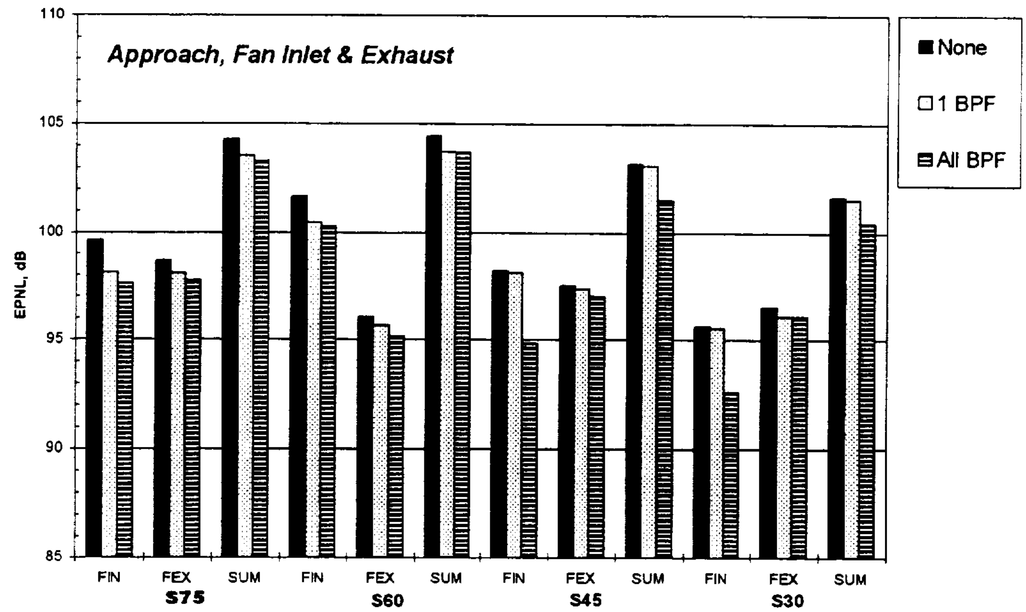


Figure 10. Effect of applying ANC to the fan inlet and exhaust for all study engines for various tone combinations at approach condition.

For Fan Inlet Noise (FIN), in general, these figures suggest the following trends:

1. Application of ANC to BPF results in reduction in the inlet (FIN) component EPNL. This benefit, for a given engine, decreases with decrease in rpm (i.e., decrease in operating fan pressure ratio, tip speed, BPF). This benefit, among the four engines, also decreases with decrease in fan design pressure ratio. The impact on the overall noise (SUM) is either small or insignificant.
2. The application of ANC to 2BPF alone has no impact on FIN or SUM EPNL.
3. The trends in the application of ANC to 3BPF are somewhat opposite to those observed with ANC application to BPF. The benefit, for a given engine, improves with decrease in rpm (i.e., decrease in operating fan pressure, tip speed, and BPF). This benefit, among the four engines, also improves with decrease in fan design pressure ratio. The impact on the SUM levels is noticed with the S45 and the S30 engines at approach.

For Fan Exhaust Noise (FEX), in general, these figures suggest the following trends:

1. The trends in the benefits of ANC application to aft-radiated BPF are similar to those noted with ANC application to forward-radiated BPF. The benefit on the exhaust-radiated noise (FEX) component EPNL, for a given engine, decreases with decrease in rpm (i.e., decrease in operating fan pressure, tip speed, and BPF). This benefit, among the four engines, also decreases with decrease in fan design pressure ratio. A SUM benefit is noted for the S75 and S60 engines at sideline and cutback conditions.

2. The application of ANC to 2BPF alone has little or no impact on FEX or SUM EPNL.
3. The application of ANC to 3BPF has little or no impact on FEX and SUM EPNL except for S45 at sideline.

In summary, the maximum overall benefit obtained for the suppression of BPF alone (both FEX and FIN) was 2.5 EPNdB at high fan pressure ratios. The maximum overall benefit obtained for suppression of the first three harmonics was 3 EPNdB at high fan pressure ratios. In both cases, the suppression decreases as the fan pressure ratio decreases.

### 3.4 Correlation of Data versus Fan Pressure Ratio

Fan pressure ratio was found to be a strong correlating parameter for ANC suppression. The following charts show trends in ANC suppression for inlet, exhaust, and overall suppression for all engines at all operating conditions. To interpret the charts, it should be noted that the three operating conditions are given different symbols, but the symbols at each operating condition are the same for all four engines. To differentiate among the engines at one operating condition, it can be noted that the fan pressure ratio increases in the order S30, S45, S60, and S75.

#### 3.4.1 Trends in Fan Inlet ANC Suppression and Fan Exhaust ANC Suppression

The ANC suppressions (in terms of $\Delta$SPL in dB removed from the tone) for ANC applied to the Fan Inlet BPF, 2BPF and 3BPF are presented in Figures 11 to 13 as a function of fan pressure ratio .The suppressions for ANC applied to BPF and 2BPF *decrease* with decrease in fan pressure ratio while the suppressions for ANC applied to 3BPF *increase* with decrease in fan pressure ratio. The suppressions for ANC applied to BPF decrease from 14 to 4 dB. The suppressions for ANC applied to 2BPF decrease from 6 to 1 dB, and the suppressions for ANC applied to 3BPF increase from 3 to 14 dB with decrease in fan pressure ratio from 1.8 to 1.1.

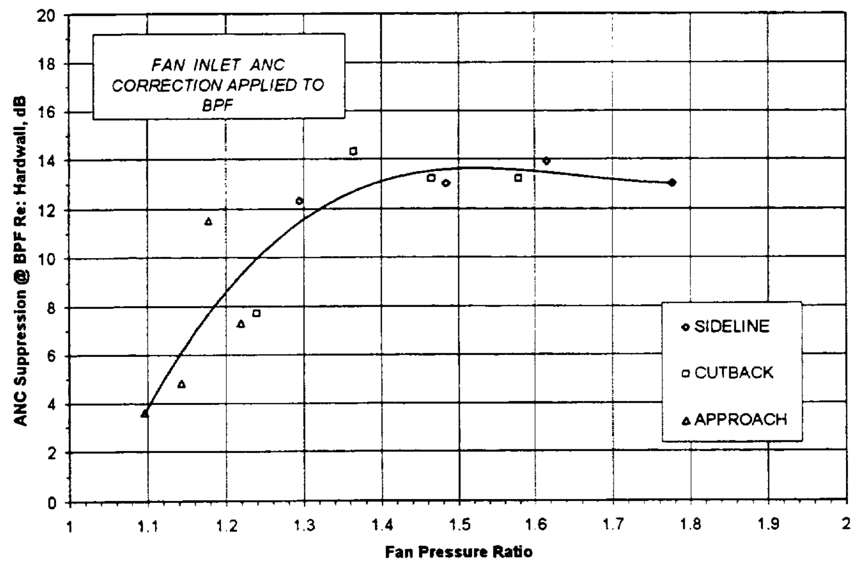


Figure 11. ANC suppression applied to fan inlet of study engines at BPF versus fan pressure ratio.

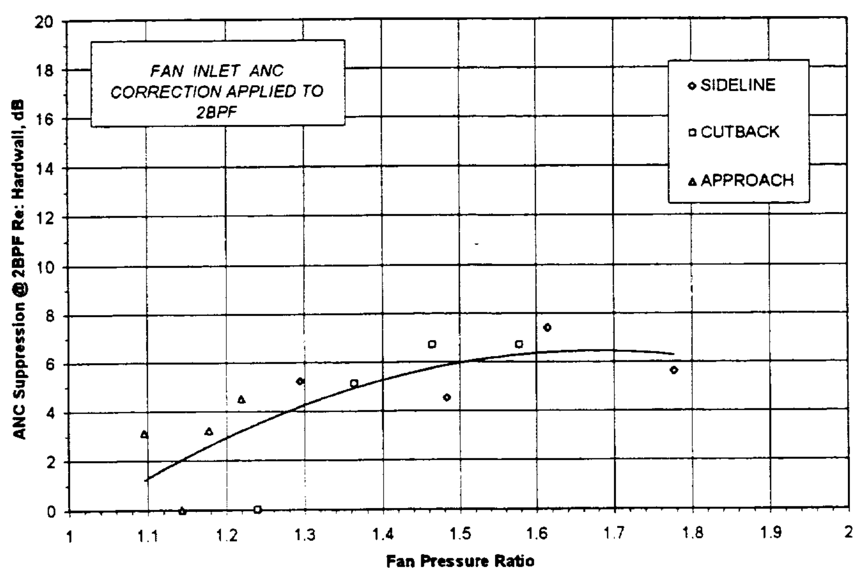


Figure 12. ANC suppression applied to inlet of study engines at 2BPF versus fan pressure ratio.

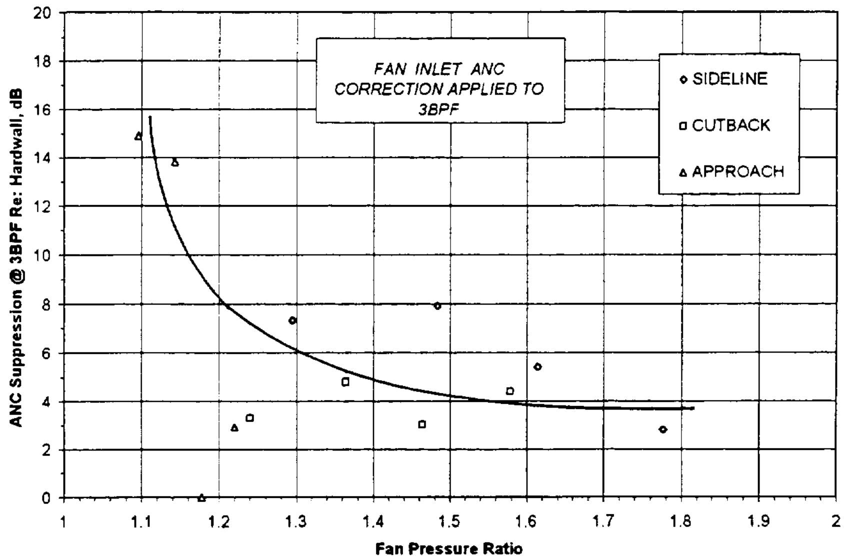


Figure 13. ANC suppression applied to inlet of study engines at 3BPF versus fan pressure ratio.

The ANC suppressions applied to the aft radiated BPF, 2BPF and 3BPF are plotted in Figures 14 to 16. The suppressions to BPF are *constant* (at 8 dB) with fan pressure ratio and the suppressions to 2BPF *decrease* (from 5 to 0 dB) with decrease in fan pressure ratio while the suppressions to 3BPF are effective over a *narrow_range* in fan pressure ratio.

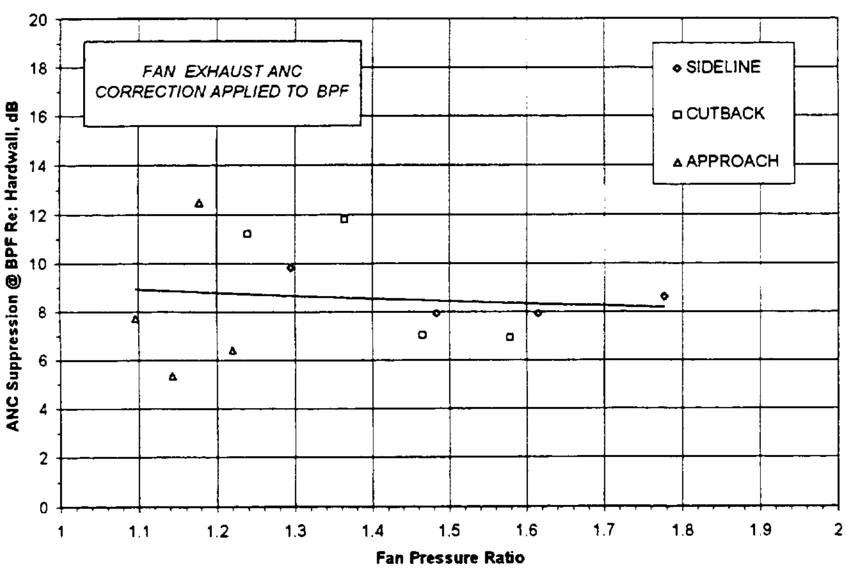


Figure 14. ANC suppression applied to exhaust of study engines at BPF versus fan pressure ratio.

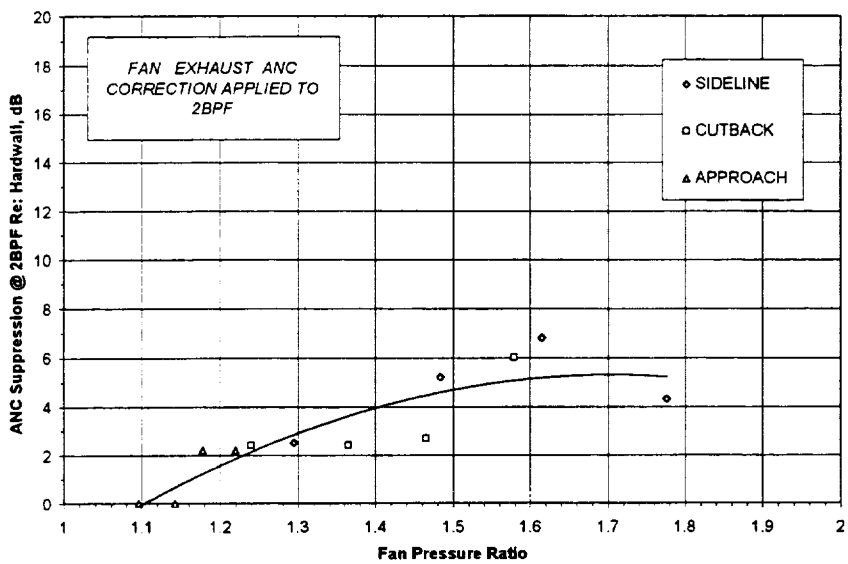


Figure 15. ANC suppression applied to exhaust of study engines at 2BPF versus fan pressure ratio.

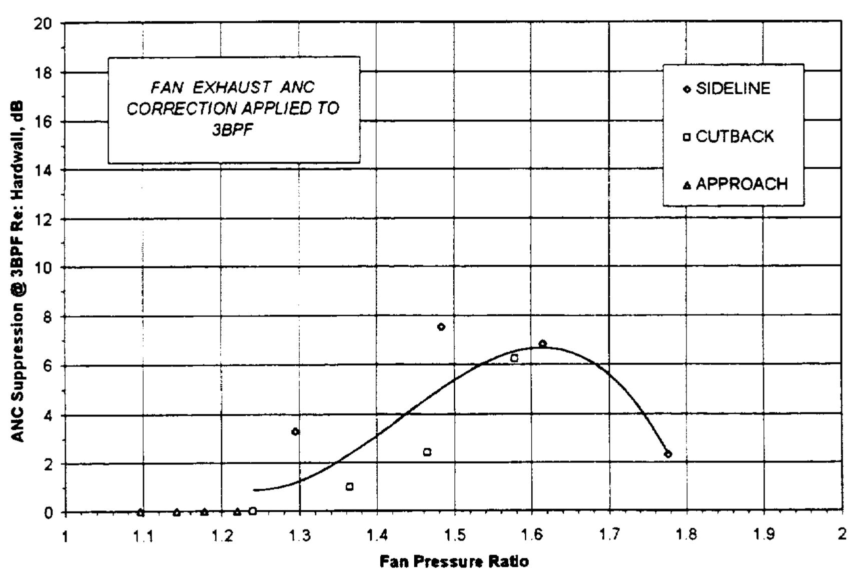


Figure 16. ANC suppression applied to exhaust of study engines at 3BPF versus fan pressure ratio.

### 3.4.2 Trends in FIN and SUM Benefits due to Fan Inlet ANC Suppression

The FIN and SUM benefits (in terms of ΔEPNL) due to ANC suppressions applied to forward radiated BPF are plotted in Figures 17 and 18. The FIN and SUM benefits *decrease* with decrease in fan pressure ratio (similar to the trend in BPF applied suppressions, see Figure 11). The FIN benefit is significant at high fan pressure ratios. However, the impact on the SUM is small and less than 1.0 dB, even with large FIN benefits at high fan pressure ratios, as the noise is exhaust dominated under these conditions.

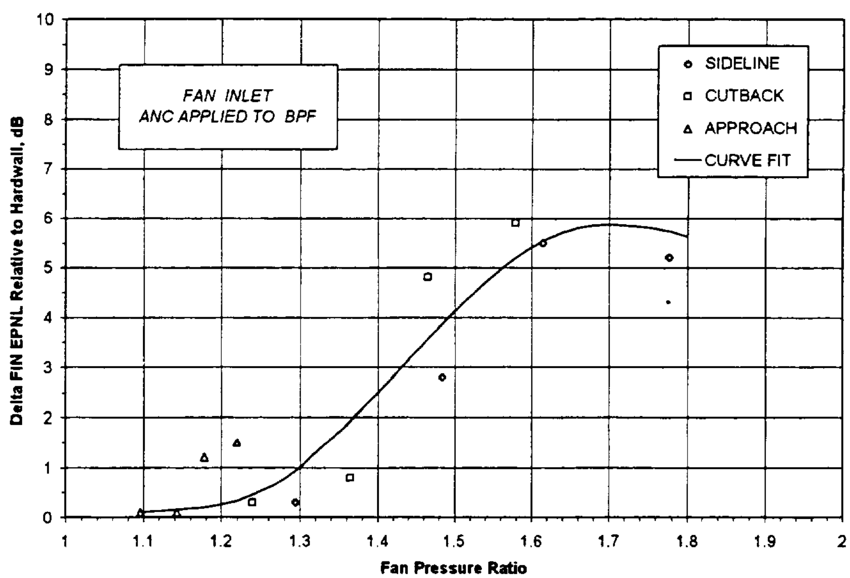


Figure 17. Effect on FIN EPNL of applying ANC to fan inlet of study engines at BPF as a function of fan pressure ratio.

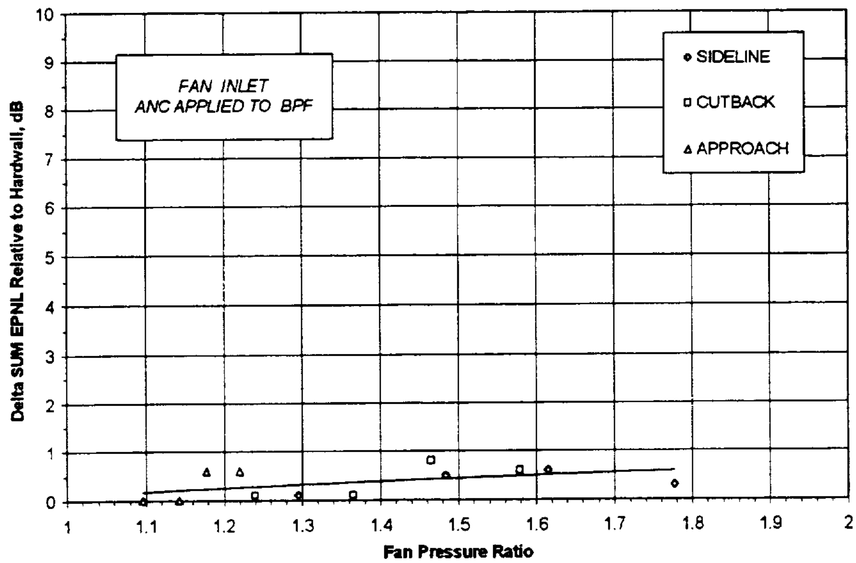


Figure 18. Effect on SUM EPNL of applying ANC to fan inlet of study engines at BPF as a function of fan pressure ratio.

The FIN benefits due to ANC suppressions applied to forward radiated 2BPF are small and have no impact on the SUM. No plots were made for 2BPF.

The FIN and SUM benefits due to ANC suppressions applied to forward radiated 3BPF are shown in Figures 19 and 20. The FIN and SUM benefits *increase* with decrease in fan pressure ratio (similar to the trend in 3BPF suppressions, see Figure 13). No benefits are noted at high fan pressure ratios.

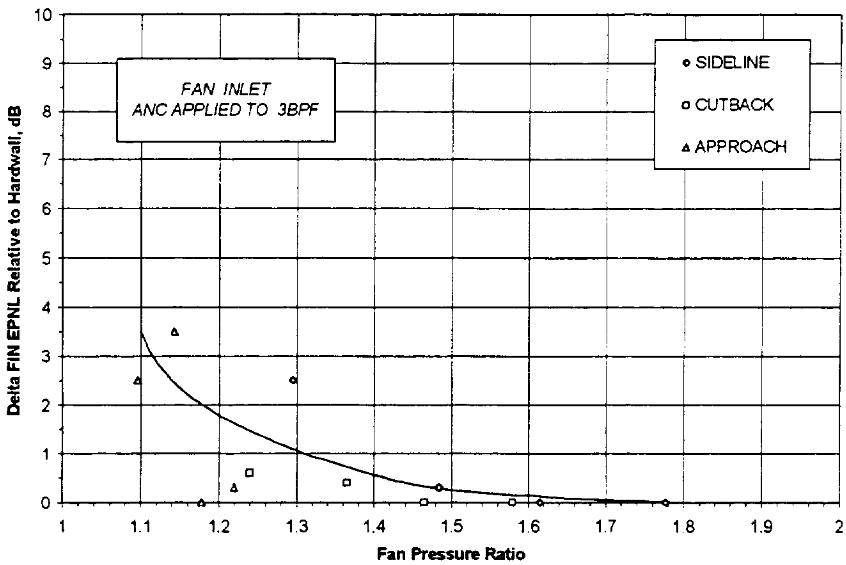


Figure 19. Effect on FIN EPNL of applying ANC to fan inlet of study engines at 3BPF as a function of fan pressure ratio.

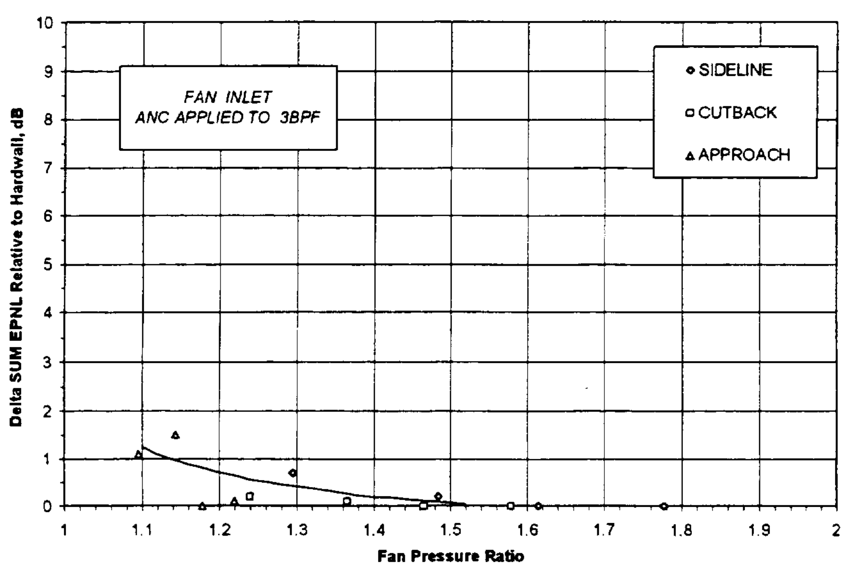


Figure 20. Effect on SUM EPNL of applying ANC to fan inlet of study engines at 3BPF as a function of fan pressure ratio.

The FIN benefits due to ANC suppressions applied to FIN (forward radiated) BPF, 2BPF and 3BPF tones combined are shown in Figure 21, and compared to the suppression that would be obtained from passive acoustic treatment. The inlet suppression benefits are compared, in Figure 22, with benefits noted earlier with suppressions applied to BPF and 3BPF individually

(Figures 17 and 19). The small increase in FIN benefits at high fan pressure ratios with ANC applied to all three harmonics is due to an additional benefit now achieved with ANC to 2BPF (and, to a smaller extent, 3BPF).

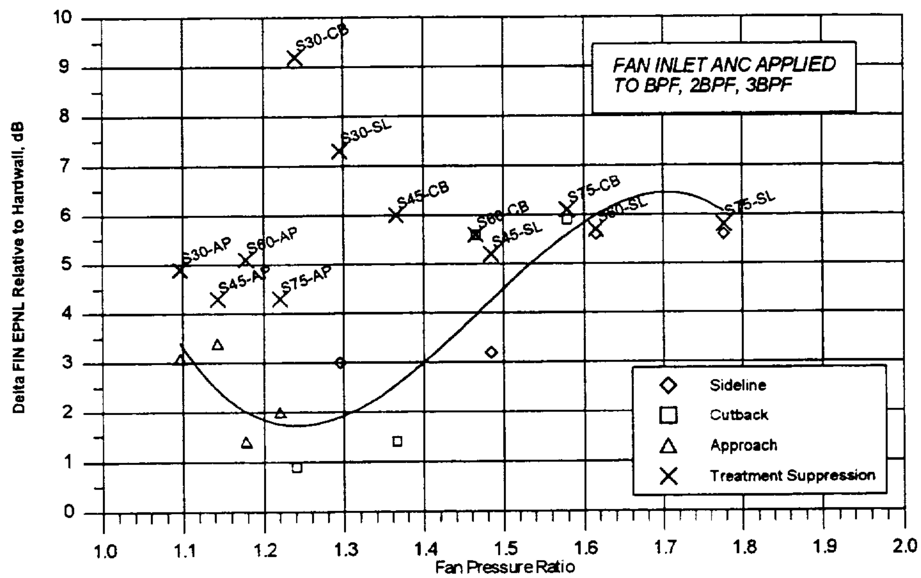


Figure 21. Effect on FIN EPNL of applying ANC to inlet of all engines for BPF, 2BPF, and 3BPF tones as a function of fan pressure ratio, comparing suppression due to passive acoustic treatment.

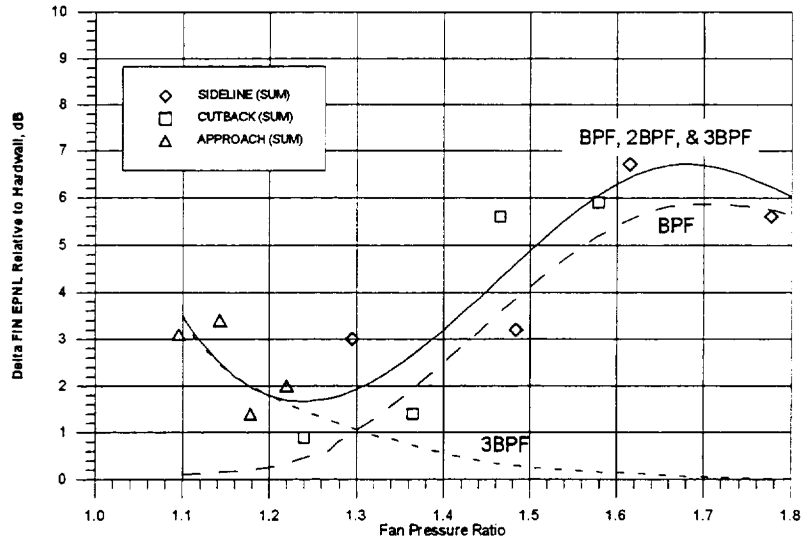


Figure 22. Comparison of inlet ANC suppression benefits for all engines for ANC applied to BPF alone, 3BPF alone, and BPF, 2BPF, and 3BPF combined, as a function of fan pressure ratio.

The SUM benefits with ANC applied to the first three harmonics is summarized in Figure 23. The SUM benefit is limited to 0.5 EPNdB at all conditions except at approach where a maximum benefit of 1.0 EPNdB is noted.

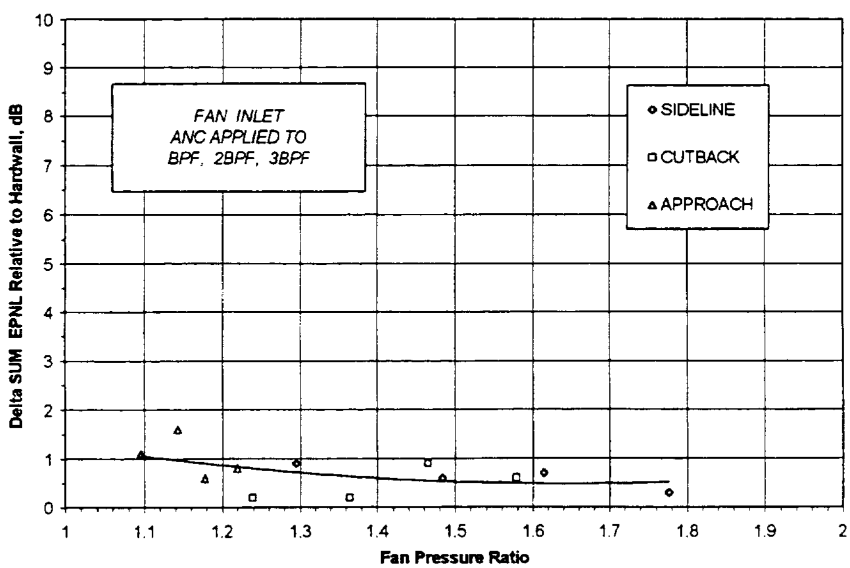


Figure 23. Benefit to overall SUM levels of ANC applied for all three tones to fan inlet of all three engines as a function of fan pressure ratio.

### 3.4.3 Trends in FEX and SUM Benefits due to Fan Exhaust ANC Suppression

The FEX and SUM benefits due to ANC suppressions applied to aft radiated BPF are plotted in Figures 24 and 25. The FEX and SUM benefits *decrease* with decrease in fan pressure ratio because, although the tone suppressions due to ANC are approximately constant with variations in FPR, as shown in Figure 14, the frequency decreases (see Figure 1) and hence the NOY-weighted contribution decreases. The FEX benefit at high fan pressure ratios is 2-3 dB and the corresponding SUM benefit is 1-1.5 dB.

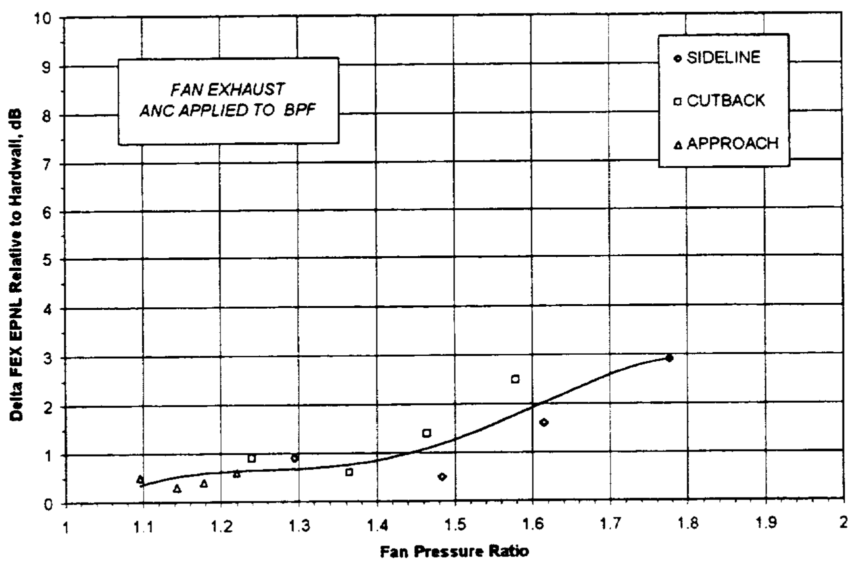


Figure 24. Effect on exhaust noise EPNL of ANC applied to BPF in exhaust for all engines as a function of fan pressure ratio.

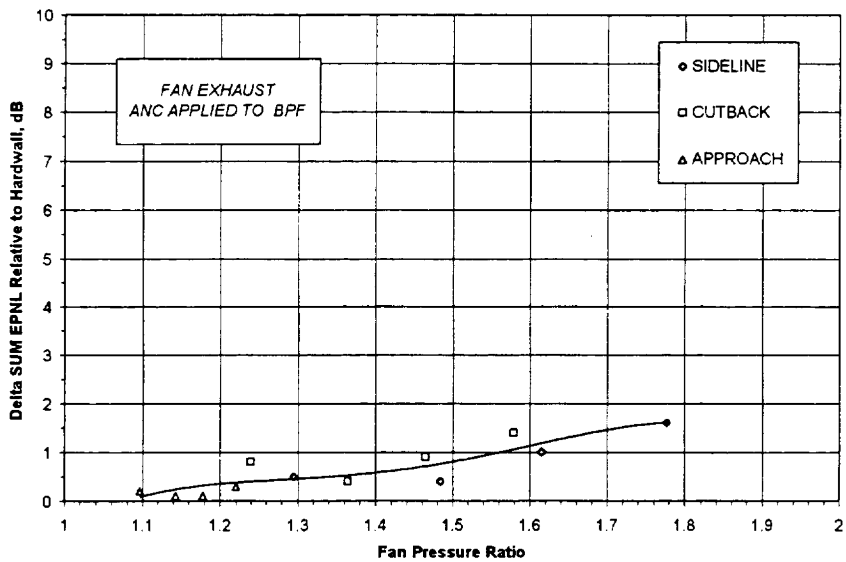


Figure 25. Effect on total noise (SUM EPNL) of ANC applied to BPF in exhaust for all engines as a function of fan pressure ratio.

The FEX benefits due to ANC suppressions applied to aft radiated 2BPF are small (see Figures 3, 6, and 9) and have no significant impact on the SUM. No plots were made for the 2BPF exhaust case.

The FEX and SUM benefits due to ANC suppressions applied to aft radiated 3BPF are small except in a narrow fan pressure ratio range of 1.5-1.6. No plots were made of the effect of applying ANC to 3BPF in the exhaust.

The FEX benefits from ANC suppressions applied to aft radiated BPF, 2BPF and 3BPF are shown in Figure 26. They are compared, in Figure 27, with benefits noted earlier with suppressions applied to BPF only (Figure 24). The increased FEX benefits noted are due to an additional benefit now achieved with ANC to 2BPF and 3BPF. Recall that ANC suppression applied to 2BPF and 3BPF without suppressions of BPF had not shown significant benefits. The SUM benefits with ANC applied to the first three harmonics is summarized in Figure 28. The SUM benefit is limited to 1-1.5 EPNdB at fan pressure ratios greater than 1.3.

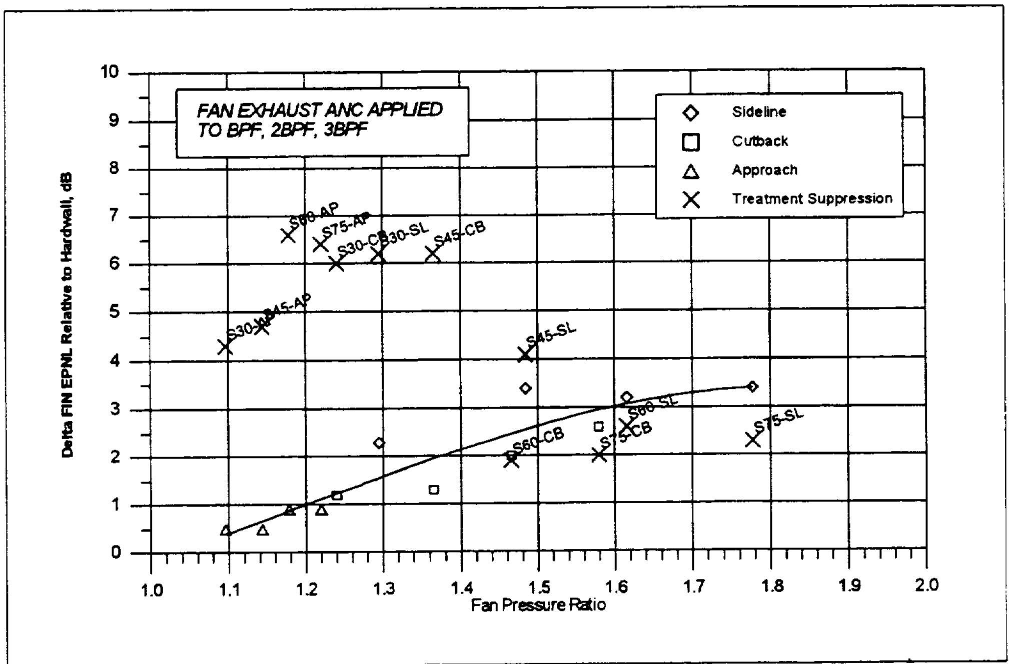


Figure 26. Effect on FEX EPNL of applying ANC to exhaust of all engines for BPF, 2BPF, and 3BPF tones as a function of fan pressure ratio, comparing suppression due to passive acoustic treatment.

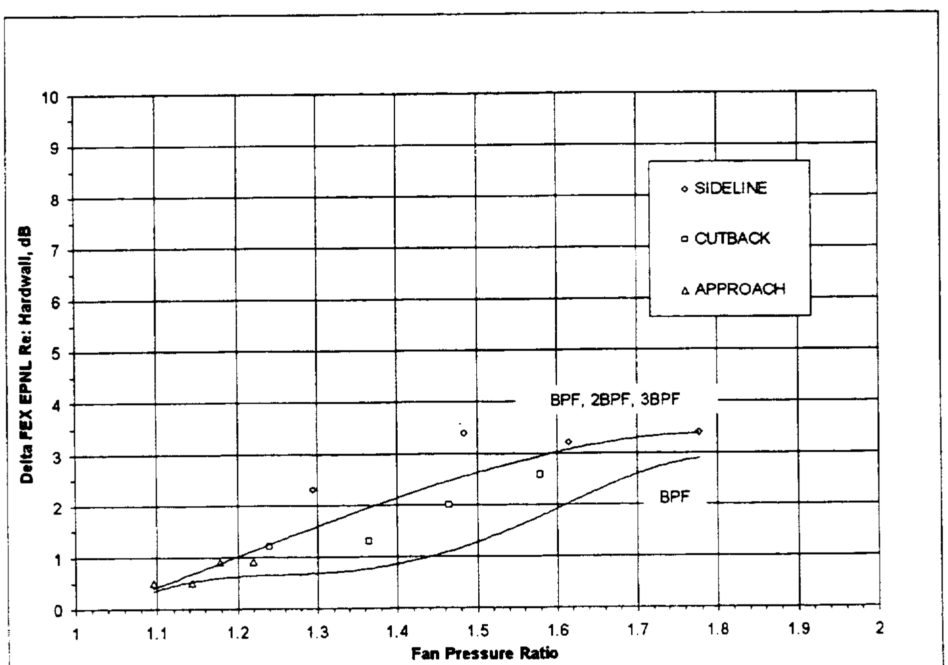


Figure 27. Comparison of exhaust ANC suppression benefits for all engines for ANC applied to BPF alone, 3BPF alone, and BPF, 2BPF, and 3BPF combined, as a function of fan pressure ratio.

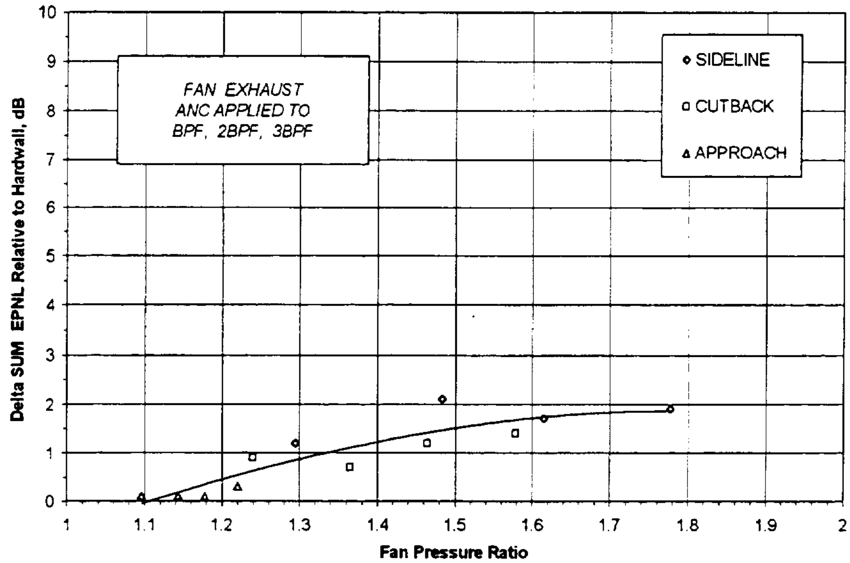


Figure 28. Benefit to overall SUM EPNL levels of ANC applied to all three tones in fan exhaust as a function of fan pressure ratio.

It can be noted that the passive acoustic treatment is significantly more effective than the ANC at low fan pressure ratios and about equally effective at high fan pressure ratios, as shown in Figures 21 and 26. The effects of combined ANC and treatment were not studied.

### 3.4.4 Trends in SUM Benefits due to Fan Inlet and Fan Exhaust ANC Suppression

The total benefit due to ANC suppressions of both forward and aft radiated BPF is shown in Figure 29. The benefit is limited 2 dB at high fan pressure ratios.

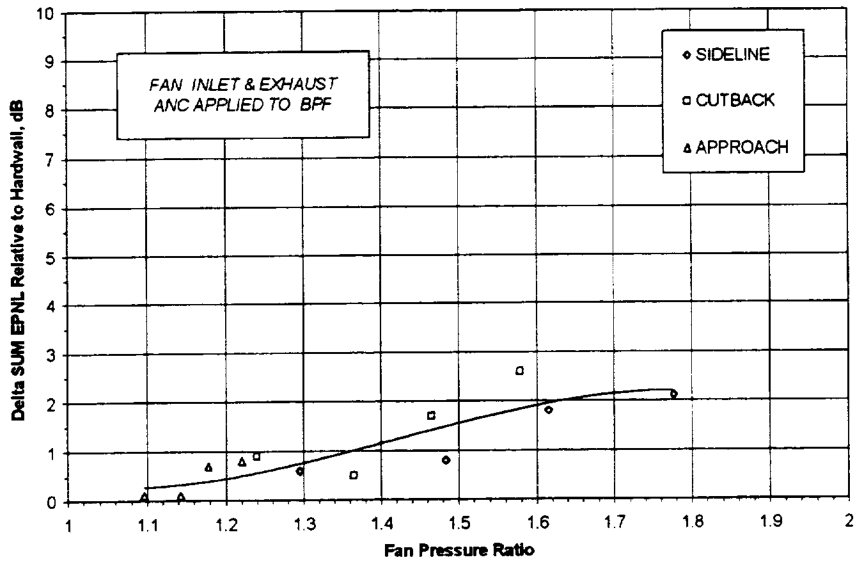


Figure 29. Total noise benefit obtained by applying ANC at BPF to both the inlet and exhaust of all engines, as a function of fan pressure ratio.

The total benefit due to ANC suppressions applied to the first three harmonics of both forward and aft radiated fan noise is shown in Figure 30. The benefit is limited to approximately 3 dB at high fan pressure ratios. The additional benefit of applying ANC to 2BPF and 3BPF improves the noise benefits by about 1 dB at all engine conditions.

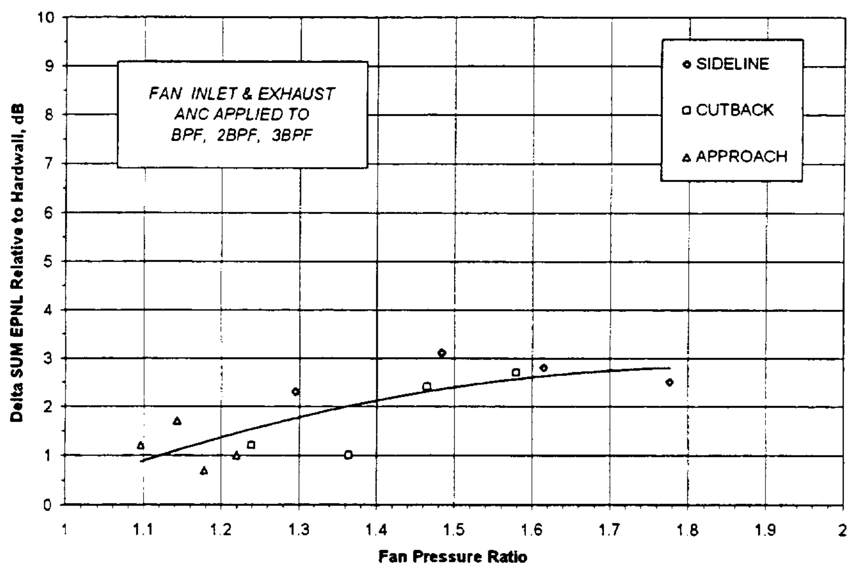


Figure 30. Total noise benefit obtained by applying ANC at BPF,2BPF, and 3BPF to both the inlet and exhaust of all engines, as a function of fan pressure ratio.

### 3.5 Evaluation in Terms of NOY-Weighting

The analysis is concluded by providing selected spectral and NOY-weighting comparisons of forward and aft quadrant S75, S60, S45 and S30 results at sideline, cutback and approach conditions. These spectral comparisons indicate that the ANC benefits depend upon a) the tone frequency, b) the amount of ANC suppression, and c) the noisiness of the tone (i.e., its NOY value) relative to the noisiness levels of the other relevant tones and peak broadband.

The SPL and NOY spectral comparisons are presented in Figures 31 to 38. Typical forward quadrant (60 degree) data are in Figures 31 to 34 and aft quadrant (120 degree) results in Figures 35 to 38. In each of the figures SPL and NOY characteristics are predicted at engine cycle conditions that correspond to sideline, cutback and approach, for a single engine on a 150-ft. arc with no ANC suppressions. These figures should be analyzed in conjunction with applied suppression levels provided in Figures 11 to 13 and 14 to 16.

An examination of the forward quadrant spectra of S75 in Figure 31 indicates that though the sideline and cutback SPL at BPF are within one dB of each other, the NOY value associated with cutback BPF is much smaller relative to the NOY at sideline BPF due to the lower blade passing frequency at cutback. Hence, for the typical spectra of our study engines, just a reduction in the BPF with no SPL change results in a lesser BPF NOY contribution to the sum NOY number that determines the PNL of the spectra (sum NOY = peak NOY + 15% of summation of rest of NOYs). If the BPF NOY is not the peak NOY of the spectra, then its movement to a lower frequency results in an even lesser impact into the sum NOY value.

An examination of the forward quadrant spectra of S75 at approach indicates that, though the sound pressure level of BPF is greater than those of 2BPF, 3BPF, and the 2-4 khz broadband noise, the NOY values in the neighborhood of 3BPF and peak broadband are much greater than those at BPF and 2BPF. Hence, the NOY impact of BPF and 2BPF on the total NOY value and PNL is limited. The impact of an ANC suppression on the PNL/PNLT, therefore, depends not only on the applied suppression value but also on the tone frequency and its NOY level relative to other tones and the peak broadband.

These general trends are noted in the forward and aft quadrant results of all the four study engines (see Figures 31-38).

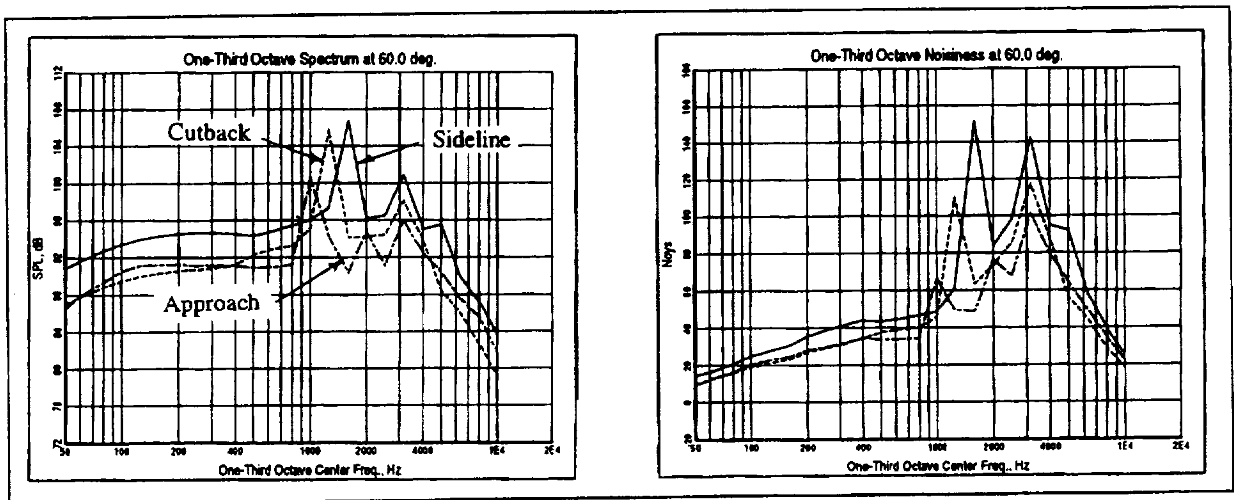


Figure 31. Forward quadrant spectra and NOY characteristics of S75 engine predicted at 60 degrees on 150 foot arc.

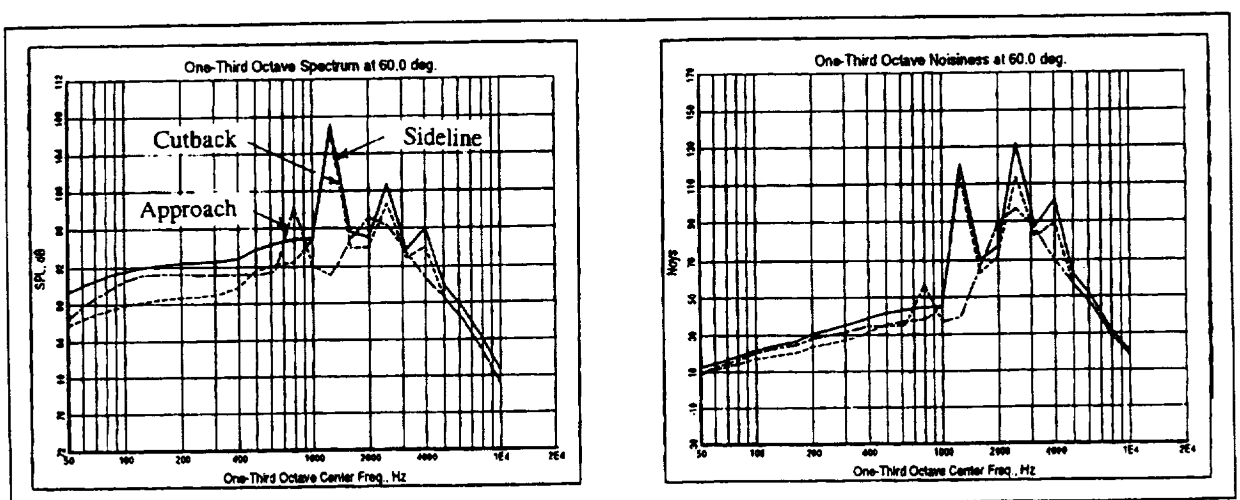


Figure 32. Forward quadrant spectra and NOY characteristics of S60 engine predicted at 60 degrees on 150 foot arc.

The potential benefit of ANC application to forward 3BPF of S45 and S30 engines at approach can be noted from Figures 33 and 34, where the dominance of the 3BPF NOY-weighted tones is obvious. Refer to Figure 13 for the 3BPF suppression levels.

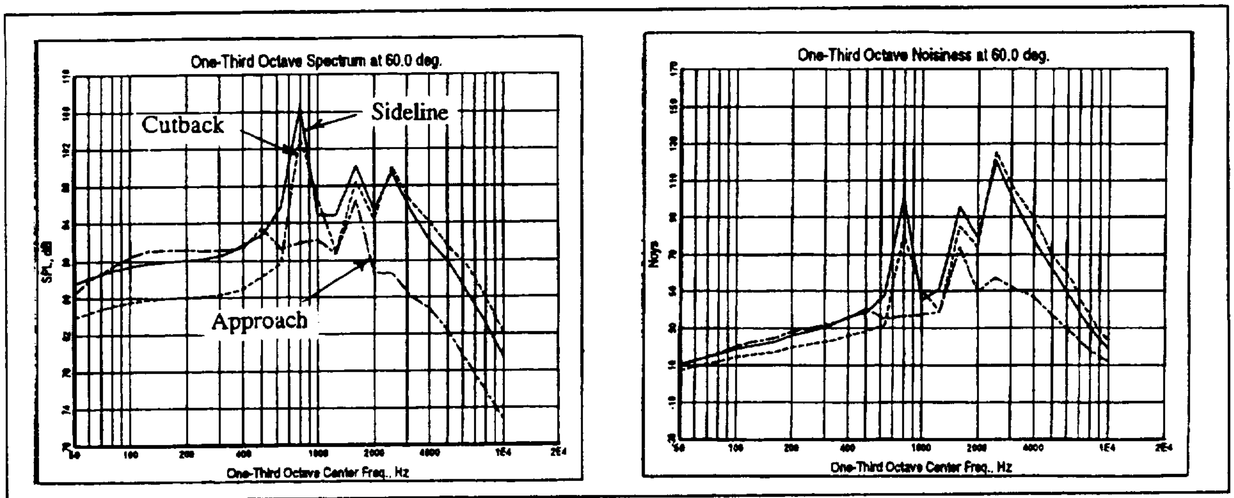


Figure 33. Forward quadrant spectra and NOY characteristics of S45 engine predicted at 60 degrees on 150 foot arc.

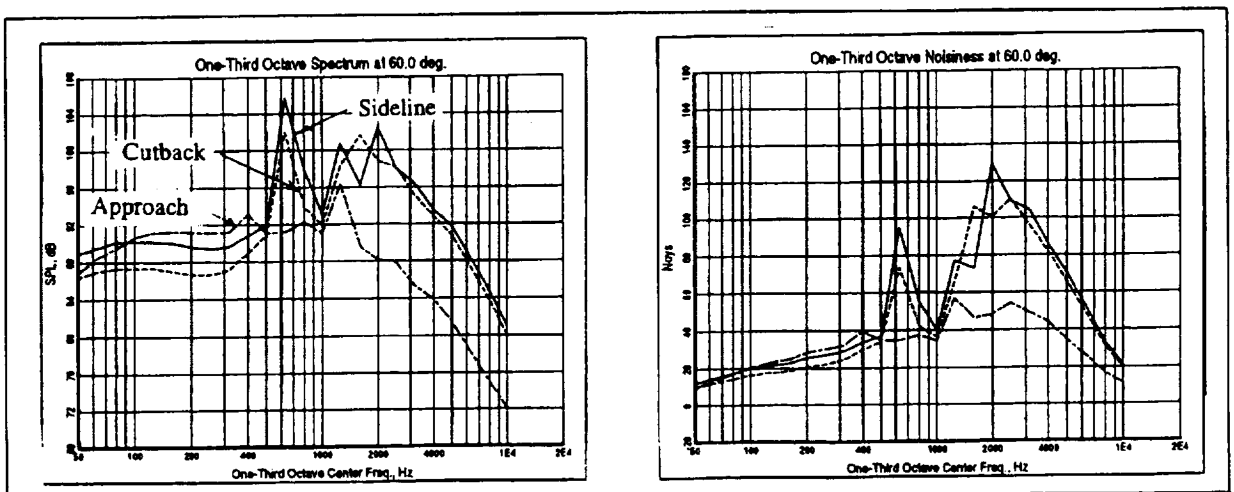


Figure 34. Forward quadrant spectra and NOY characteristics of S30 engine predicted at 60 degrees on 150 foot arc.

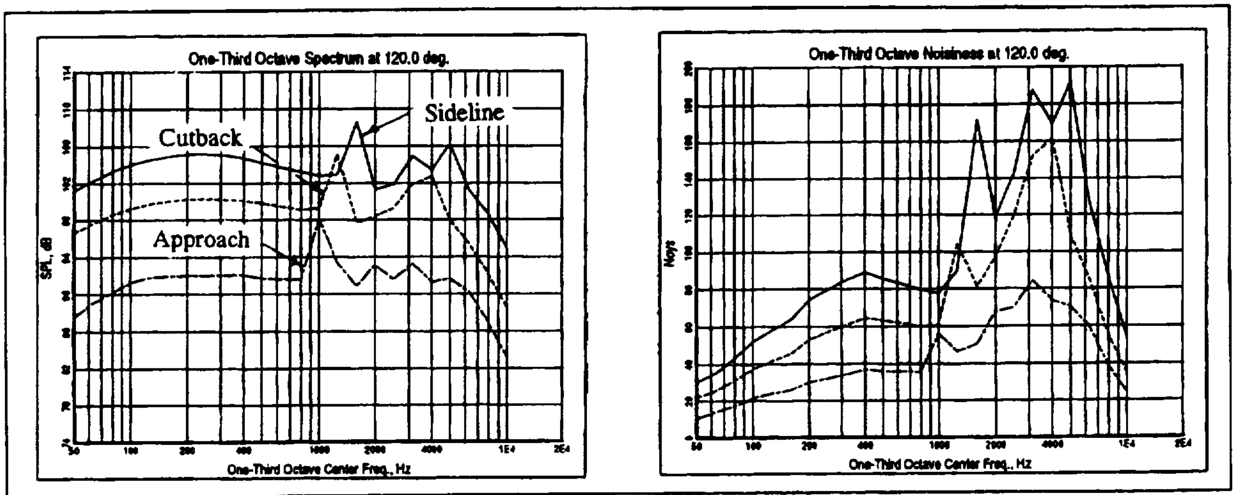


Figure 35. Aft quadrant spectra and NOY characteristics of S75 engine at 120 degrees on 150 foot arc.

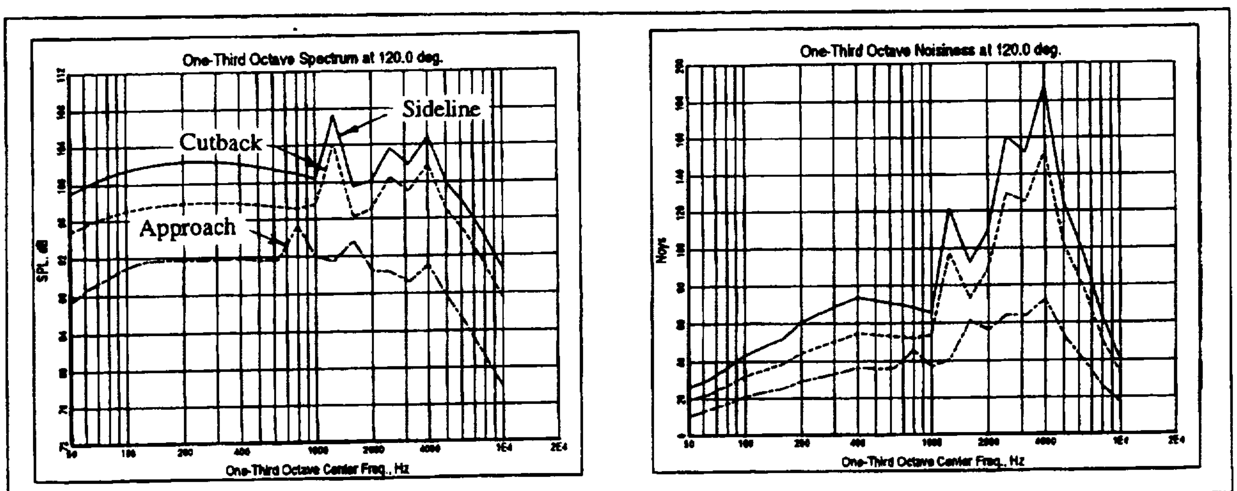


Figure 36. Aft quadrant spectra and NOY characteristics of S60 engine at 120 degrees on 150 foot arc.

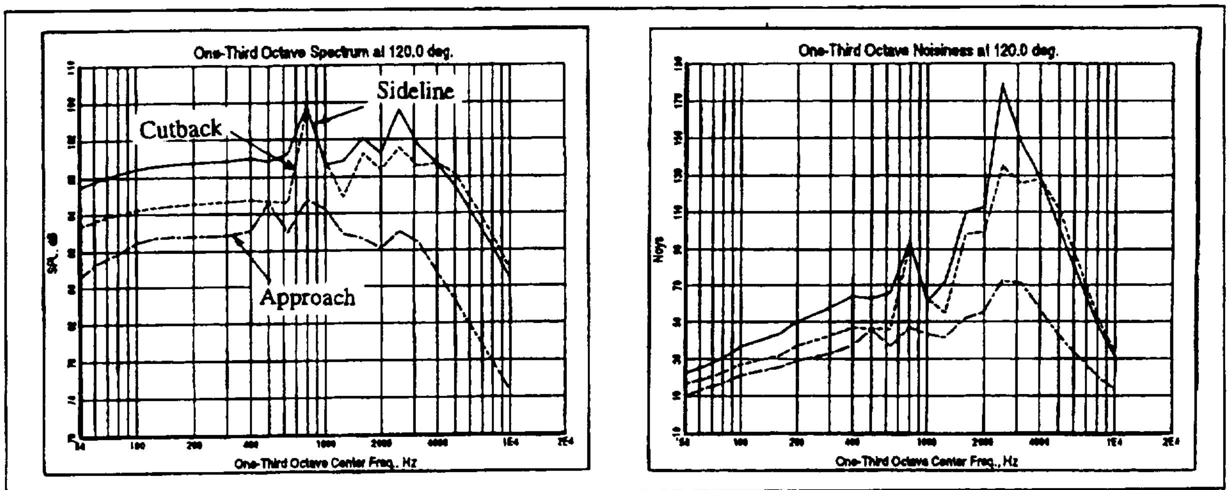


Figure 37. Aft quadrant spectra and NOY characteristics of S45 engine at 120 degrees on 150 foot arc.

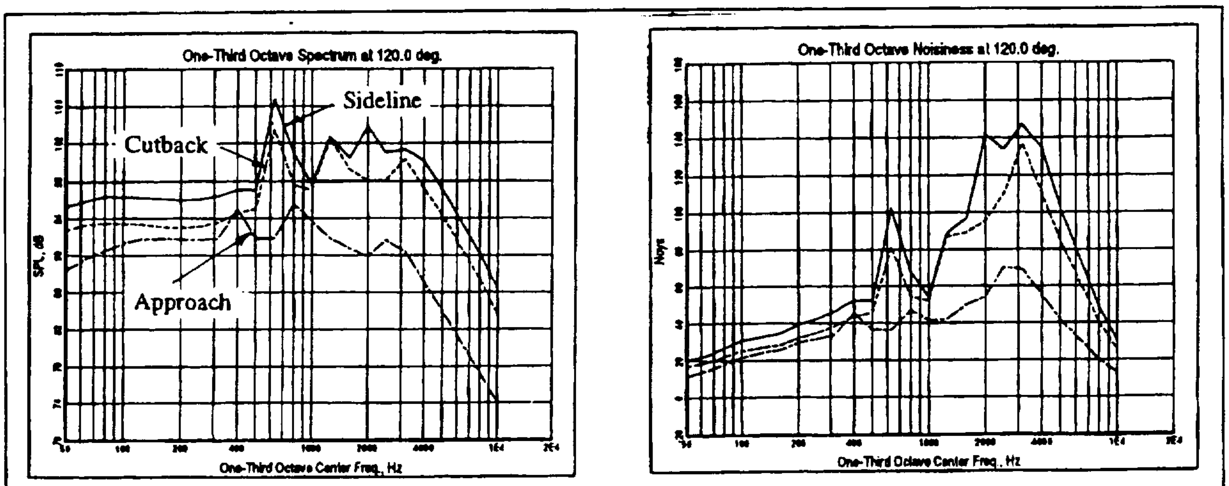


Figure 38. Aft quadrant spectra and NOY characteristics of S30 engine at 120 degrees on 150 foot arc.

The NOY values of BPF and peak broadband are compared in Figures 39 and 40 for the forward (60 degree) and aft (120 degree) quadrant spectra. They are plotted as a function of fan pressure ratio. They indicate the regions in which BPF NOY is greater than the peak broadband NOY and vice versa. Note that these are applicable only to the indicated microphone angles. ANC suppression to BPF is most beneficial when its NOY value is greater than that of peak broadband noise.

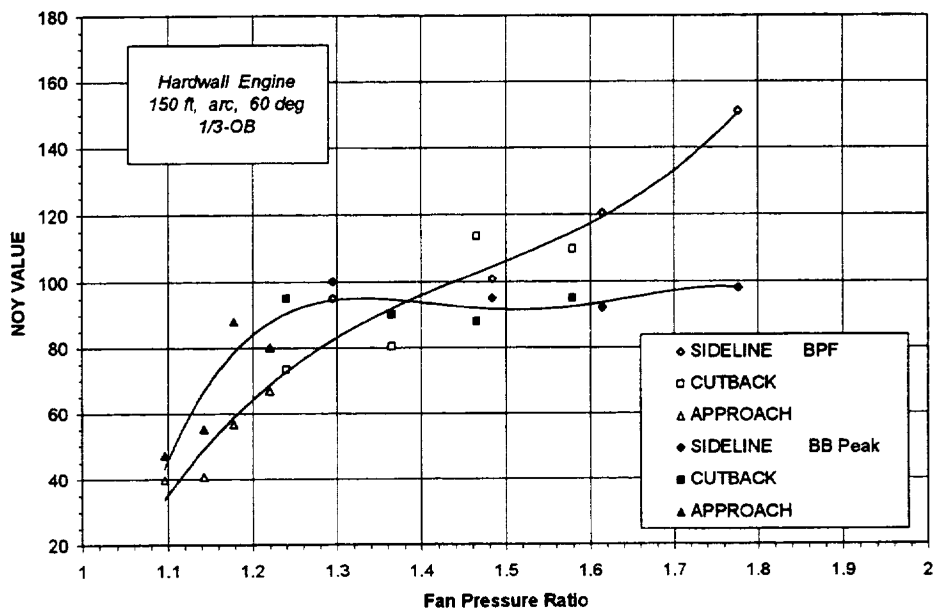


Figure 39. Comparison of NOY values at BPF and for the peak broadband level for all engines at all conditions in the forward arc (60° radiation angle).

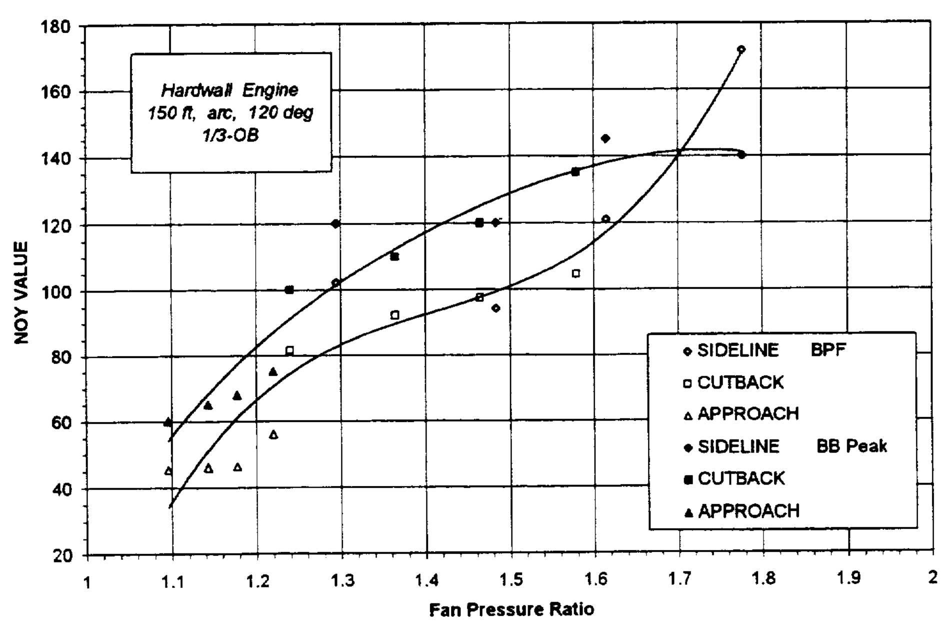


Figure 40. Comparison of NOY values at BPF and for the peak broadband level for all engines at all conditions in the aft arc (120° radiation angle).

Hence, to obtain an effective ANC impact, one must pay close attention to a) the tone frequency, b) the amount of ANC suppression, and c) the noisiness of the tone (i.e., its NOY value) relative to the noisiness levels of other relevant tones and peak broadband.

## 4. Examination of S30 Engine ANC Effects Using QCSEE Database

A study objective was to make system noise predictions with ANC applied to the S30 engine using the QCSEE engine database[3]. Since the QCSEE design fan pressure ratio is very close to 1.30, and it had a gear-driven, variable-pitch fan, it was felt that this engine might provide a more representative basis for evaluation of the ANC effects.

QCSEE hardwall database test points were identified that are reasonably close to the sideline, cutback and approach test conditions of the S30 application (FPR = 1.295, 1.24, 1.096; UTC = 947, 859, 566 respectively). The following three database test points were identified for use:

| Reading | FPR | UTC, fps |
|---|---|---|
| X017 | 1.25 | 953 |
| X006 | 1.24 | 928 |
| X023 | 1.18 | 850 |

The "FAST" prediction deck for the S30 study engine was modified to extract the FIN and FEX components from the above selected QCSEE hardwall database. The tone protrusions of the first three harmonics above the broadband were computed and the maximum values identified. They are listed in Table 9 and compared with the corresponding values obtained from the $E^3$ database predictions. On the average, the tone protrusions derived from the two databases compare reasonably well. The fan inlet BPF and 2BPF protrusions are higher from the QCSEE database results and the fan inlet 3BPF protrusions are higher from the $E^3$ database results. The fan exhaust protrusion levels are more or less similar for both the sets. The ANC was applied in a manner similar to the previous studies

**Table 9. Maximum protrusion of tones above broadband level for S30 engine using $E^3$ and QCSEE databases.**

| | | Fan Inlet | | | Fan Exhaust | | | |
|---|---|---|---|---|---|---|---|---|
| | Tone | S/L | C/B | APP | S/L | C/B | APP | Database |
| Freq, Hz. | BPF | 615 | 558 | 367 | 615 | 558 | 367 | |
| Tone | BPF | 12.3 | 7.7 | 3.6 | 9.8 | 11.2 | 7.7 | |
| Protrusion | 2BPF | 5.2 | 0.0 | 3.1 | 2.5 | 2.4 | 0.0 | $E^3$ |
| dB | 3BPF | 7.3 | 3.3 | 14.9 | 3.3 | 0.0 | 0.0 | |
| Tone | BPF | 17.9 | 15.0 | 4.7 | 9.8 | 9.8 | 4.3 | |
| Protrusion | 2BPF | 6.2 | 5.5 | 9.3 | 3.5 | 7.5 | 3.5 | QCSEE |
| dB | 3BPF | 0.0 | 3.8 | 5.9 | 0.4 | 1.3 | 3.0 | |

The component FIN and FEX, and SUM EPNL values obtained with ANC application to both inlet and aft radiated tones of the S30 engine, using both the $E^3$ and QCSEE hardwall databases, are compared in Figures 41 to 43. While there are some variations (based on the applied ANC levels and the database), the FEX and SUM noise levels of the S30 calculated from two different databases are very comparable. The FIN component data obtained from the use of QCSEE database are generally lower in levels relative to corresponding $E^3$ based results.

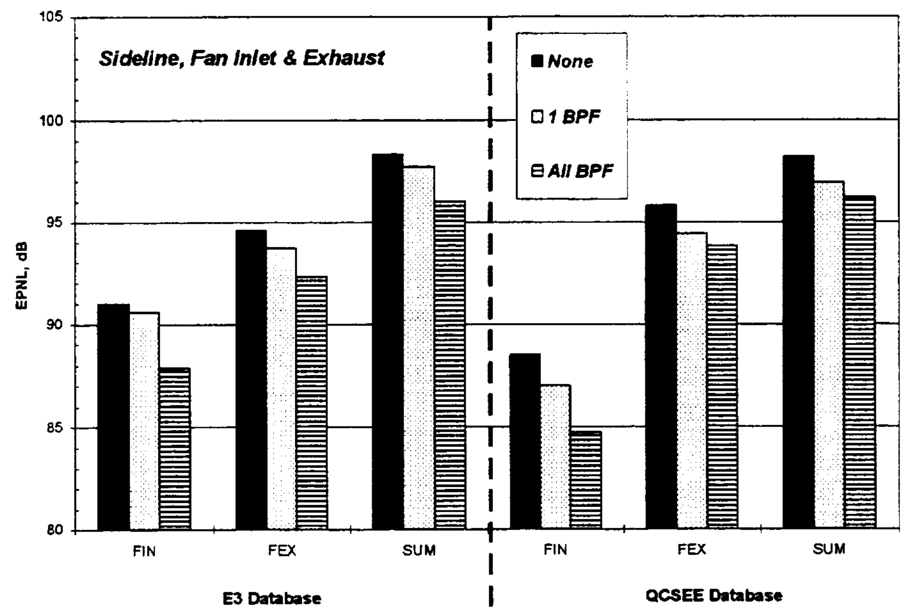


Figure 41. Effect of applying ANC to fan inlet and exhaust on engine S30 for sideline condition, comparing results from $E^3$ and QCSEE databases.

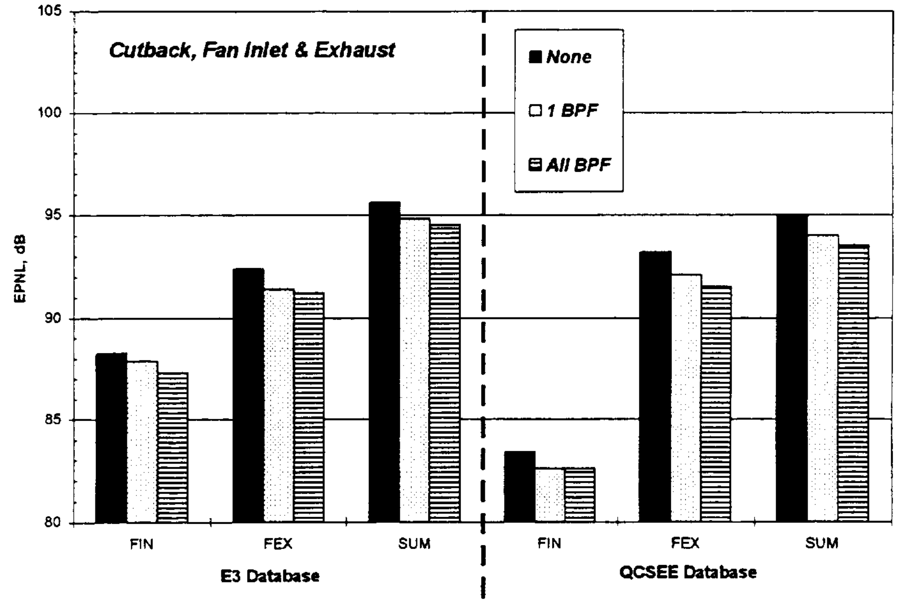


Figure 42. Effect of applying ANC to fan inlet and exhaust on engine S30 for cutback condition, comparing results from $E^3$ and QCSEE databases.

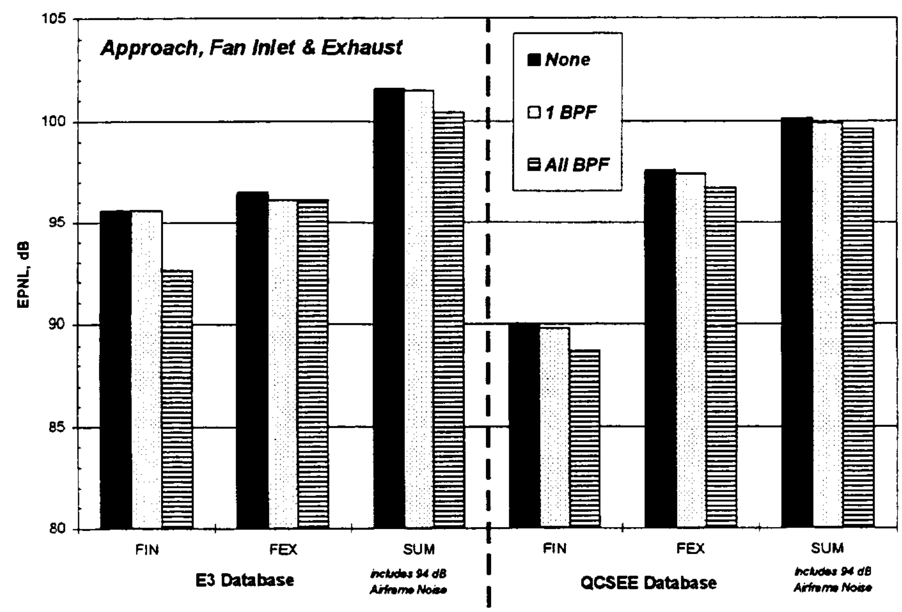


Figure 43. Effect of applying ANC to fan inlet and exhaust on engine S30 for approach condition, comparing results from $E^3$ and QCSEE databases.

The benefits from the application of ANC to the S30 engine are tabulated and compared in Table 10 for the two databases used. The component and sum benefits with the application of ANC to the first three harmonics are very similar at sideline and cutback. At approach, they differ due to the higher benefit obtained by the application of ANC to the strong third harmonic of the fan inlet noise calculated using the $E^3$ database.

**Table 10. Effect of applying active noise control to BPF, 2BPF, and 3BPF on engine S30, comparing results from $E^3$ and QCSEE databases.**

| | Sideline | | | Cutback | | | Approach | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *ANC Applied* | *EPNL Benefit* | | | *EPNL Benefit* | | | *EPNL Benefit* | | | |
| **Fan Inlet Only** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | $E^3$ |
| 1BPF | 0.3 | | 0.1 | 0.3 | | 0.1 | 0.1 | | 0.0 | |
| 2BPF | 0.1 | | 0.0 | 0.0 | | 0.0 | 0.1 | | 0.0 | |
| 3BPF | 2.5 | | 0.7 | 0.6 | | 0.2 | 2.5 | | 1.0 | |
| All BPFs | 3.0 | | 0.9 | 0.9 | | 0.2 | 3.1 | | 1.1 | |
| **Fan Exhaust Only** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | |
| 1BPF | | 0.9 | 0.5 | | 0.9 | 0.8 | | 0.5 | 0.1 | |
| 2BPF | | 0.3 | 0.1 | | 0.0 | 0.1 | | 0.0 | 0.0 | |
| 3BPF | | 0.4 | 0.3 | | 0.0 | 0.0 | | 0.0 | 0.0 | |
| All BPFs | | 2.3 | 1.2 | | 1.2 | 0.9 | | 0.5 | 0.1 | |
| **Fan Inlet & Exhaust** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | |
| 1BPF | 0.3 | 0.9 | 0.6 | 0.3 | 0.9 | 0.9 | 0.1 | 0.5 | 0.1 | |
| All BPFs | 3.0 | 2.3 | 2.3 | 1.0 | 1.2 | 1.2 | 3.1 | 0.5 | 1.2 | |
| **Fan Inlet Only** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **QCSEE** |
| 1BPF | 1.3 | | 0.2 | 0.8 | | 0.1 | 0.2 | | 0.0 | |
| 2BPF | 1.7 | | 0.3 | 0.0 | | 0.0 | 0.3 | | 0.0 | |
| 3BPF | 0.1 | | 0.0 | 0.0 | | 0.0 | 0.9 | | 0.0 | |
| All BPFs | 3.7 | | 0.4 | 0.8 | | 0.1 | 1.0 | | 0.1 | |
| **Fan Exhaust Only** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | |
| 1BPF | | 1.4 | 1.1 | | 1.1 | 0.9 | | 0.2 | 0.1 | |
| 2BPF | | 0.7 | 0.5 | | 0.5 | 0.4 | | 0.0 | 0.0 | |
| 3BPF | | 0.0 | 0.0 | | 0.0 | 0.0 | | 0.6 | 0.3 | |
| All BPFs | | 2.0 | 1.6 | | 1.6 | 1.4 | | 0.9 | 0.4 | |
| **Fan Inlet & Exhaust** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | **FIN** | **FEX** | **SUM** | |
| 1BPF | 1.5 | 1.4 | 1.3 | 0.8 | 1.1 | 1.0 | 0.2 | 0.2 | 0.1 | |
| All BPFs | 3.9 | 2.0 | 2.0 | 0.9 | 1.6 | 1.5 | 1.3 | 0.9 | 0.4 | |

It can be generally concluded that the differences in effects of applying ANC to the S30 engine using the $E^3$ or the QCSEE database are minimal. This indicates that the extrapolation of the $E^3$ database to the 1.30 fan pressure ratio condition was a reasonable procedure.

## 5. Conclusions and Recommendations

The key conclusions that summarize this study are the following:

- The maximum overall benefit obtained for the suppression of BPF alone was 2.5 EPNdB at high fan pressure ratios. The benefit decreases with a decrease in FPR.

- The maximum overall benefit obtained for suppression of the first three harmonics combined was 3 EPNdB at high fan pressure ratios. The benefit decreases with a decrease in FPR.
- Application of ANC to 2BPF alone has little impact.

The benefit to be obtained from application of active noise control to fan engine tones depends on:

1. The frequencies of the tones
2. The amount of ANC suppression (tone protrusion relative to broadband level)
3. The NOY-weighted contribution of the controlled tone(s) relative to NOY-weighted values of other tones and the peak broadband level

ANC application is about as effective as passive liner suppression at the higher fan pressure ratios and fan speeds, but is less effective at the lower fan pressure ratios and fan speeds, where the tone protrusion is less. Even the high pressure ratio fans lose effectiveness relative to passive treatment at approach conditions.

The ANC suppression for this study was applied to hardwall engine configurations with no treatment. The results were compared to benefits due to treatment only. A useful extension of this study would be to apply ANC suppression to a treated engine, to determine what additional benefits might be obtained from the combination of active and passive treatments.

To conduct a passively-treated duct study effectively, it would be necessary to determine what loss in passive treatment effectiveness might result from installation of the ANC system, which would require preliminary design specifications for the ANC system, in terms of the required duct wall area for ANC installation. To proceed beyond that, one might inquire how the passive treatment and active system might be designed as an optimized suppression system, and what potential benefit might be gained from such a procedure.

## 6. Nomenclature

ANC .............. Active Noise Control
BPF ............... Blade-Passing Frequency
2BPF.............. Second harmonic of Blade Passing Frequency (Twice BPF)
3BPF.............. Third harmonic of Blade Passing Frequency (Three times BPF)
BPR............... By-Pass Ratio
dB.................. decibel
$E^3$ .................. Energy Efficient Engine
EPNL............. Effective Perceived Noise Level
EPNdB .......... dB units for Effective Perceived Noise Level
FAST ............. GEAE aircraft flyover system noise prediction program
FEX............... Designation for fan exhaust noise component
FIN................ Designation for fan inlet noise component
FPR ............... Fan Pressure Ratio
GEAE............ General Electric Aircraft Engines
H/T................ Hub-to-Tip radius ratio
NASA............ National Aeronautics and Space Administration
OPR............... Overall engine Pressure Ratio
PNL............... Perceived Noise Level
QCSEE.......... Quiet Clean Short Haul Experimental Engine
SPL................ Sound Pressure Level
SUM.............. Designation for combined fan inlet and fan exhaust noise components
T41max.......... Combustor exit temperature
UBE............... Ultrahigh-Bypass Engine
UTC............... Fan corrected tip speed

## 7. References


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**13. ABSTRACT** ***(Maximum 200 words)***

An extension of a prior study has been completed to examine the potential reduction of aircraft flyover noise by the method of active noise control (ANC). It is assumed that the ANC system will be designed such that it cancels discrete tones radiating from the engine fan inlet or fan exhaust duct, at least to the extent that they no longer protrude above the surrounding broadband noise levels. Thus, without considering the engineering details of the ANC system design, tone levels are arbitrarily removed from the engine component noise spectrum and the flyover noise EPNL levels are compared with and without the presence of tones. The study was conducted for a range of engine cycles, corresponding to fan pressure ratios of 1.3, 1.45, 1.6, and 1.75. This report is an extension of an effort reported previously in Reference 1. The major conclusions drawn from the prior study, which was restricted to fan pressure ratios of 1.45 and 1.75, are that, for a fan pressure ratio of 1.75, ANC of tones gives about the same suppression as acoustic treatment without ANC. For a fan pressure ratio of 1.45, ANC appears to offer less effectiveness than passive treatment. In the present study, the other two fan pressure ratios are included in a more detailed examination of the benefits of the ANC suppression levels. The key results of this extended study are the following observations: (1) The maximum overall benefit obtained from suppression of BPF alone was 2.5 EPNdB at high fan speeds. The suppression benefit increases with increase in fan pressure ratio (FPR), (2) The maximum overall benefit obtained from suppression of the first three harmonics was 3 EPNdB at high speeds. Suppression benefit increases with increase in FPR, ( 3) At low FPR, only about 1.0 EPNdB maximum reduction was obtained. Suppression is primarily from reduction of BPF at high FPR values and from the combination of tones at low FPR, (4) The benefit from ANC is about the same as the benefit from passive treatment at fan pressure ratios of 1.75 and 1.60. At the two lower fan pressure ratios, the effectiveness of treatment is much greater than that of ANC, and (5) No significant difference in ANC suppression behavior was found from the QCSEE engine database analysis compared to that of the $E^3$ engine database, for the FPR = 1.3 engine cycle. The effects of ANC on EPNL noise reduction are difficult to generalize. It was found that the reduction obtained in any particular case depended upon the frequency of the tones and their shift with rpm, the amount of ANC suppression received by each tone (which depended on its protrusion from the background), and the NOY-value of the tone relative to the NOY-value of other tones and the peak broadband levels, because PNL is determined from the sum of the NOY-values.

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