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Improved NASA-ANOPP Noise Prediction  
Computer Code for Advanced Subsonic  
Propulsion Systems  
Volume 1: ANOPP Evaluation and Fan Noise Model  
Improvement

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## *Nomenclature*

ANOPP.....	Aircraft Noise Prediction Program
B.....	number of fan blades
BPF.....	blade passing frequency
dB.....	decibel
E <sup>3</sup> .....	Energy Efficient Engine
$f/f_b$ .....	ratio of frequency to BPF frequency
F <sub>n</sub> .....	normalized SPL
GE.....	General Electric
IGV.....	inlet guide vane
k.....	harmonic order
L <sub>c</sub> .....	characteristic peak SPL, dB
L <sub>n</sub> .....	normalized peak sound pressure level, dB
m.....	airflow, lb/s
m <sub>o</sub> .....	reference airflow, lb/s
M <sub>t</sub> .....	fan blade tip Mach number
M <sub>t</sub> or MTR.....	rotor tip relative inlet Mach number
M <sub>td</sub> or MTRD.....	rotor tip relative inlet Mach number at fan design point
MPT.....	multiple pure tone
NASA.....	National Aeronautics and Space Administration
RSS.....	Rotor/Stator Spacing (in % of blade chord length)
SPL.....	Sound Pressure Level, dB
ΔT.....	delta T (total temperature rise across fan stage), deg R
ΔT <sub>o</sub> .....	reference value of ΔT, 1 deg R
TCS.....	turbulence control screen
UHB.....	Ultra High Bypass
V.....	number of stator vanes
QCSEE.....	Quiet, Clean, Short Haul Experimental Engine
δ.....	fan inlet tone cutoff ratio
θ.....	Angle relative to engine inlet, deg.

## ***1.0 Summary***

Recent experience using ANOPP (Aircraft Noise Prediction Program) to predict turbofan engine flyover noise suggests that it over-predicts overall EPNL by a significant amount. An improvement in this prediction method is desired for system optimization and assessment studies of advanced UHB engines.

An assessment of the ANOPP fan inlet, fan exhaust, jet, combustor, and turbine noise prediction methods was made using static engine component noise data from the CF6-80C2, E<sup>3</sup>, and QCSEE turbofan engines. It was shown that the ANOPP prediction results are generally higher than the measured GE data, and that the fan inlet noise prediction method (Heidmann method) is the most significant source of this overprediction. Fan noise spectral comparisons show that improvements to the fan tone, broadband, and combination tone noise models are required to yield results that more closely simulate the GE data.

Suggested changes that yield improved fan noise predictions but preserve the Heidmann model structure were identified and are described herein. These changes are based on the engine data sets mentioned above, as well as additional CFM56 engine data that was used to expand the combination tone noise database. It should be noted that the recommended changes are based on an analysis of engines that are limited to single stage fans with design tip relative mach numbers greater than one.

## ***2.0 Introduction***

The purpose of the Aircraft Noise Prediction Program is to predict aircraft noise with the best currently available methods (Gillian, 1982). The task of predicting the aircraft noise is divided into four areas within ANOPP:

1. Aircraft Flight Definition
2. Source Noise Modeling
3. Propagation and Ground Effects
4. Noise Calculations

The work described in this report is concerned entirely with the Source Noise Modeling portion of the ANOPP program. In keeping with the promise of ANOPP to contain the best methods available, an industry-established reputation for over-prediction, and the need to refine ANOPP for the completion of advanced UHB studies, GE was provided with the task of evaluating the engine source noise models in ANOPP. The evaluation of ANOPP was made by comparing fan, jet, combustor, and turbine noise prediction model results with GE data on a static, single engine basis.

The results of these comparisons identified that the Heidmann fan noise model contained in ANOPP was contributing significantly to the trend of noise over-prediction, and under the existing contract, GE was given the task of resolving this problem. Rather than replace the fan noise model in its entirety, it was recommended by NASA that the basic Heidmann model be retained, but modified to yield results that would more closely predict the commercial turbofan noise.

Each part of the Heidmann fan noise prediction model was carefully evaluated relative to three GE databases -- CF6-80C2, E<sup>3</sup>, and QCSEE. A CFM engine database was also used to expand the combination tone database in order to evaluate that part of the model. Volume 1 of this report presents the results of the ANOPP fan, jet, combustor, and turbine noise module assessment. Also included are specific recommendations for changes to the Heidmann fan noise model (Heidmann, 1979) that were determined to yield results in closer agreement with these databases.

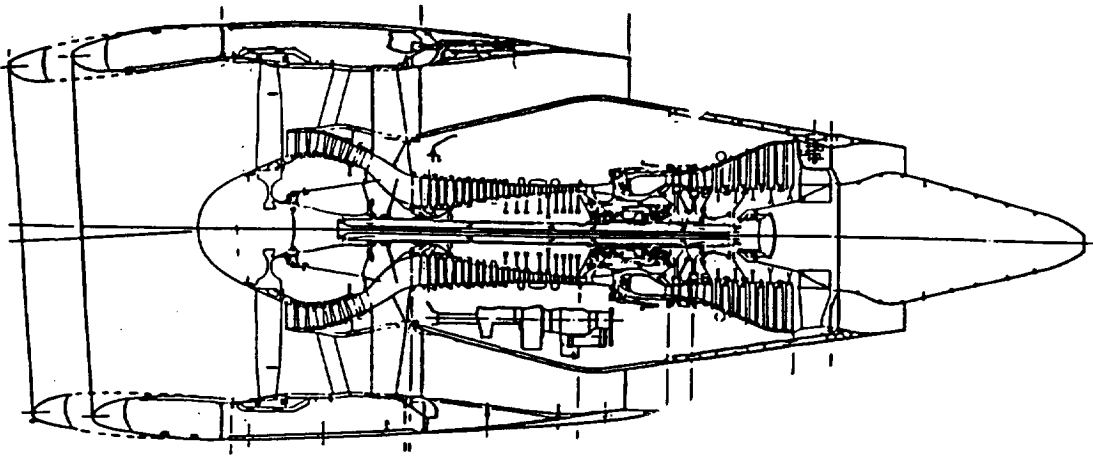
Volume 2 of this report (to be published at a later date) will describe the results of ongoing work relative to the correlation of fan inlet and fan exhaust noise suppression with various treatment design parameters. This follow-on work is an enhancement to the Heidmann method, which currently predicts noise for only hardwall engine nacelles.



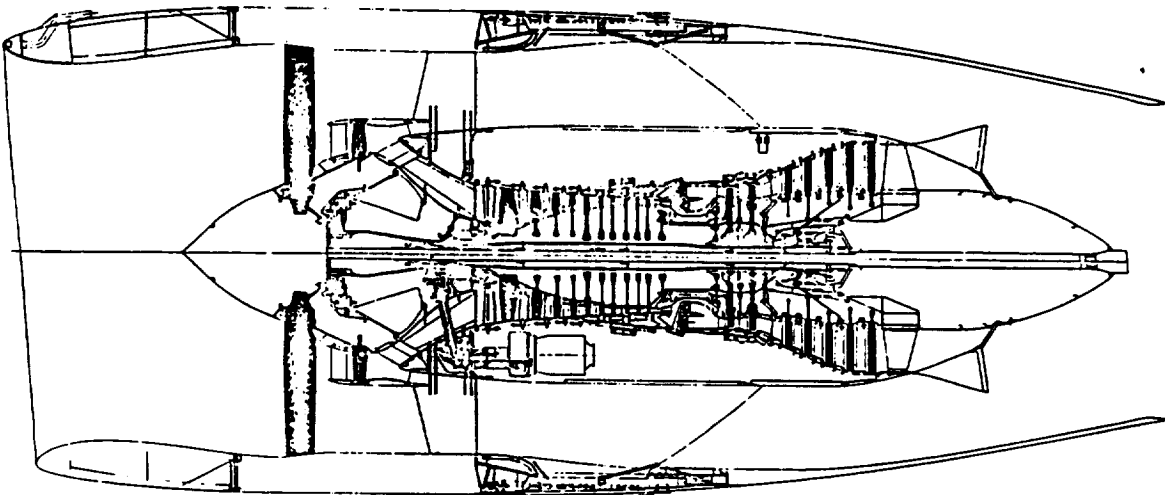
### ***3.0 Results and Discussion -- ANOPP Evaluation***

An assessment of ANOPP was carried out to evaluate the ability of ANOPP to predict engine component noise of high bypass ratio engines. Predictions were made for representative engines for which detailed noise measurements were available. These engines were the CF6-80C2 (Biebel, J., and Hoerst, D., "Acoustic Data Report for CF6-80C2", GE TM #87-80, 1987, private communication), The Energy Efficient Engine (E<sup>3</sup>) (Lavin et al., 1978), and the Quiet Clean Short-Haul Experimental Engine (QCSEE) (Stimpert, 1979). Cross-sections of each engine are shown in Figures 3.0.1, 3.0.2, and 3.0.3. A summary of general cycle and geometry information for these three engines is given in Table 3.0.1.

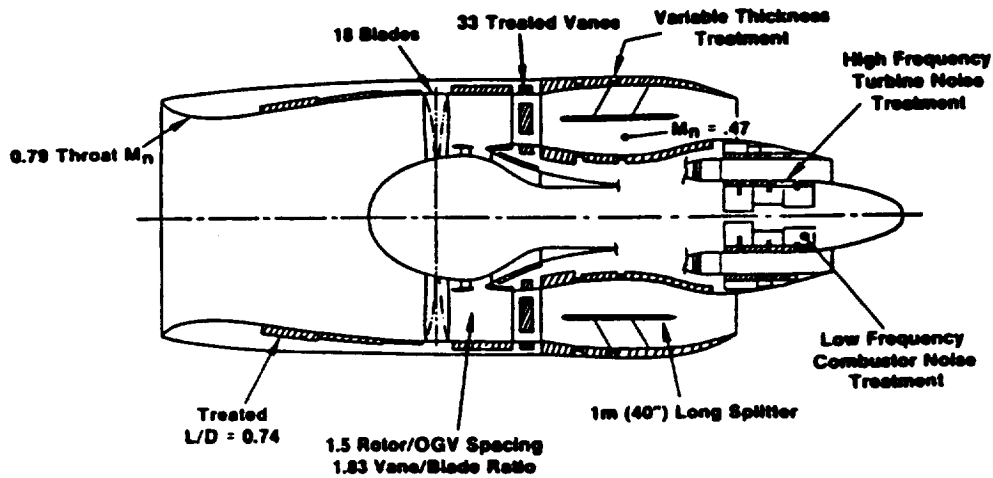
**Figure 3.0.1 CF6-80C2 Engine**



**Figure 3.0.2 E<sup>3</sup> Engine**



**Figure 3.0.3 QCSEE UTW (Under The Wing) Engine**



**Table 3.0.1 Engine Summary -Typical Takeoff Condition**

	<u>CF6</u>	<u>E<sup>3</sup></u>	<u>QCSEE</u>
<b>FN</b>	57	32	19 K lbs
<b>BPR</b>	5.0	7.7	12.1
<b>tip speed</b>	1434	1123	956 ft/s
<b>Core jet velocity</b>	1577	889	868 ft/s
<b>Exhaust type</b>	separate	mixed	separate
<b>PR</b>	1.8	1.4	1.3
<b>Fan Treatment</b>	hardwall	hardwall	hardwall

In order to assess the ANOPP source noise models, the following component noise predictions were made:

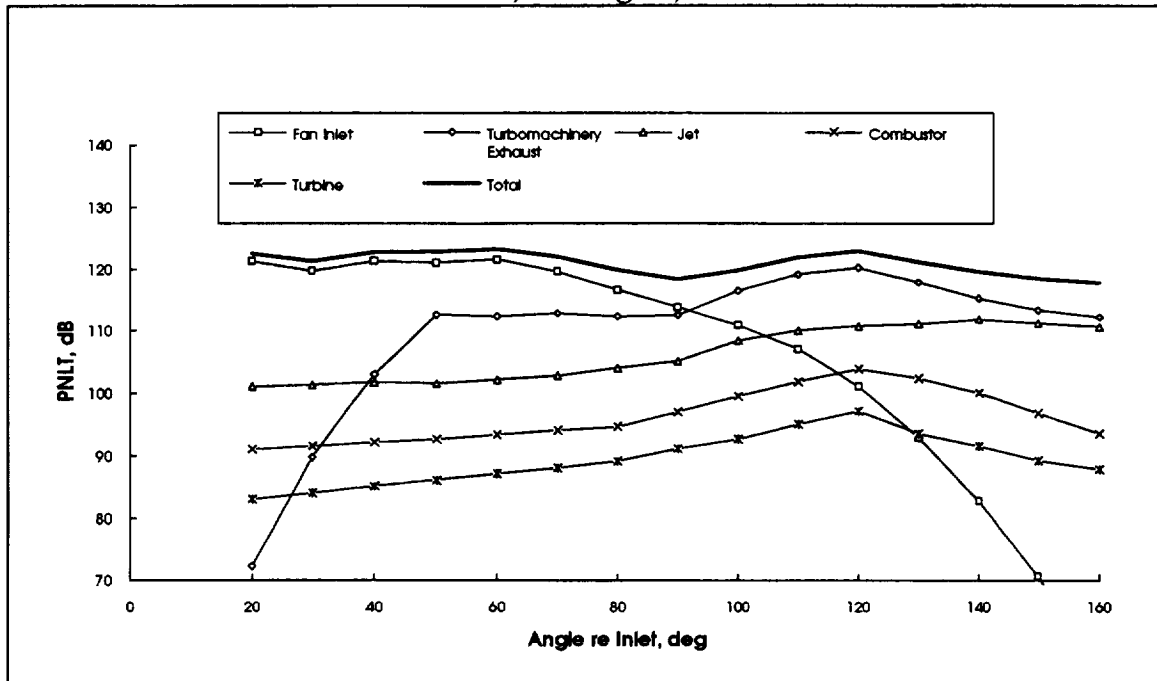
<u>Component</u>	<u>ANOPP Module</u>
fan	- HDNFAN
jet	- STNJET
combustor	- GECOR
turbine	- GETUR

Predictions were made for each of three engines: the CF6-80C2, E<sup>3</sup>, and QCSEE.

All predictions were made for a static, single engine on a 150 ft arc, and were made on the VAX system using ANOPP version 03/02/10. For each engine, typical takeoff, cutback, and approach conditions were predicted. These conditions were selected to facilitate comparison with the existing GE engine component noise database. A sample ANOPP input listing (E<sup>3</sup> takeoff case) is given in Appendix A.

The GE in-house component noise databases are created by using engine geometry and cycle information in order to split the measured static acoustic data into jet, fan inlet, and turbomachinery exhaust components. Figure 3.0.4 shows a typical E<sup>3</sup> component database generated for the takeoff condition. The combustor and turbine noise predictions shown were made using GE in-house prediction methods.

**Figure 3.0.4 Sample E' Component Noise  
150 ft arc, one engine, Takeoff**

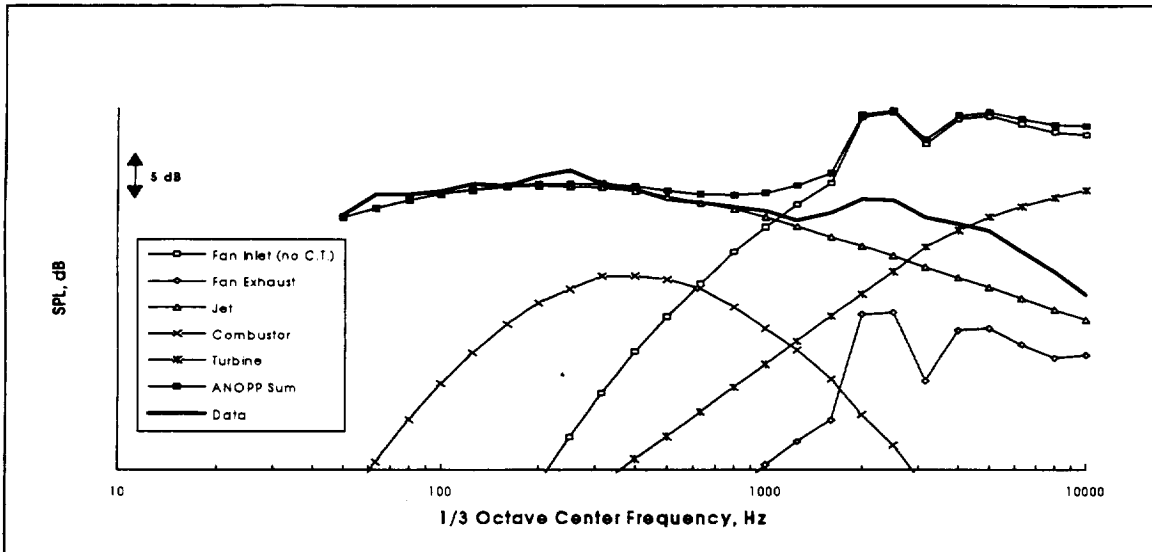


For the E<sup>3</sup> and QCSEE engines, the GE database used was for a hardwall fan inlet and fan exhaust. For the CF6-80C2, a treated fan inlet and fan exhaust database was used (a hardwall fan exhaust database did not exist at the time this work was completed). In order to compare the ANOPP predictions with the CF6-80C2 database, calculated treatment suppressions were applied to the ANOPP fan inlet and fan exhaust component results.

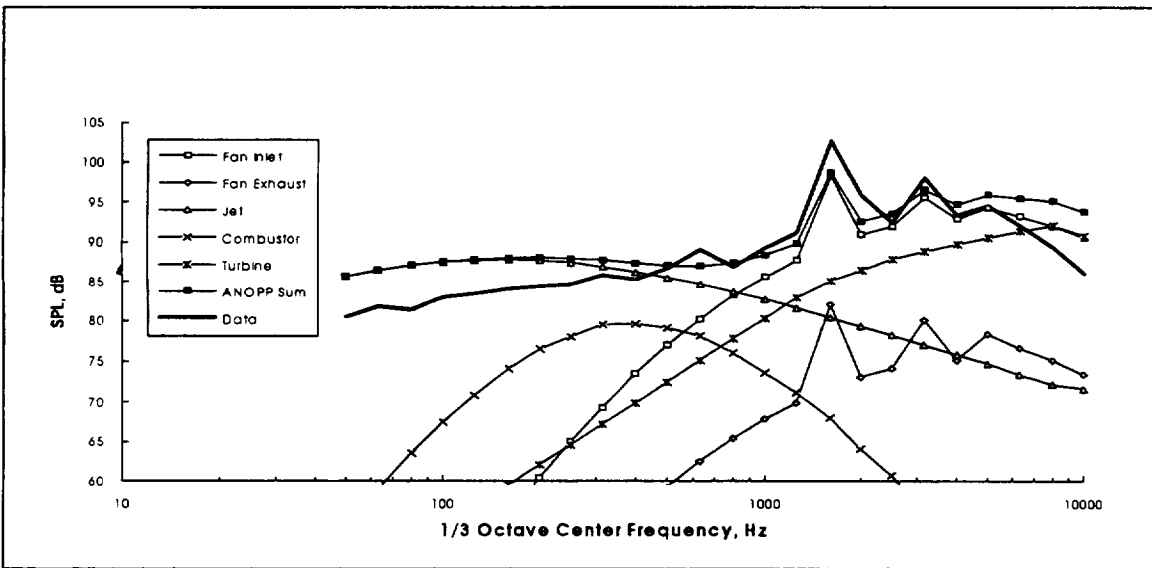
### 3.1 Overall Results

Figures 3.1.1 -- 3.1.6 show summaries on a spectral basis of the ANOPP component predictions for all three engines at the takeoff condition. For each engine, there are separate plots for both the peak forward and peak aft angles. The heavy, solid line represents the total measured engine noise, and the solid squares represent a static SPL sum of all of the ANOPP components. These plots show how well ANOPP predicts total engine noise, and indicate where particular ANOPP component predictions are yielding noise levels greater than the total engine noise.

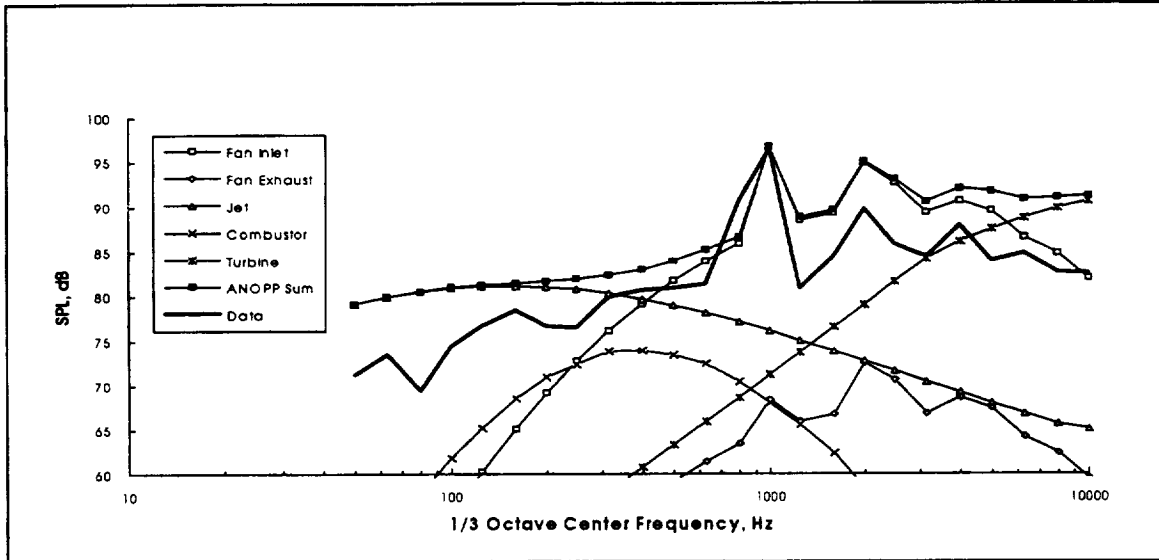
**Figure 3.1.1 ANOPP Component Summary, CF6-80C2, forward angle, takeoff, 150 ft arc, one engine**



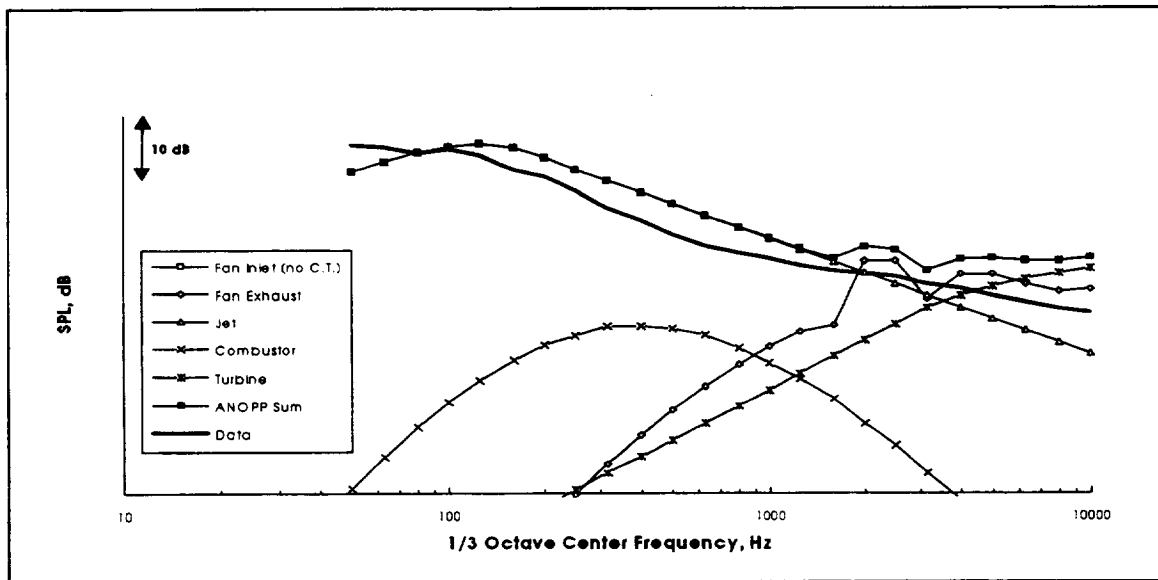
**Figure 3.1.2 ANOPP Component Summary, E3, forward peak angle, takeoff, 150 ft arc, one engine**



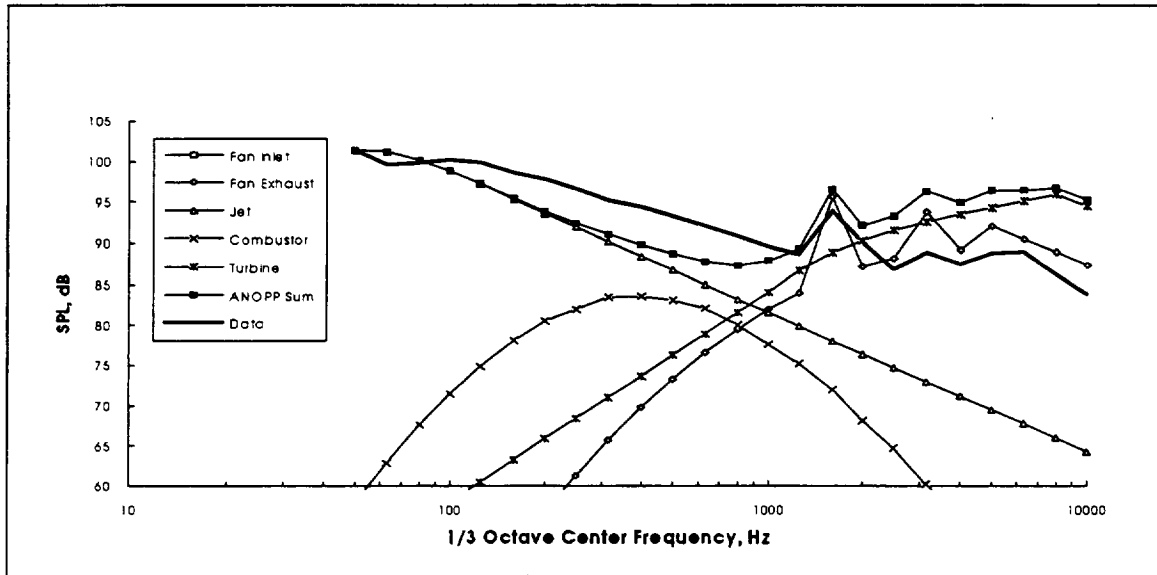
**Figure 3.1.3 ANOPP Component Summary, QCSEE, forward angle, takeoff, 150 ft arc, one engine**



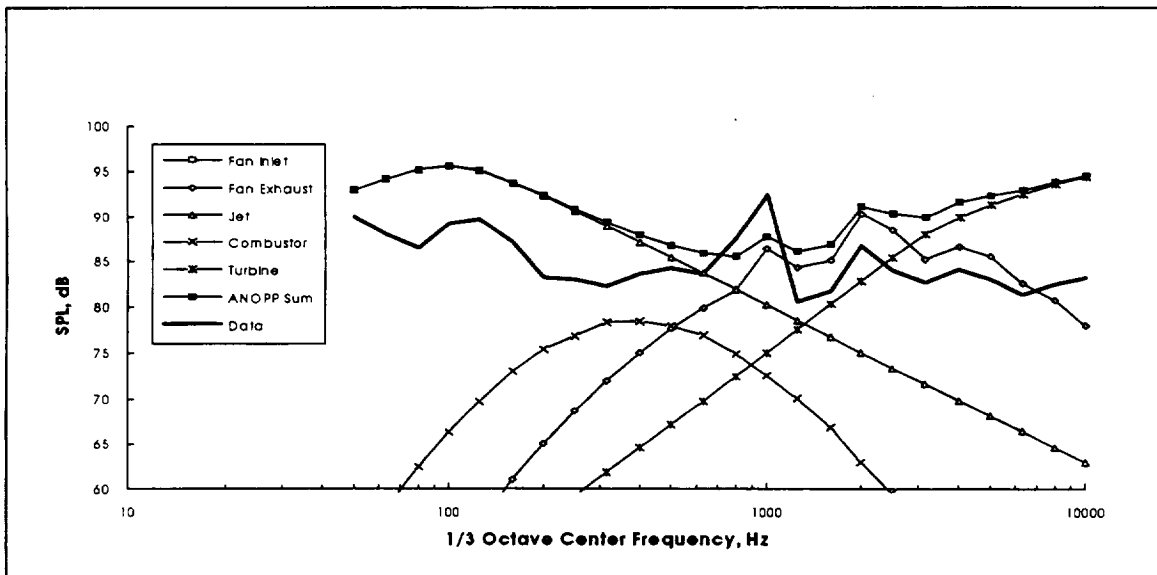
**Figure 3.1.4 ANOPP Component Summary, CF6-80C2, aft angle, takeoff, 150 ft arc, one engine**



**Figure 3.1.5 ANOPP Component Summary, E<sup>3</sup>, aft angle, takeoff, 150 ft arc, one engine**



**Figure 3.1.6 ANOPP Component Summary, QCSEE, aft angle, takeoff, 150 ft arc, one engine**



The general results for each noise component are presented in the following subsections. Because of the large amount of data, only selected charts are shown in this section. For each component, a peak angle spectrum at the takeoff condition for each of the three engines is shown. Additional charts are given in Appendices B-J.

## 3.2 Fan Inlet Noise

### General Results

The data show that the fan inlet noise ANOPP results depend heavily on the fan tip relative Mach number ( $M_{tr}$ ). At a subsonic value ( $M_{tr} < 1$ ), ANOPP shows a slight underprediction relative to the GE component database (0.5 - 5 dB). At higher tip speeds (such as for the CF6-80C2 engine at typical takeoff and cutback conditions), the ANOPP results show a significant overprediction (11 - 19 dB). This overprediction is due largely to the combination tone noise model in ANOPP. The amount of overprediction seems related to the value of  $M_{tr}$ ; the greater the value, the greater the degree of overprediction.  $M_{tr}$  values and the range of  $M_{tr}$  values covered in the databases are as follows:

**Table 3.2.1 Rotor Tip Relative Inlet Mach Number**

Engine	$M_{tr}$	$M_{tr}$ Range
CF6-80C2	1.53	0.65 -- 1.53
E <sup>3</sup>	1.14	0.64 -- 1.14
QCSEE	1.01	0.89 -- 1.01

### Results -- Takeoff

One-third octave spectra from the peak forward angle are shown in Figures 3.2.1, 3.2.2, and 3.2.3 for takeoff conditions of the CF6-80C2, E<sup>3</sup>, and QCSEE engines, respectively. A large overprediction by ANOPP is shown relative to the CF6-80C2 engine data (Figure 3.2.1). Since there was such a large difference, an inlet noise prediction was made which excluded the contribution of the combination tone noise portion of the fan noise model in ANOPP. Relative to the CF6-80C2 data, the ANOPP method is shown to overpredict in this case as well. The ANOPP E<sup>3</sup> prediction (Figure 3.2.2) also shows that the fan inlet noise is overpredicted when the combination tone noise model is included. If the combination tone noise calculation is excluded, the engine noise is actually slightly underpredicted. An overprediction is shown relative to the QCSEE engine data (Figure 3.2.3) -- but in this case the combination tone noise model does not significantly contribute to the prediction due to the lower tip relative Mach number. Detailed information regarding the combination tone noise model is given in Section 4.6.

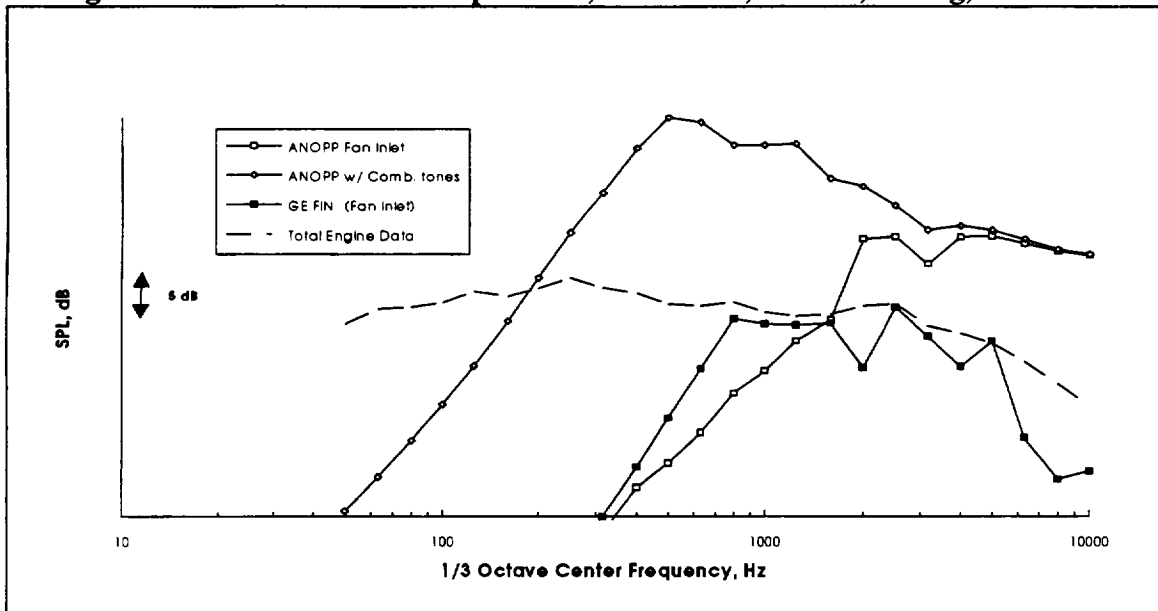
Note that the CF6-80C2 ANOPP prediction does not include the inflow distortion noise effect, since the GE data was measured using a turbulence control screen (TCS). The ANOPP E<sup>3</sup> and QCSEE predictions do include the inflow distortion effect, since this data was measured without a TCS.

### Results -- Cutback, and Approach

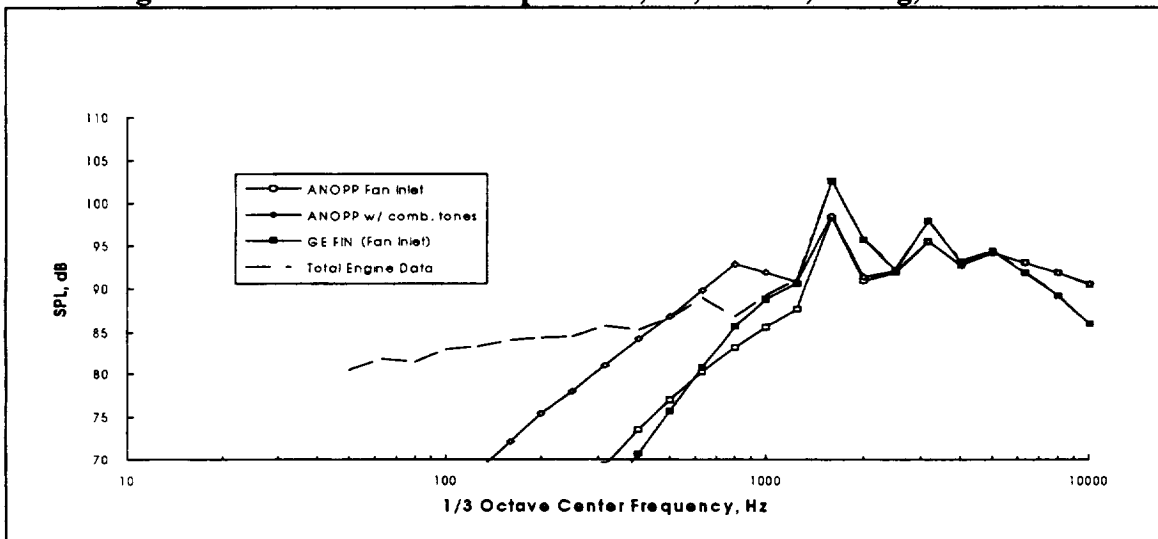
The same trends are shown for each engine for the cutback and approach conditions as were demonstrated at the takeoff condition. Spectra plots for all engine conditions and at all angles of interest are given in Appendix B for CF6-80C2, Appendix C for E<sup>3</sup>, and Appendix D for QCSEE.



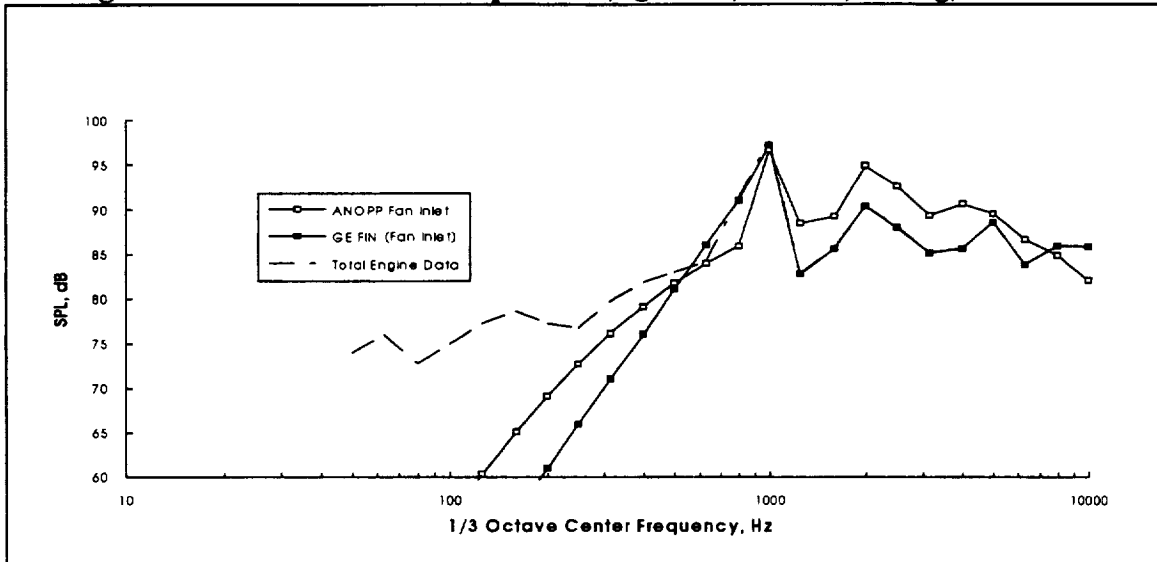
**Figure 3.2.1 Fan Inlet Noise Spectrum, CF6-80C2, takeoff, 40 deg, 150 ft arc**



**Figure 3.2.2 Fan Inlet Noise Spectrum, E3, takeoff, 40 deg, 150 ft arc**



**Figure 3.2.3 Fan Inlet Noise Spectrum, QCSEE, takeoff, 30 deg, 150 ft arc**

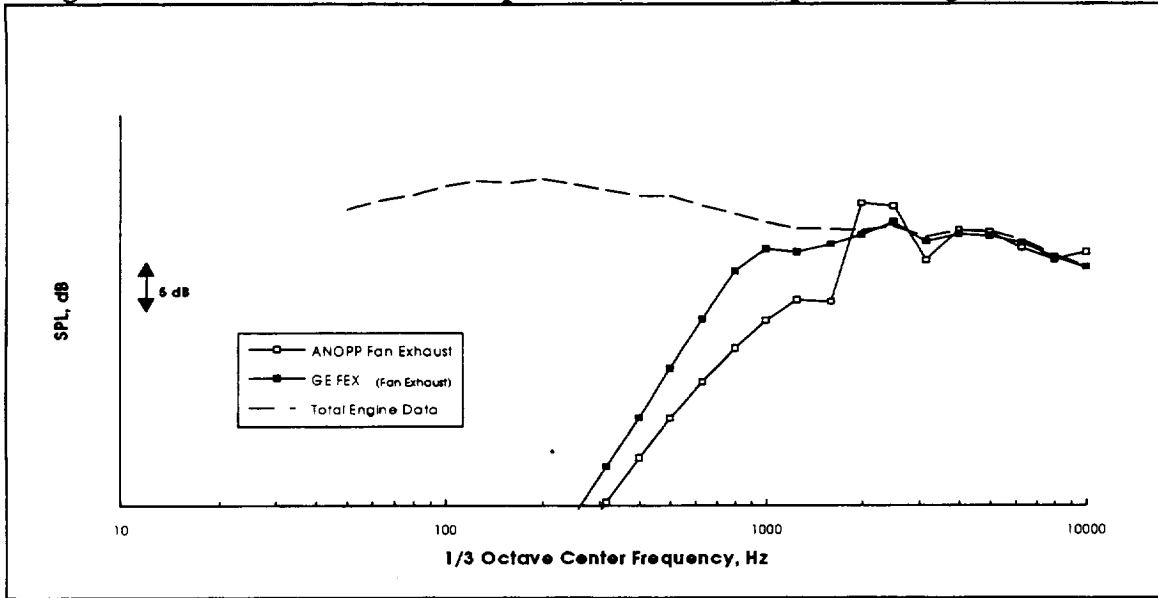


### **3.3 Fan Exhaust Noise**

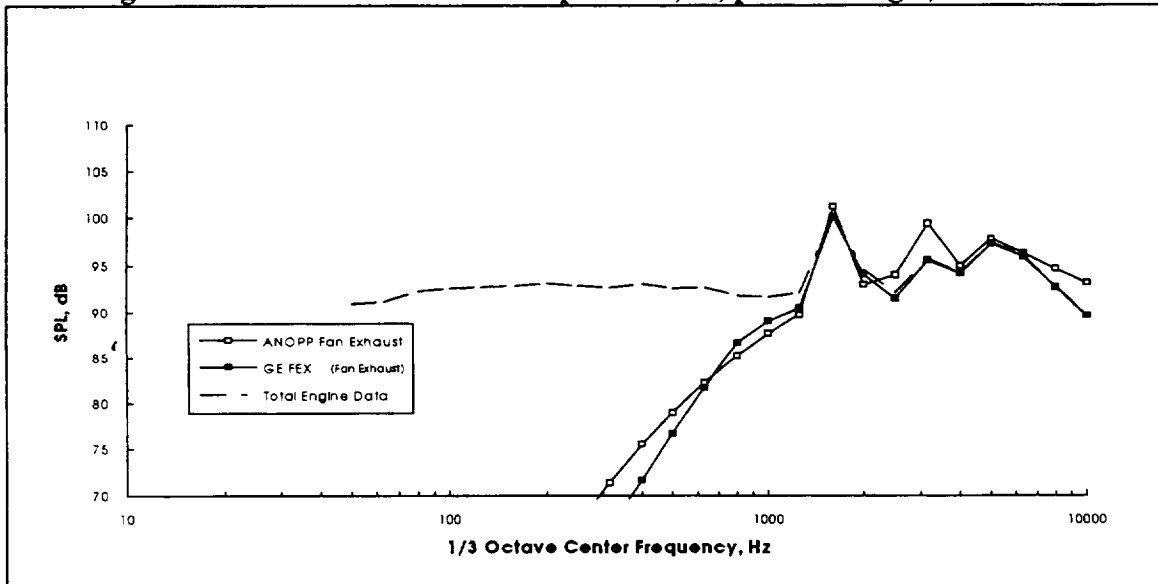
#### **Results -- Takeoff, Cutback, and Approach**

The fan exhaust noise ANOPP predictions vary with the type of engine as well as condition. Peak aft angle spectra of takeoff fan exhaust noise are shown in Figures 3.3.1, 3.3.2, and 3.3.3 for the CF6-80C2, E<sup>3</sup>, and QCSEE engines. The spectral content and amplitudes for the CF6-80C2 and the E<sup>3</sup> ANOPP predictions (Figures 3.3.1 and 3.3.2) show a slight overprediction relative to the GE component database, while the QCSEE prediction is well below the measured engine data. Additional spectra plots at other angles and for the other cycle conditions are given in Appendices E, F, and G for the CF6-80C2, E<sup>3</sup>, and QCSEE data respectively. The same trends demonstrated at takeoff are shown in the cutback and approach conditions for the E<sup>3</sup> and QCSEE Engines. The CF6-80C2 results vary from overprediction at takeoff to underprediction at approach.

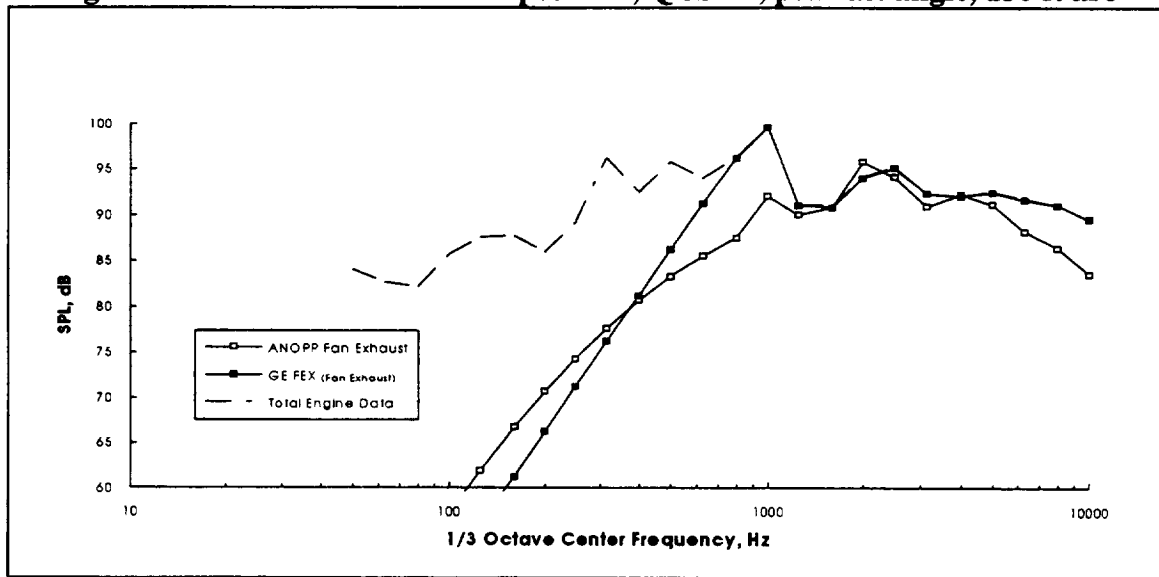
**Figure 3.3.1 Fan Exhaust Noise Spectrum, CF6-80C2, peak aft angle, 150 ft arc**



**Figure 3.3.2 Fan Exhaust Noise Spectrum, E3, peak aft angle, 150 ft arc**



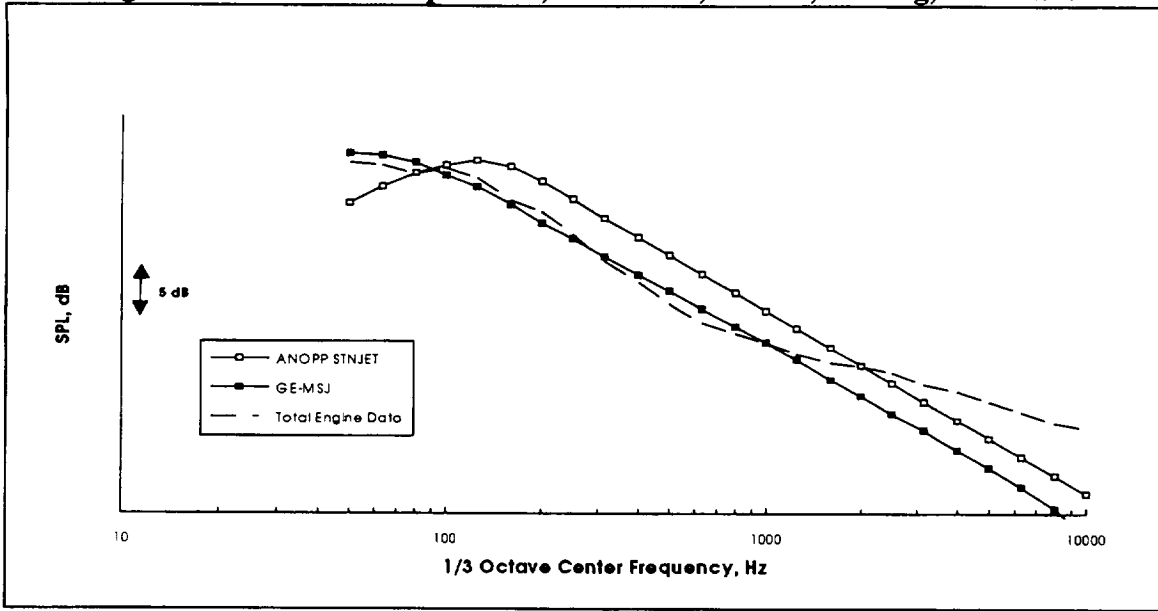
**Figure 3.3.3 Fan Exhaust Noise Spectrum, QCSEE, peak aft angle, 150 ft arc**



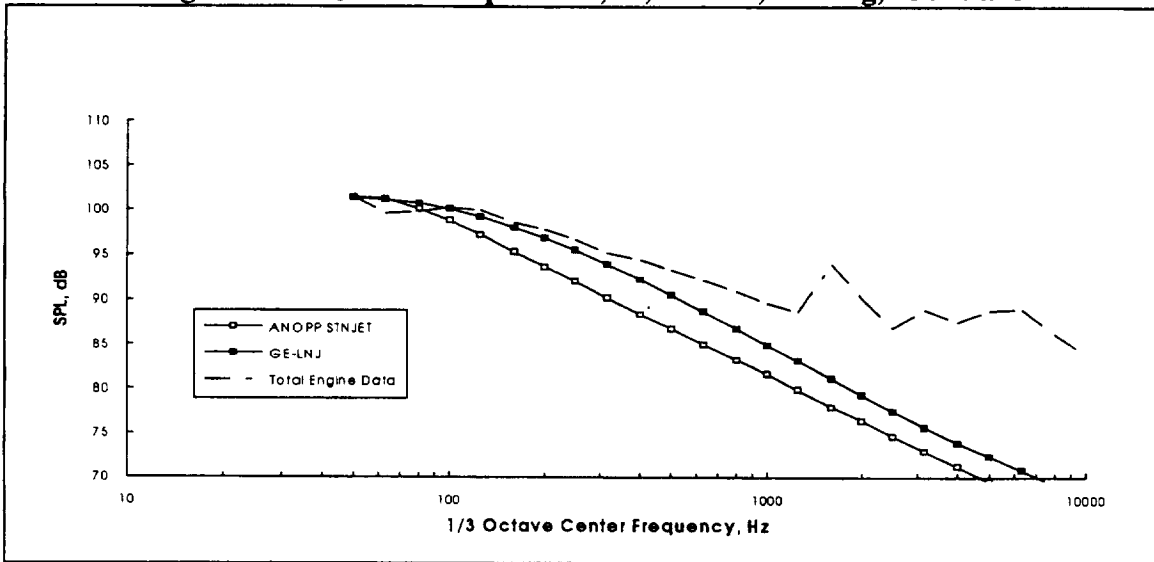
### **3.4 Jet Noise**

Figures 3.4.1, 3.4.2, and 3.4.3 show the ANOPP predictions and GE jet noise database spectra at takeoff conditions for the CF6-80C2, E<sup>3</sup>, and QCSEE engines. Additional jet noise spectra for the other engine conditions are shown in Appendix H. The ANOPP-predicted amplitudes are generally above those of the GE database, especially for predictions of the lower velocity jets. A clear trend of overprediction (1-6 dB) is indicated in the CF6-80C2 and the QCSEE predictions (Figure 3.4.1 and 3.4.3). The peak frequency is quite different between data and prediction for the CF6-80C2 and QCSEE engines. The ANOPP and GE jet noise component results are closer in agreement in terms of peak noise (amplitude and frequency) for the mixed flow E<sup>3</sup> engine at takeoff (Figure 3.4.2) and cutback, but show a slight underprediction at approach.

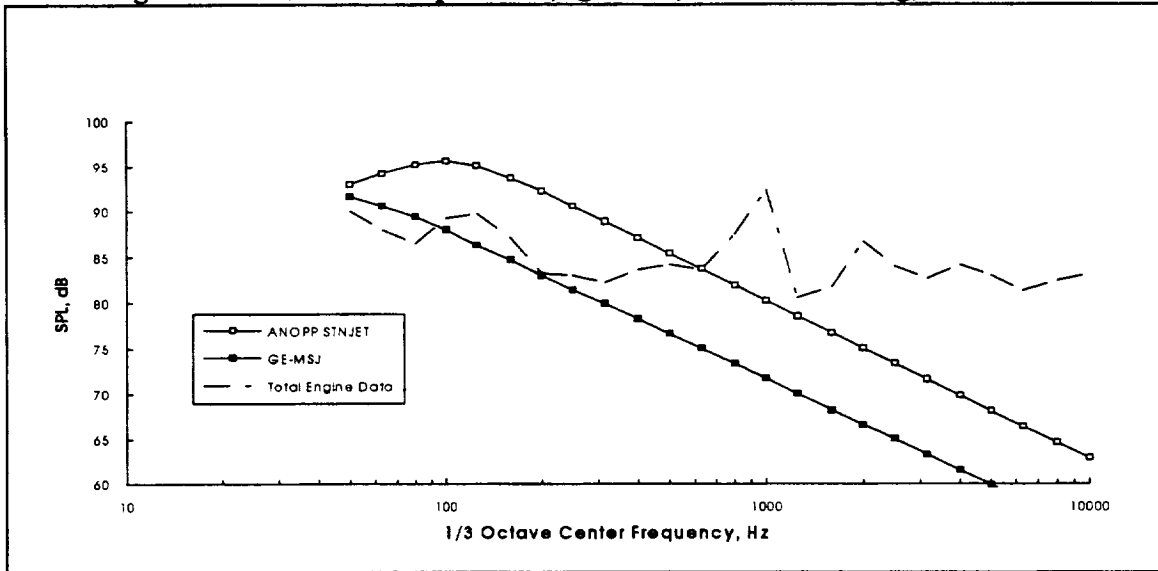
**Figure 3.4.1 Jet Noise Spectrum, CF6-80C2, takeoff, 150 deg, 150 ft arc**



**Figure 3.4.2 Jet Noise Spectrum, E3, takeoff, 150 deg, 150 ft arc**



**Figure 3.4.3 Jet Noise Spectrum, QCSEE, takeoff, 150 deg, 150 ft arc**

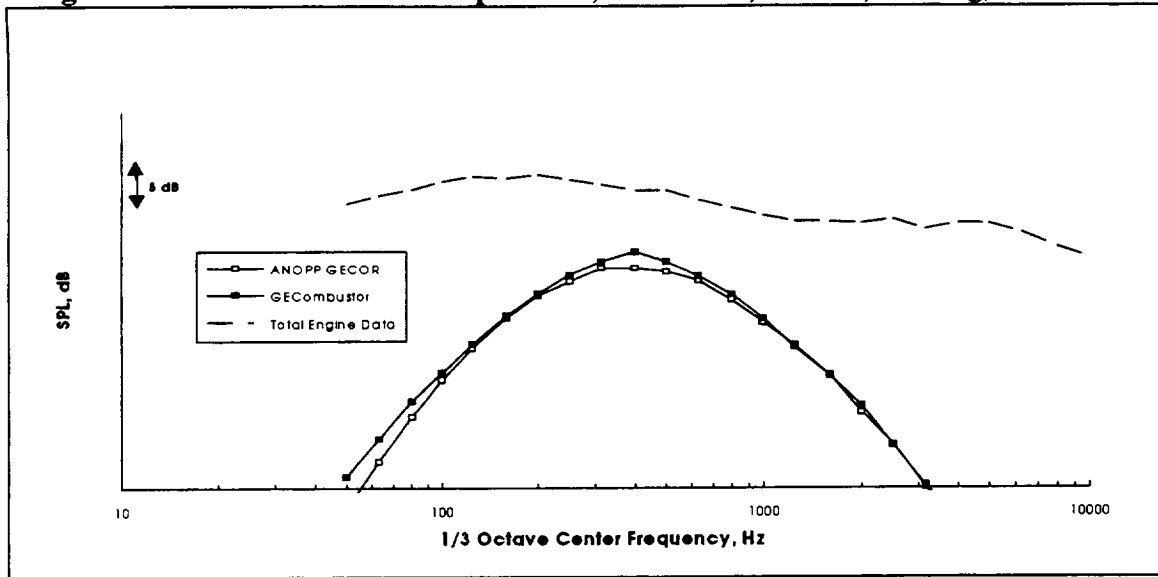


### **3.5 Combustor Noise**

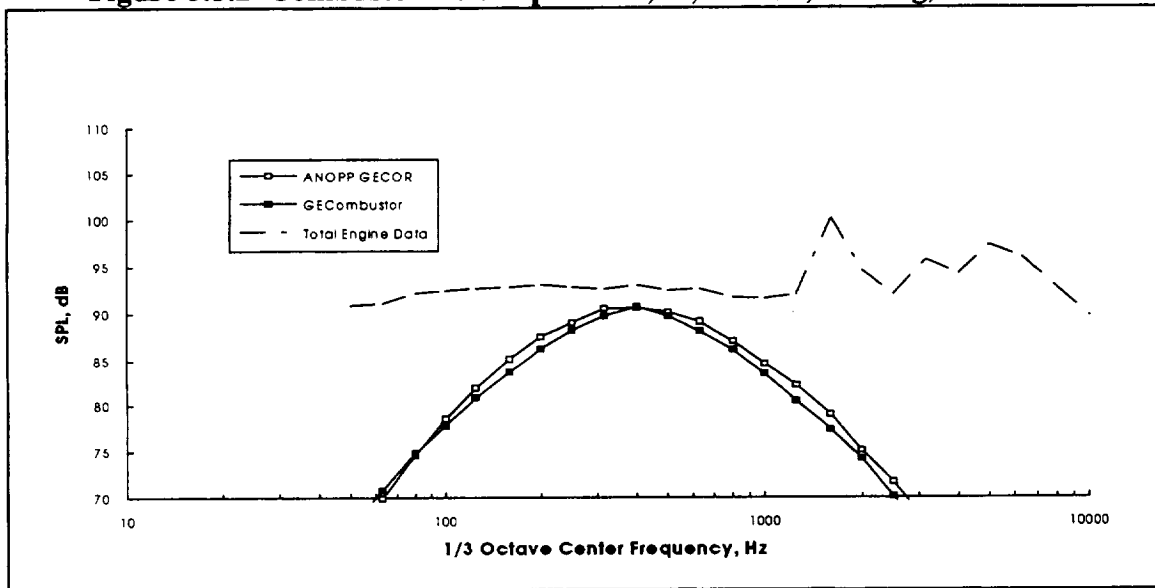
ANOPP combustor noise predictions agree closely with the GE predictions (the two prediction methods are identical, except that the cycle input parameters are slightly different). The discrepancies observed in the QCSEE predictions are attributable to the QCSEE cycle estimations that were made. Figures 3.5.1, 3.5.2, and 3.5.3 show the combustor noise spectra at the peak noise angle for each of the three engines at takeoff power. Spectra for the other engine conditions can be found in Appendix I.

Although the ANOPP and GE combustor noise predictions agree, it is difficult to assess the absolute accuracy of the predicted levels and peak frequency. It can at least be stated that the combustor noise predictions do not cause the total predicted engine noise to assume an unreasonable spectral shape or to exceed the level of total measured engine noise.

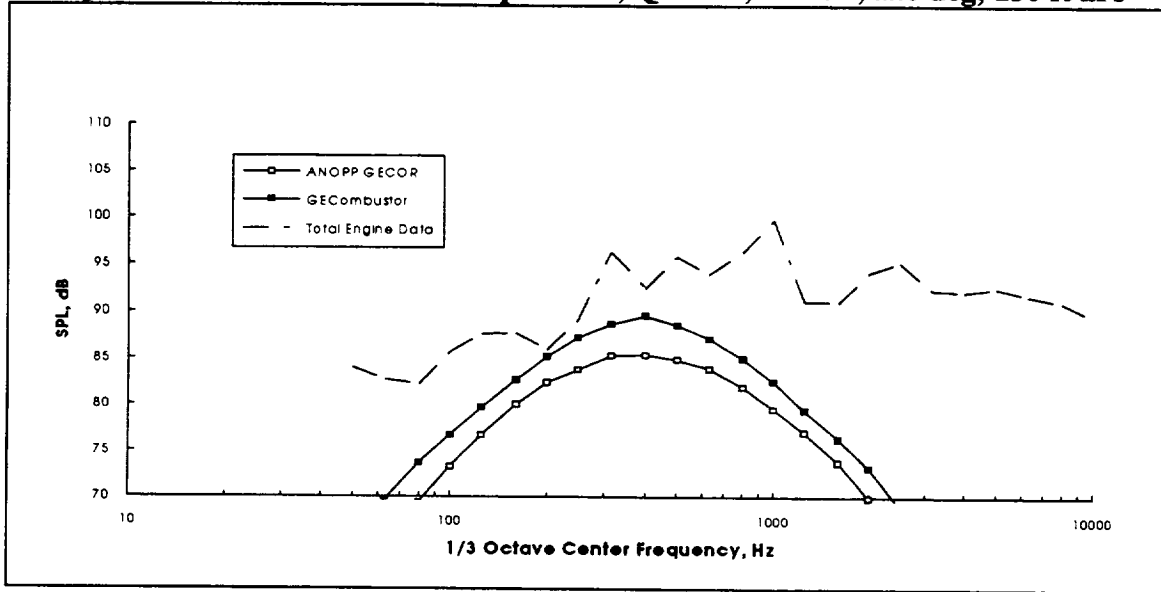
**Figure 3.5.1 Combustor Noise Spectrum, CF6-80C2, takeoff, 120 deg, 150 ft arc**



**Figure 3.5.2 Combustor Noise Spectrum, E3, takeoff, 120 deg, 150 ft arc**



**Figure 3.5.3 Combustor Noise Spectrum, QCSEE, takeoff, 120 deg, 150 ft arc**



### **3.6 Turbine Noise**

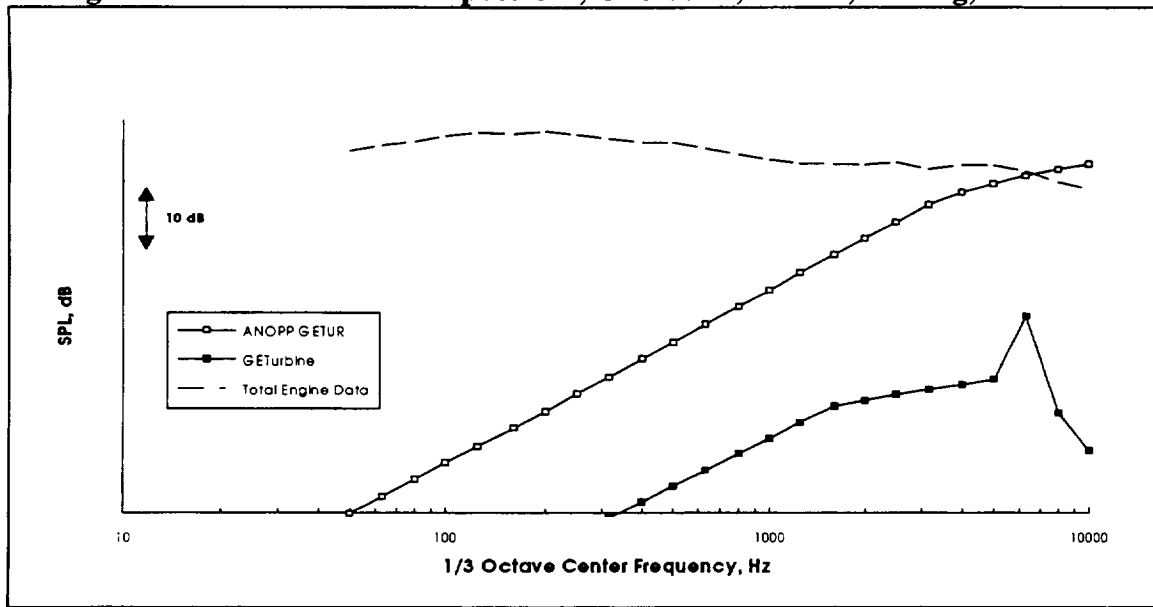
The ANOPP turbine noise predictions are on the order of 30 dB greater than the corresponding GE predictions. Figures 3.6.1, 3.6.2, and 3.6.3 show the spectra for all three engines at takeoff power. Additional peak noise spectra for the other engine conditions are in Appendix J. All of these plots show an unusual turbine noise spectral shape (no tones), and that the ANOPP component predictions are much greater than the turbine noise data.

There are several reasons for the differences observed. On the basis of previous engine experience, GE turbine noise predictions assume that there is one dominant stage (usually the last stage) of the low pressure turbine that significantly contributes to the turbine noise component. Input parameters for the GE turbine noise prediction are adjusted accordingly. If these adjustments are not made, the turbine noise component prediction increases dramatically, nearly matching the ANOPP prediction in magnitude. Figure 3.6.4 demonstrates these results.

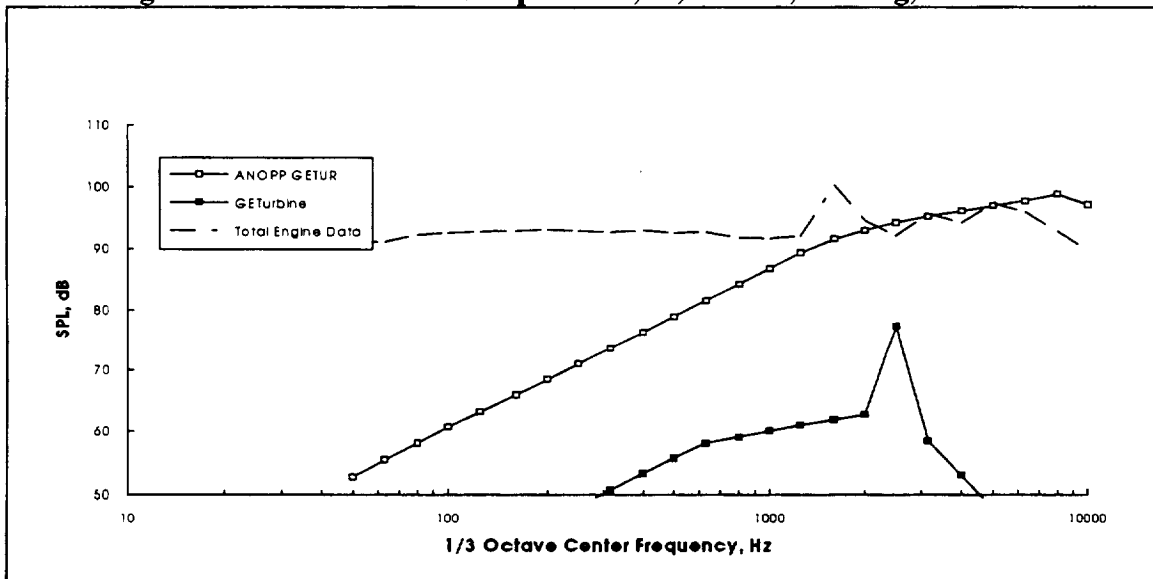
Although this "adjustment" seems to explain a significant portion of the large differences observed, the discrepant spectral content of the ANOPP predictions still requires explanation. (It should be noted that the ANOPP prediction method, despite the name "GETUR", is in no way related to the GE turbine noise prediction method used.)



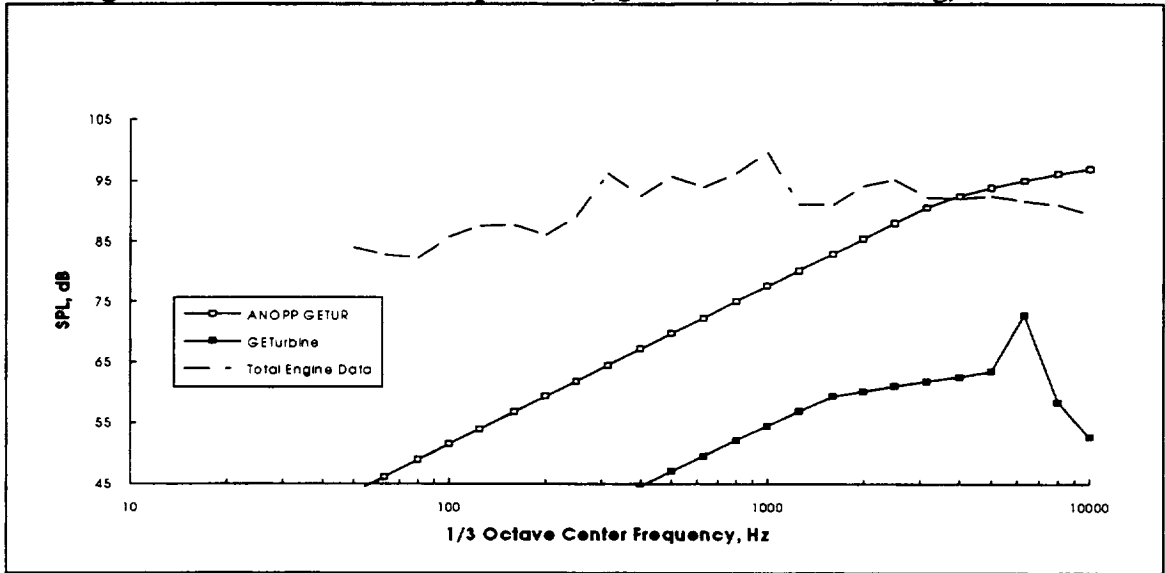
**Figure 3.6.1 Turbine Noise Spectrum, CF6-80C2, takeoff, 120 deg, 150 ft arc**



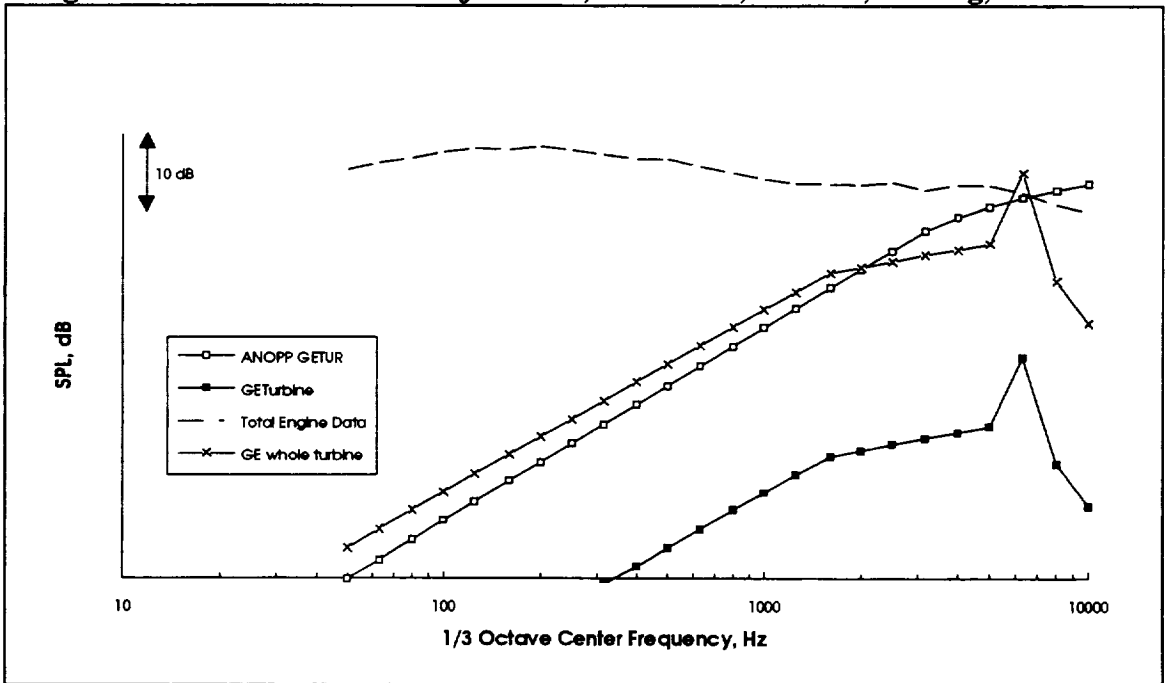
**Figure 3.6.2 Turbine Noise Spectrum, E3, takeoff, 120 deg, 150 ft arc**



**Figure 3.6.3 Turbine Noise Spectrum, QCSEE, takeoff, 120 deg, 150 ft arc**



**Figure 3.6.4 Turbine Noise Adjustment, CF6-80C2, Takeoff, 120 deg, 150 ft arc**



## ***4.0 Results and Discussion -- Fan Noise Model Improvements***

This section, which describes all of the recommended changes to the Heidmann fan noise model, refers extensively to the Interim Prediction Method for Fan and Compressor Source Noise (Heidmann, 1979). Complete understanding of the content of this section requires familiarity with the Heidmann fan noise model.

A detailed description of the model would be impossible to give within the context of this report. However, in order to help the reader who may be unfamiliar with the method, a brief summary of the Heidmann model is attempted in the following paragraph (excerpted from Heidmann, 1979).

The Heidmann procedure predicts one-third octave band levels of the free-field noise pattern. The prediction method was initially developed by The Boeing Company, under contract with NASA Ames Research Center. Heidmann made modifications to this method, based on correlations and interpretations of the acoustic data from full-scale fan tests performed at NASA Lewis (Heidmann, 1973). The noise predictions applicable to one- and two-stage turbofans with or without inlet guide vanes (IGVs). The procedure involves predicting spectrum shape, spectrum level, and free-field directivity for each of the following components:

- fan inlet broadband noise
- fan inlet tone noise
- fan inlet combination-tone noise
- fan exhaust noise
- fan exhaust tone noise

Four parameters are required to predict the basic spectrum levels: mass flow rate ( $m$ ), total temperature rise across the fan stage ( $\Delta T$ ), and the design and operating point values of the rotor tip relative inlet Mach number ( $M_{rd}$ ,  $M_r$ ). The basic levels are then corrected for presence of IGV, rotor-stator spacing (RSS), inlet flow distortions, and cutoff.

In order to compare with the Heidmann model, tone and broadband noise components for the fan inlet and fan exhaust were separated for all three engine databases. Using the Heidmann method normalization (fan temperature rise and mass flow), the GE data was corrected and plotted relative to each appropriate Heidmann method correlation. Using the CF6-80C2 data, the Heidmann method was adjusted to agree with the data, as necessary. These adjustments were then further evaluated using the E<sup>3</sup> and QCSEE data. Since these databases did not contain much combination tone noise information, a typical CFM56 noise database was also used to provide additional direction for the combination tone noise model adjustments.

In the following sections, the specific results for each of the noise models are described. The figures make reference in the title to the corresponding figure numbers in the original Heidmann method documentation.

## 4.1 Fan Inlet Broadband Noise

Fan inlet broadband, fan exhaust broadband, fan inlet tone, and fan exhaust tone noise components are each described by the following equation (Heidmann, 1979)

$$L_c = 20\log(\Delta T/\Delta T_o) + 10\log(m/m_o) + F_1(M_{trd}, M_{tr}) + F_2(RSS) + F_3(\theta) \quad (1)$$

where:

$L_c$  is the peak characteristic sound pressure level of the noise component,  $\Delta T/\Delta T_o$  is the temperature rise across the fan stage normalized by a reference delta temperature,  $m/m_o$  is the mass flow through the fan relative to a reference mass flow,  $F_1$  is a function of rotor tip relative inlet mach numbers at the design and operating points,  $F_2$  is a function of the rotor to stator spacing, and  $F_3$  is a function of observer angle relative to the engine inlet. Values for  $F_1$ ,  $F_2$ , and  $F_3$  vary for each noise component.

In the initial stages of the Heidmann method evaluation, comparisons of the GE data with the Heidmann method predictions did not show consistent results for the different engines. It was found that when the  $F_2$  term (rotor-stator spacing effect) was eliminated, more consistent results were predicted. Elimination of this term is in accord with prior GE commercial engine experience, in which no effect of rotor-stator spacing on fan inlet broadband noise is observed.

Figure 4.1.1 shows the "Figure 4a" (Heidmann, 1979) fan inlet broadband noise curve for the design tip relative Mach number ( $M_{trd}$ ) of 1.53 for the CF6-80C2 engine. The CF6 inlet broadband data shown by the triangles indicate that a steeper slope on the Heidmann prediction curve is required. This can be accomplished by using -50 log instead of -20 log such that the new curve for normalized inlet broadband peak noise level,  $L_n$ , ( $F_1$  in equation (1)) is given by:

$$L_n = 58.5 + 20 \log(M_{trd}) - 50 \log(M_{tr}/0.9); M_{trd} > 1, M_{tr} > 0.9 \quad (2)$$

The solid line in Figure 4.1.1 represents the original Heidmann curve, the dotted line indicates the change described in equation (2). Similarly, Figures 4.1.2 and 4.1.3 show the results for the E<sup>3</sup> (M<sub>td</sub> = 1.14) and QCSEE(M<sub>td</sub> = 1.01) engine data, respectively. The data generally show close agreement with the new Heidmann method curve.

One-third octave spectra for the inlet angles are given in Appendix B for the CF6-80C2 engine. Each plot shows the measured engine noise, the original Heidmann prediction, and the new prediction (the new prediction reflects all of the changes that have not yet been explained, but will be described later in this section). E<sup>3</sup> inlet spectra are shown in Appendix C, and QCSEE inlet spectra are in Appendix D. These plots generally show close agreement between the new broadband prediction and the measured data.

The directivity correction, F<sub>3</sub> in equation (1), remains unchanged (see Section 4.5).

**Figure 4.1.1 “Figure 4a”, CF-80C2 Fan Inlet Broadband Noise**

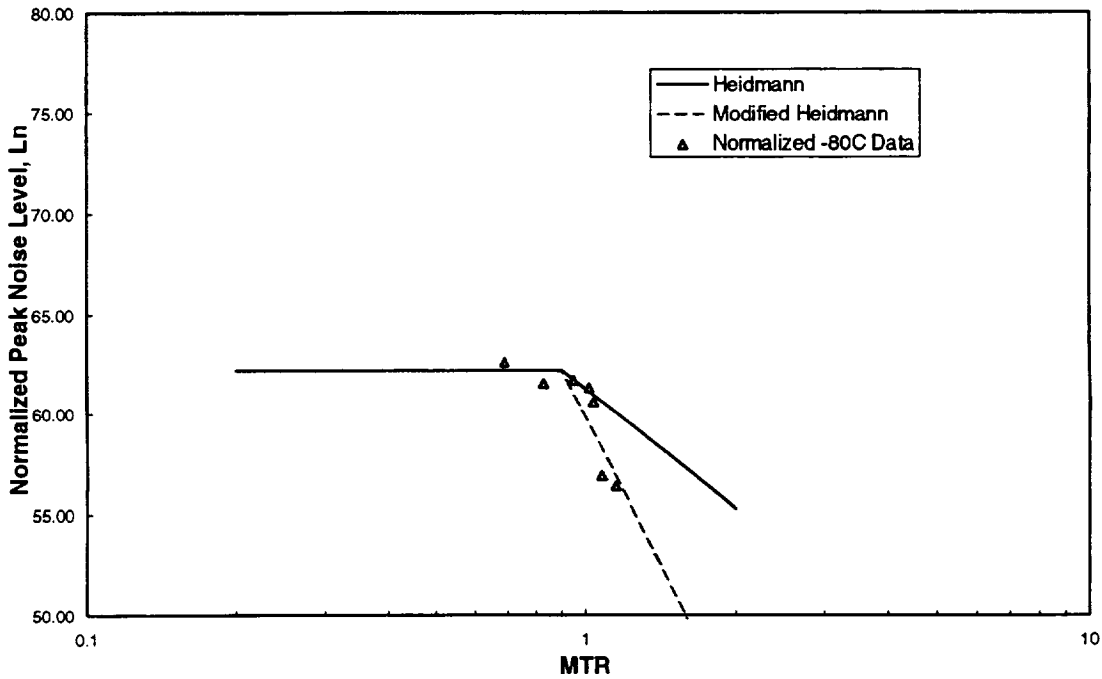


Figure 4.1.2 "Figure 4a", E' Fan Inlet Broadband Noise

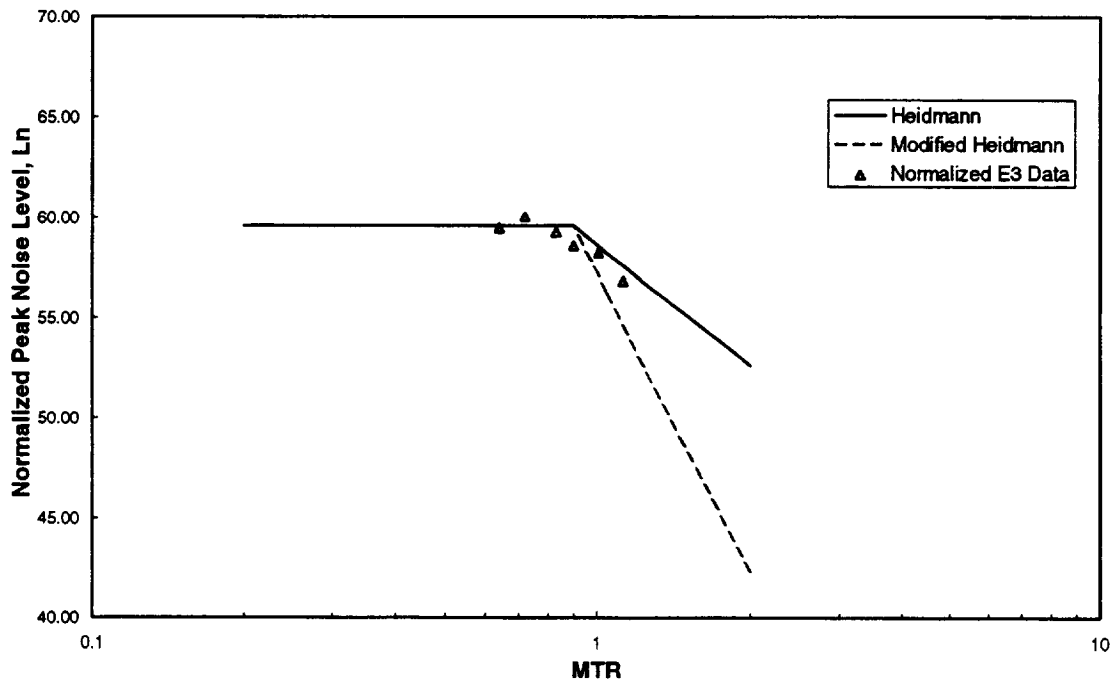
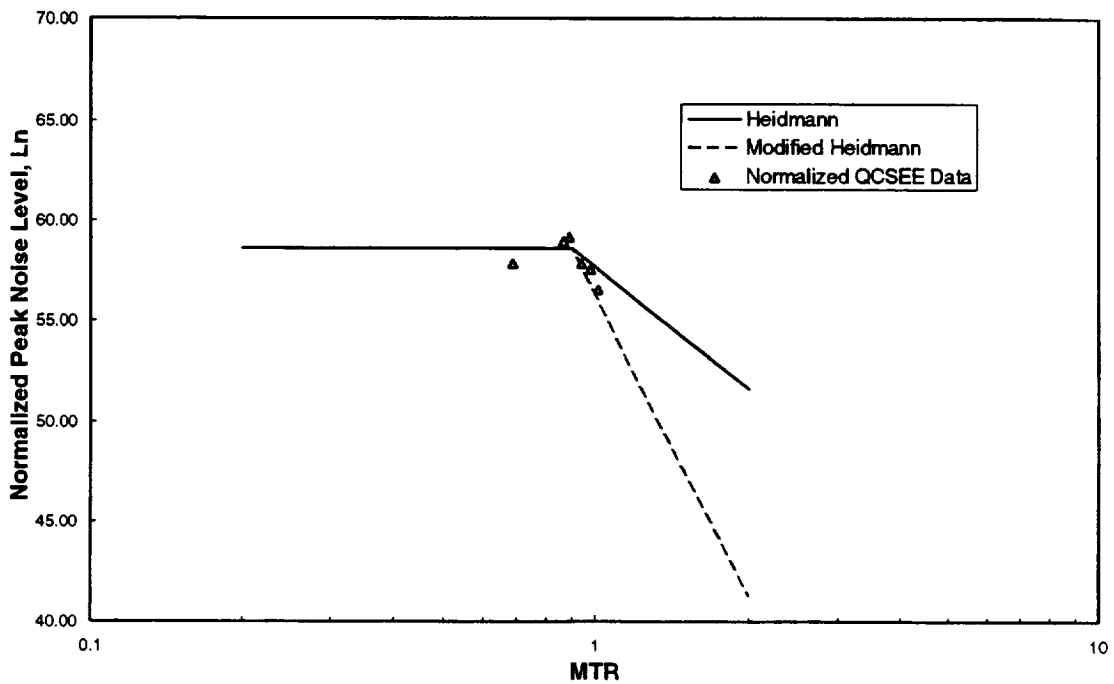


Figure 4.1.3 "Figure 4a", QCSEE Fan Inlet Broadband Noise



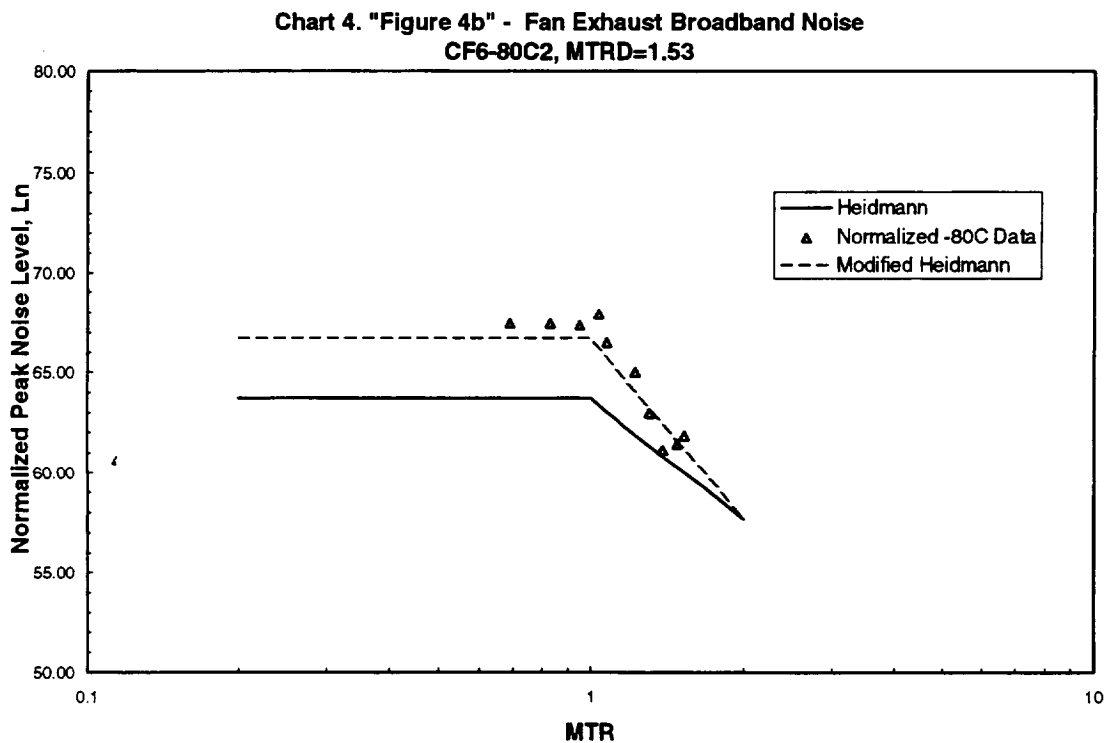
## 4.2 Fan Exhaust Broadband Noise

Fan exhaust broadband noise is also described by equation (1), with different values for  $F_1$ ,  $F_2$ , and  $F_3$ . Figure 4.2.1 shows the "Figure 4b" (Heidmann, 1979) fan exhaust broadband noise curve for a design tip relative Mach number ( $M_{trd}$ ) of 1.53 (CF6-80C2). The CF6-80C2 exhaust broadband data shown by the triangles indicate that an increased level as well as a steeper slope on the Heidmann prediction curve are required. Accordingly, the base level of the "Figure 4b" curves for  $M_{trd} > 1$  is increased by 3 dB. The slope of these curves is increased by using  $-30 \log$  instead of  $-20 \log$ . The new equations for peak normalized broadband noise levels ( $F_1$  in equation (1)) are:

$$L_n = 63 + 20 \log(M_{trd}); M_{trd} > 1, M_{tr} \leq 1.0 \quad (3a)$$

$$L_n = 63 + 20 \log(M_{trd}) - 30 \log(M_{tr}); M_{trd} > 1, M_{tr} > 1.0 \quad (3b)$$

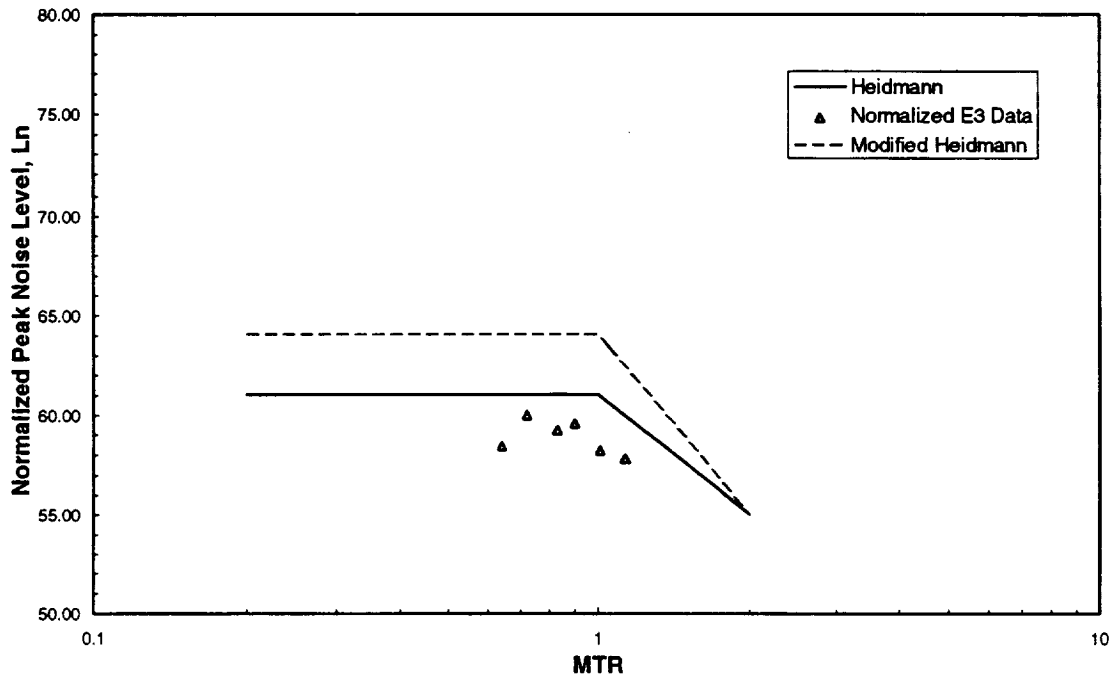
Figure 4.2.1 "Figure 4b", CF6-80C2 Fan Exhaust Broadband Noise



Figures 4.2.2 and 4.2.3 show the results for the E<sup>3</sup> (M<sub>td</sub> = 1.14) and QCSEE (M<sub>td</sub> = 1.01) engine data, respectively. The E<sup>3</sup> data do not agree well with the new Heidmann curve. However, the E<sup>3</sup> is a mixed flow exhaust engine and the fan exhaust component extracted from the measured engine noise is much lower in this case (not true for other mixed flow exhaust databases) than for the separate flow engines at comparable speeds. The QCSEE results generally agree with those of the CF6-80C2 in that an increase in the Heidmann curve level is desirable.

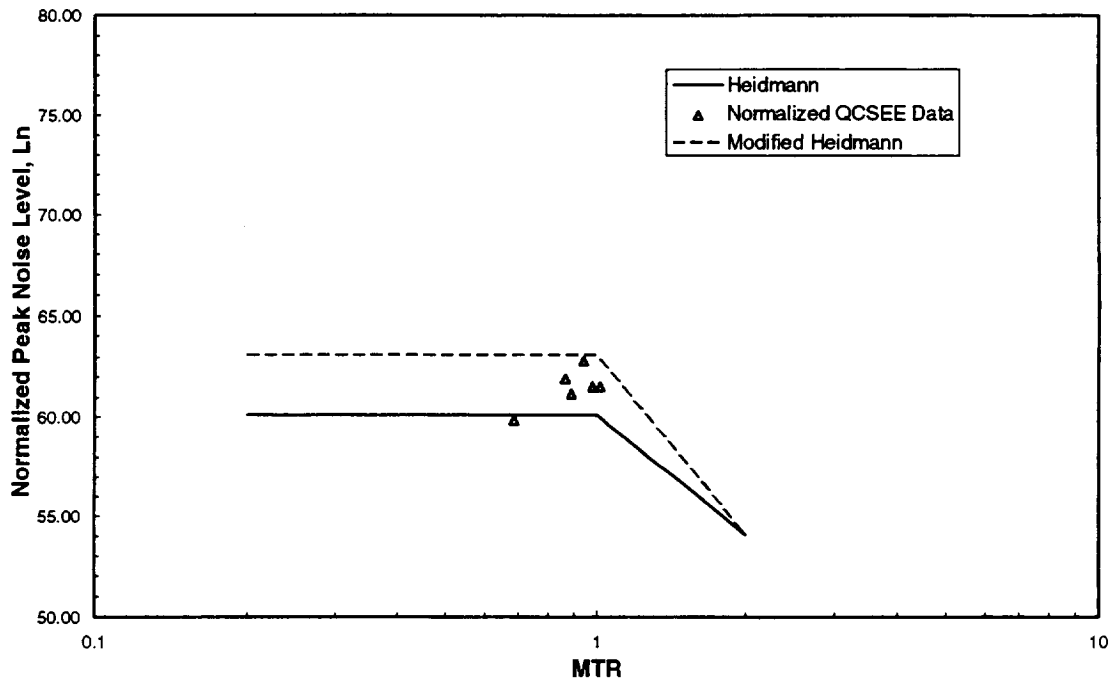
One-third octave spectra for the exhaust angles are given in Appendix E for the CF6-80C2 engine. Each plot shows the measured engine noise, the original Heidmann prediction, and the new prediction (The new prediction reflects all of the changes that have not yet been explained, but will be described later in this section). E<sup>3</sup> inlet spectra are shown in Appendix F, and QCSEE inlet spectra are in Appendix G. The E<sup>3</sup> charts show that the new Heidmann noise method is overpredicting the fan exhaust noise, as expected. The QCSEE charts generally show close agreement between the new broadband prediction and the measured data.

Figure 4.2.2 “Figure 4b”, E<sup>3</sup> Fan Exhaust Broadband Noise





**Figure 4.2.3 “Figure 4b”, QCSEE Fan Exhaust Broadband Noise**



$F_2$ , the rotor-stator spacing (RSS) correction term, should always be calculated using the equation labeled “no inlet distortion” in “Figure 6 -- Rotor Stator Spacing Correction For Broadband Noise” (Heidmann, 1979), given by:

$$F_2 = -5 \log(\text{RSS}/300) \quad (4)$$

The directivity correction,  $F_3$  in equation (1), remains unchanged (see Section 4.5).

### 4.3 Fan Inlet Discrete Tone Noise

Figure 4.3.1 shows the “Figure 10a” (Heidmann, 1979) fan inlet discrete tone noise curve for a design tip relative Mach number ( $M_{trd}$ ) of 1.53 (CF6-80C2). The CF6 inlet tone data shown by the triangles indicate that an increased level as well as “shift to the right” of the Heidmann prediction curve are required. Accordingly, “Figure 10a” curves were adjusted. The new equation for normalized peak fan inlet discrete tone noise,  $L_n$ , ( $F_1$  in equation (1)) is:

$$L_n = 64.5 + 80 \log(M_{trd}/M_{tr}); L_n = 60.5 + 20 \log(M_{trd}) + 50 \log(M_{tr}/0.72) \quad (5)$$

for  $M_{trd} > 1$ ,  $M_{tr} > 0.72$  (choose lesser value)

Figure 4.3.1 "Figure 10a", CF6-80C2 Fan Inlet Tone  
 $M_{\text{trd}} = 1.53$

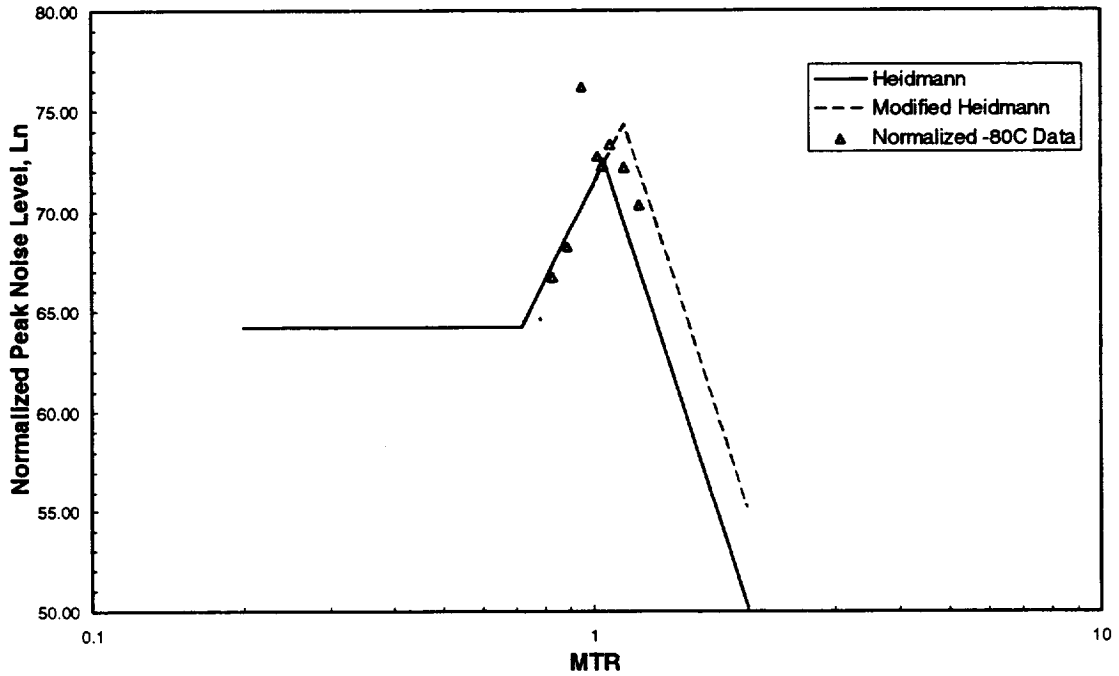


Figure 4.3.2 shows the E<sup>3</sup> engine results. This plot shows that the new curve will yield a slight overprediction for the higher speed points that were previously underpredicted. Figure 4.3.3, the QCSEE results, show very good agreement between the data and the new Heidmann curve.

Figure 4.3.2 "Figure 10a", E<sup>3</sup> Fan Inlet Tone  
 $M_{trd} = 1.14$

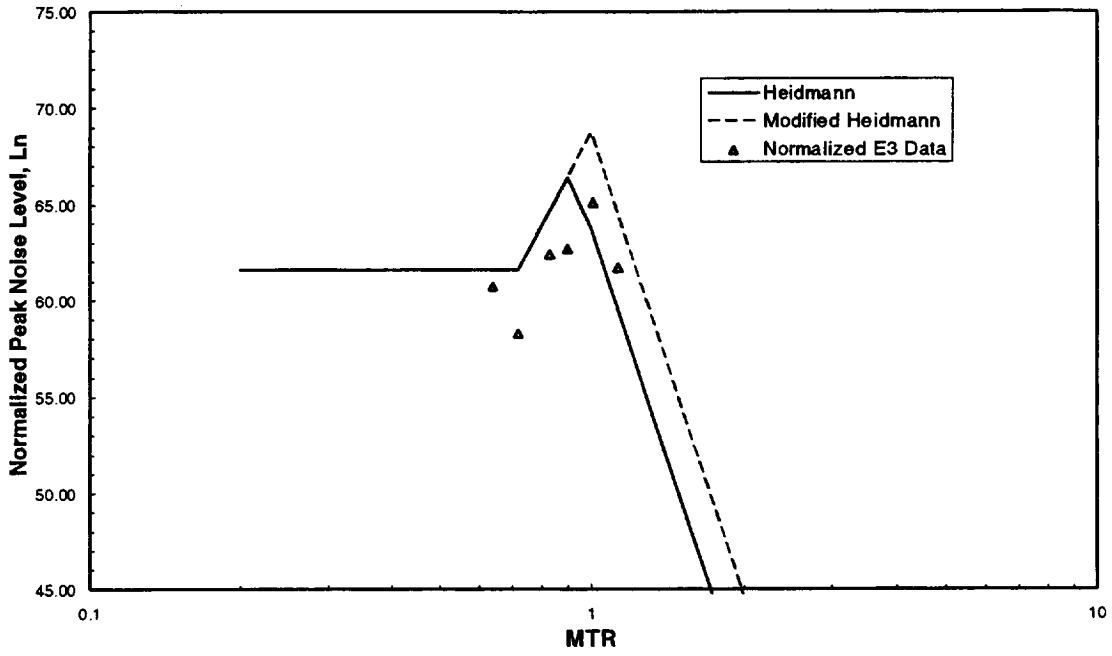
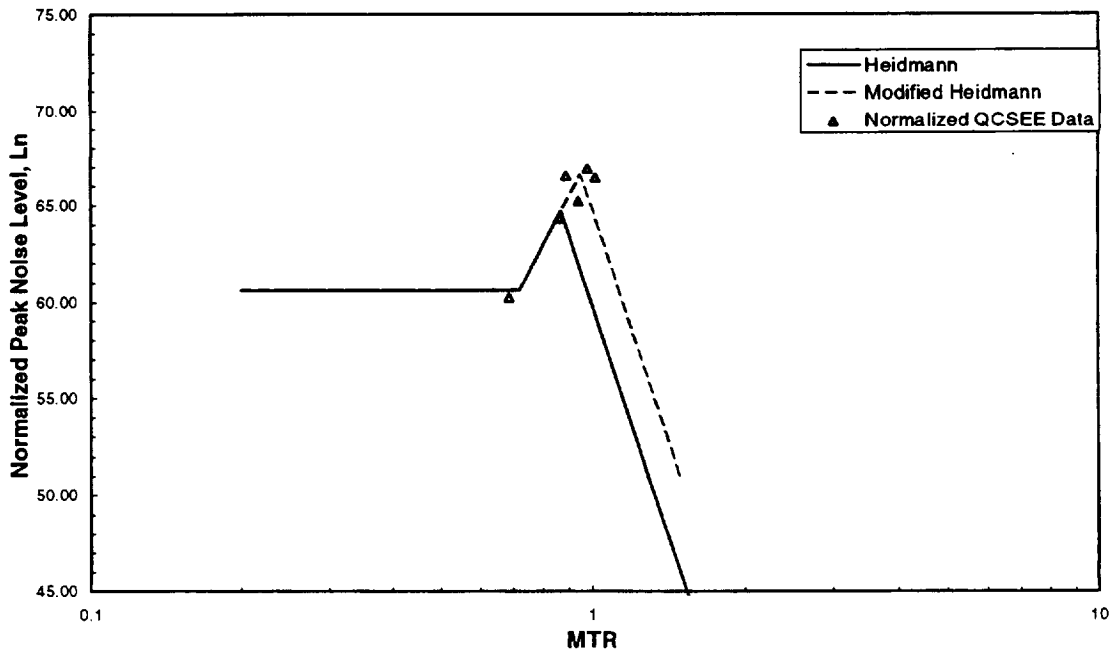


Figure 4.3.3 "Figure 10a", QCSEE Fan Inlet Tone  
 $M_{trd} = 1.01$



The cutoff factor,  $\delta$ , for the fundamental tone is given by:

$$\delta = |M_t / (1 - V/B)| \quad (6)$$

where  $M_t$  is the blade tip Mach number,  $V$  is the number of stator vanes, and  $B$  is the number of rotor blades. If the cutoff factor is less than or equal to the critical value of 1.05, then the fundamental tone level is reduced by 8 dB (“Figure 8a”, Heidmann, 1979). Based on the GE databases, it is recommended that the amount of tone reduction,  $L$ , due to cutoff become a function of the rotor tip relative Mach number, as shown by equation sets 7 and 8. The correction at cutoff remains 8 dB, but the harmonic fall-off rates are increased from 3 dB as follows:

For $M_{tr} < 1.15$ :		For $M_{tr} \geq 1.15$ :	
$L = 6 - 6k; \delta > 1.05$	(7a)	$L = 9 - 9k; \delta > 1.05$	(8a)
$L = -8; k = 1$	(7b)	$L = -8; k = 1$	(8b)
$L = 6 - 6k; k \geq 2$	(7c)	$L = 9 - 9k; k \geq 2$	(8c)

Refer to the data in Appendices B-D for the spectra plots for each of the three engines. The “modified Heidmann method curves” generally show better agreement at the BPF harmonics (reduced/eliminated over-prediction) relative to the measured engine data.

No changes are recommended to “Figure 8b”, the cutoff correction curve for fans with inlet guide vanes, since this effect could not be evaluated with the given commercial engines that do not have inlet guide vanes.

It should be noted that the BPF cutoff factor is being incorrectly calculated in ANOPP due to an error in the computer code. The vane/blade ratio is defined in the code as an integer value, but must be defined as a real number to yield the proper value of  $\delta$  that determines cutoff.

The  $F_2$  term (rotor-stator spacing effect), in accord with prior GE commercial engine experience in which no effect of rotor-stator spacing on fan inlet tone noise is observed, should be set equal to zero. The directivity correction,  $F_3$  in equation (1), remains unchanged (see Section 4.5).

During ground static test, inflow disturbances drawn into the engine and interact with the fan to cause rotor-turbulence interaction noise. A Turbulence Control Structure (TCS) is a test apparatus that is used to clean-up the airflow disturbances in static engine tests. The Heidmann model was developed from data that was taken without the benefit of such a structure. GE initially developed a set of “flight cleanup” values based on the CF6-50/A300 aircraft flight test and engine static test data (Ho, Patrick Y., GE Design Practice # 1935, 1987, private communication). Table 4.3.1 shows the suppressions that should be applied to the Heidmann fan inlet tone predictions at the fundamental (BPF) and second harmonic (2BPF) frequencies to remove the effects of inflow disturbances in the model.

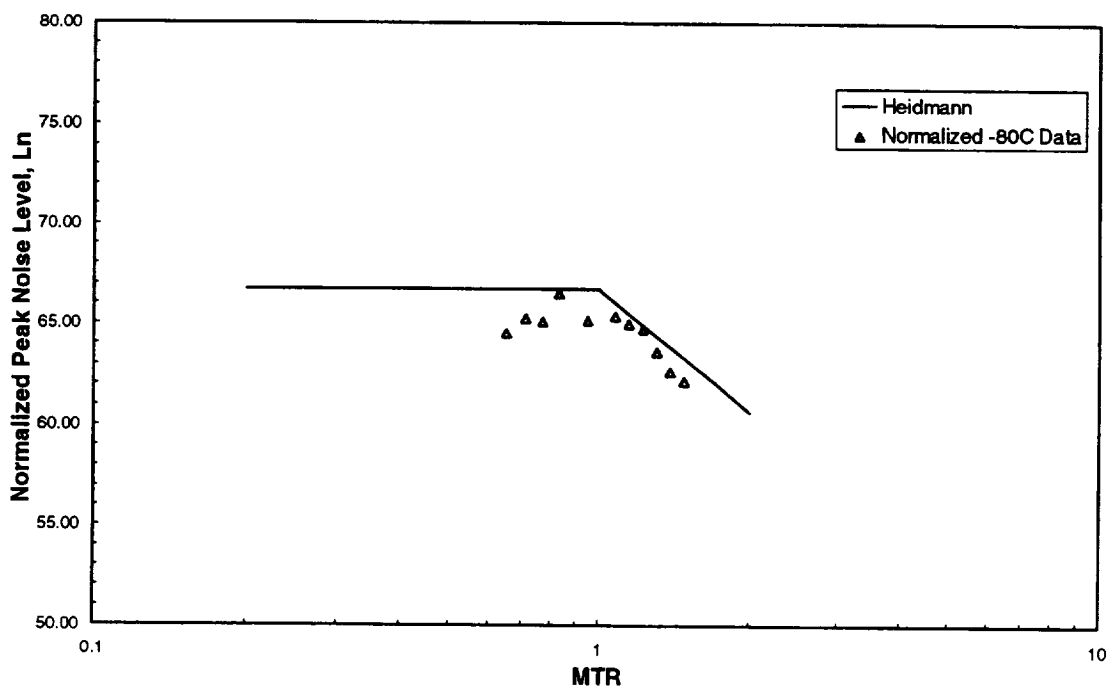
**Table 4.3.1 GE “Flight Cleanup” -- TCS Suppression**

Angle	Approach		Takeoff	
	BPF	2BPF	BPF	2BPF
10	5.6	5.4	4.8	5.8
20	5.8	4.3	5.5	3.8
30	4.7	3.4	5.5	5.3
40	4.6	4.1	5.3	6.4
50	4.9	2.0	5.3	3.5
60	5.1	2.9	5.1	3.0
70	2.9	1.6	4.4	2.1
80	3.2	1.3	3.9	2.1
90	1.6	1.5	2.6	1.1
100	1.6	1.1	2.3	1.4
110	1.8	1.4	1.8	0.9
120	2.1	1.5	2.1	0.7
130	2.4	1.0	1.7	0.7
140	2.2	1.8	1.7	0.4
150	2.0	1.6	2.6	0.6
160	2.8	1.6	3.5	0.8

#### 4.4 Fan Exhaust Discrete Tone Noise

Figures 4.4.1, 4.4.2, and 4.4.3 show the “Figure 10b” (Heidmann, 1979) normalized fan exhaust noise levels representative of the CF6-80C2, E<sup>3</sup>, and QCSEE engines, respectively. The CF6-80C2 data show fairly good agreement with the Heidmann curve. The E<sup>3</sup> and QCSEE data do not show any trends that resemble the Heidmann fan exhaust tone curve, nor do they suggest any alternative correlation. For these reasons, it is recommended that the original curve be retained.

Figure 4.4.1 “Figure 10b” CF6-80C2 Fan Exhaust Tone



$F_2$ , the rotor-stator spacing (RSS) correction term, should always be calculated using the equation labeled “no inlet distortion” in “Figure 12 -- Rotor Stator Spacing Correction For Discrete Tone Noise” (Heidmann, 1979), given by:

$$F_2 = -10 \log(\text{RSS}/300) \quad (9)$$

The directivity correction,  $F_3$  in equation (1), remains unchanged (see Section 4.5).

Figure 4.4.2 "Figure 10b" E<sup>3</sup> Fan Exhaust Tone

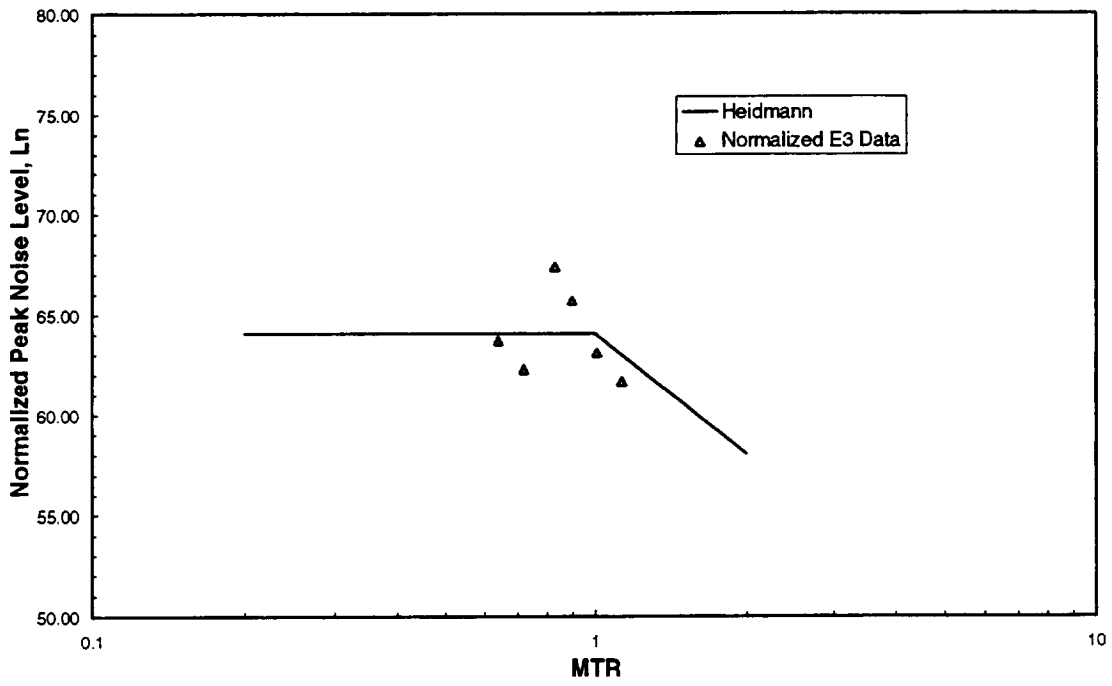
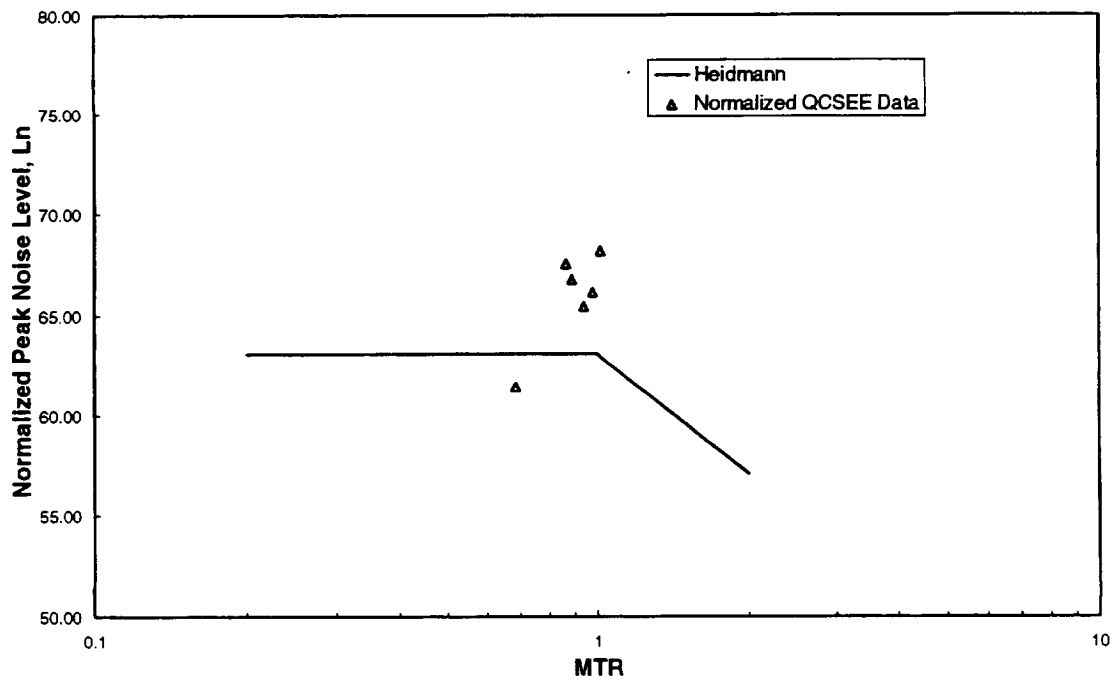


Figure 4.4.3 "Figure 10b" QCSEE Fan Exhaust Tone



## 4.5 Directivity

The directivity correction “L”, ( $F_3$  in equation 1) for fan inlet broadband, fan inlet tone, fan exhaust broadband, and fan exhaust tone noise fit the GE measured data reasonably well. The data were normalized by subtracting the peak one-third octave level from all angles. Peak angles therefore have a directivity correction equal to zero, and off-peak angles have correction values less than zero. The Heidmann directivity curves for each of the four noise components are shown in comparison to the normalized  $E^3$  data in Figures 4.5.1 - 4.5.4. Directivity comparisons relative to the CF6-80C2 and QCSEE engines are given in Appendix K. Since the data generally show a close relationship to the directivity curves in the Heidmann model, no changes are recommended.

Figure 4.5.1 “Figure 7a” Fan Inlet Broadband Directivity Correction --  $E^3$  Data

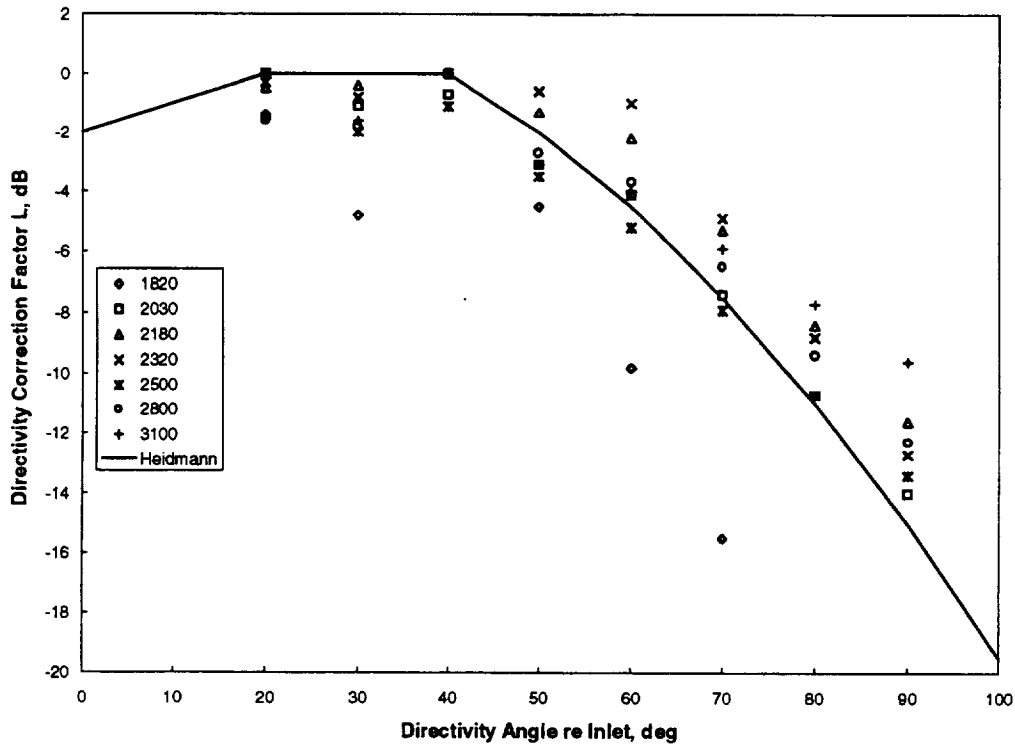




Figure 4.5.2 "Figure 13a: Fan Inlet Tone Directivity Correction -- E<sup>3</sup> Data

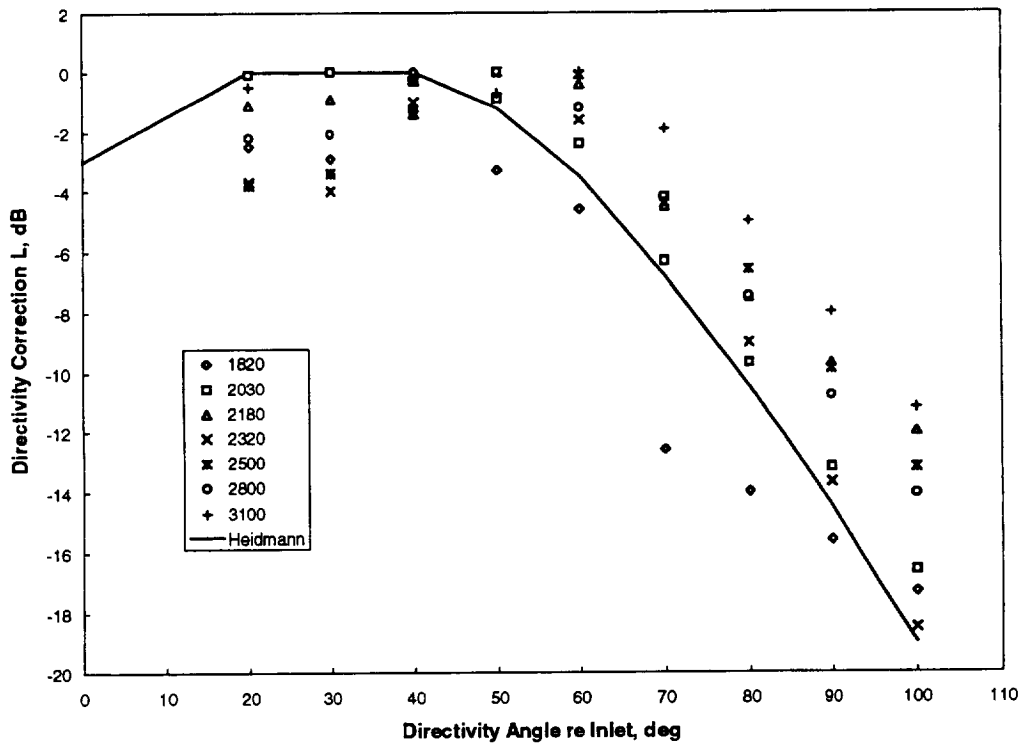


Figure 4.5.3 "Figure 7b" Fan Exhaust Broadband Directivity Correction -- E<sup>3</sup> Data

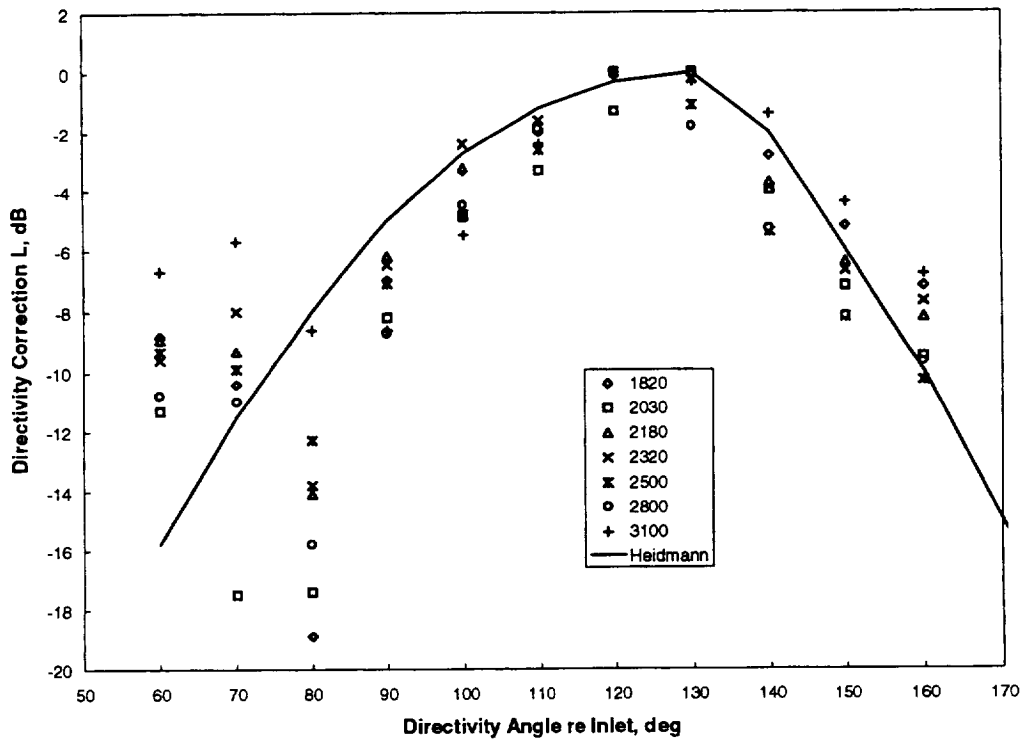
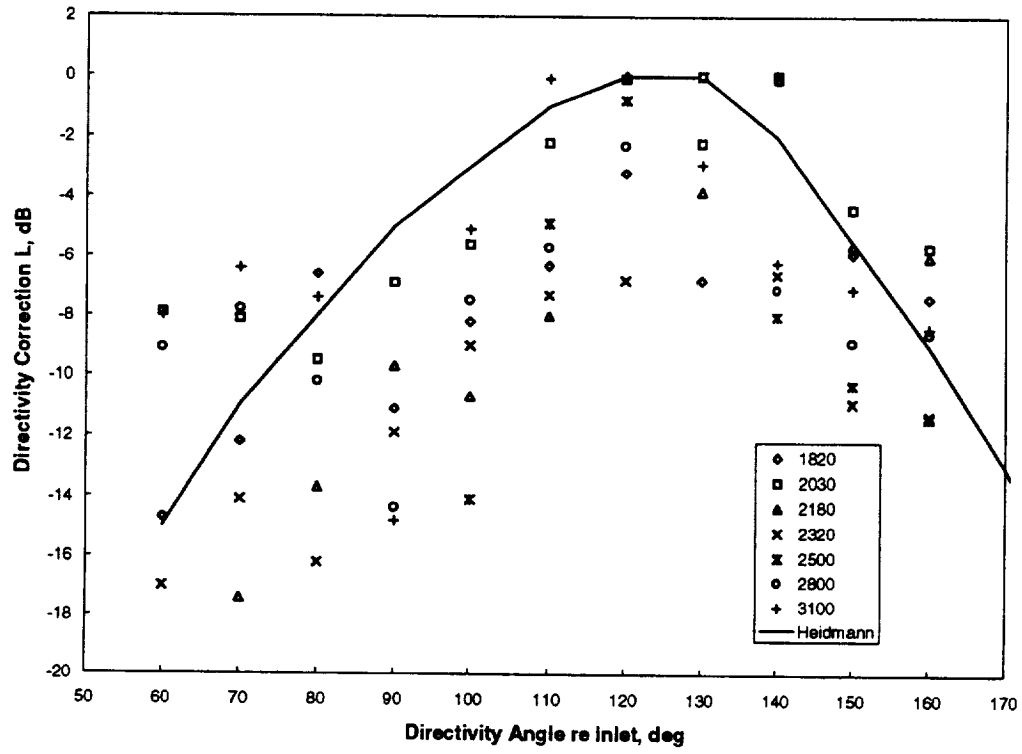


Figure 4.5.4 "Figure 13b" Fan Exhaust Tone Directivity Correction -- E<sup>3</sup> Data



## 4.6 Combination Tone Noise

The Heidmann method contains a model for predicting combination tone noise, a noise source that occurs only at supersonic tip speeds. It is also commonly referred to as “buzz-saw” noise or Multiple Pure Tone (MPT) noise. “At supersonic tip speeds, shock waves are formed at the leading edge of each rotor blade. These shocks move upstream and decay into a system of Mach waves which propagate out of the inlet duct. Ideally, these shocks would contribute to the BPF tone, but small blade-to-blade manufacturing variations result in a redistribution of the energy into various harmonics of the shaft rotational speed” (Heidmann, 1979).

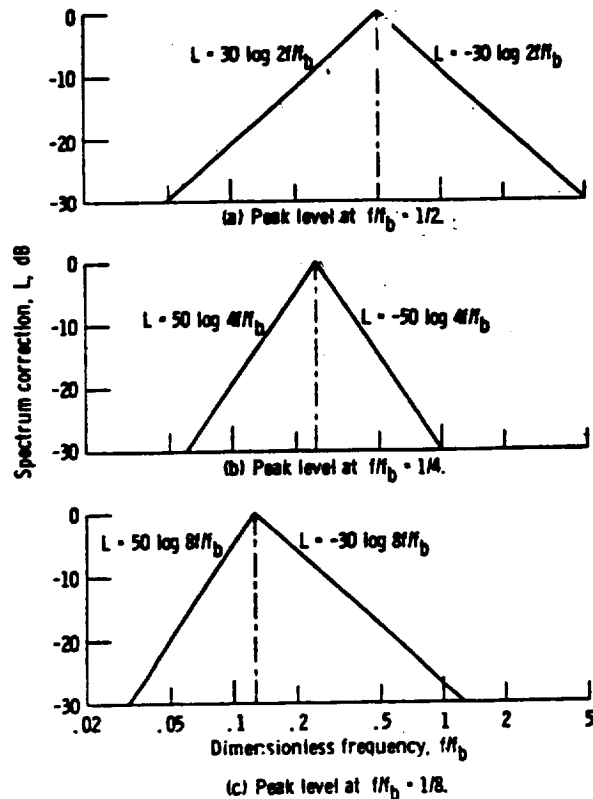
The characteristic peak level at center frequencies one-half, one-fourth, and one-eighth of the fundamental blade passage frequency  $f_b$  is given by

$$L_c = 20 \log(\Delta T/\Delta T_o) + 10 \log(m/m_o) + F_1(M_{tr}) + F_2(\theta) + C \quad (10)$$

( $C = -5$  dB for fans with inlet guide vanes,  $C = 0$  for fans without IGV)

$F_1$  is characterized by three separate spectra, which have peaks at one-half, one-fourth, and one-eighth of the fundamental blade passage frequency of the fan stage, respectively. These curves appear in Figure 4.6.1. (“Figure 14”, Heidmann, 1979).

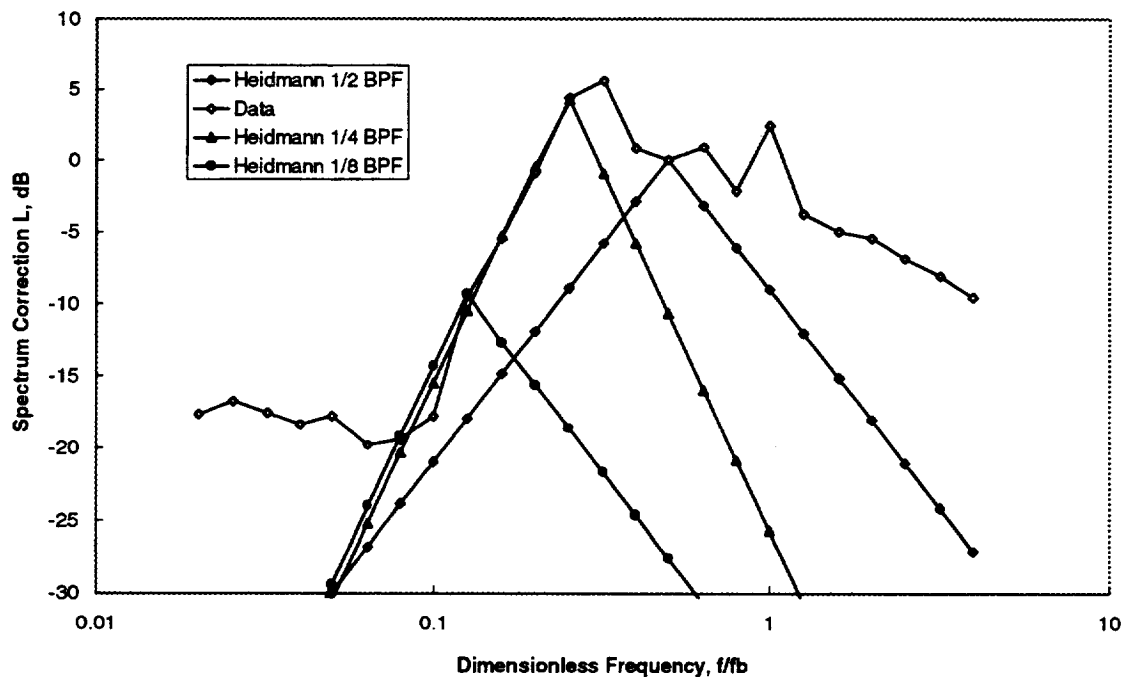
Figure 4.6.1. “Figure 14.” Combination Tone Noise Spectrum Content



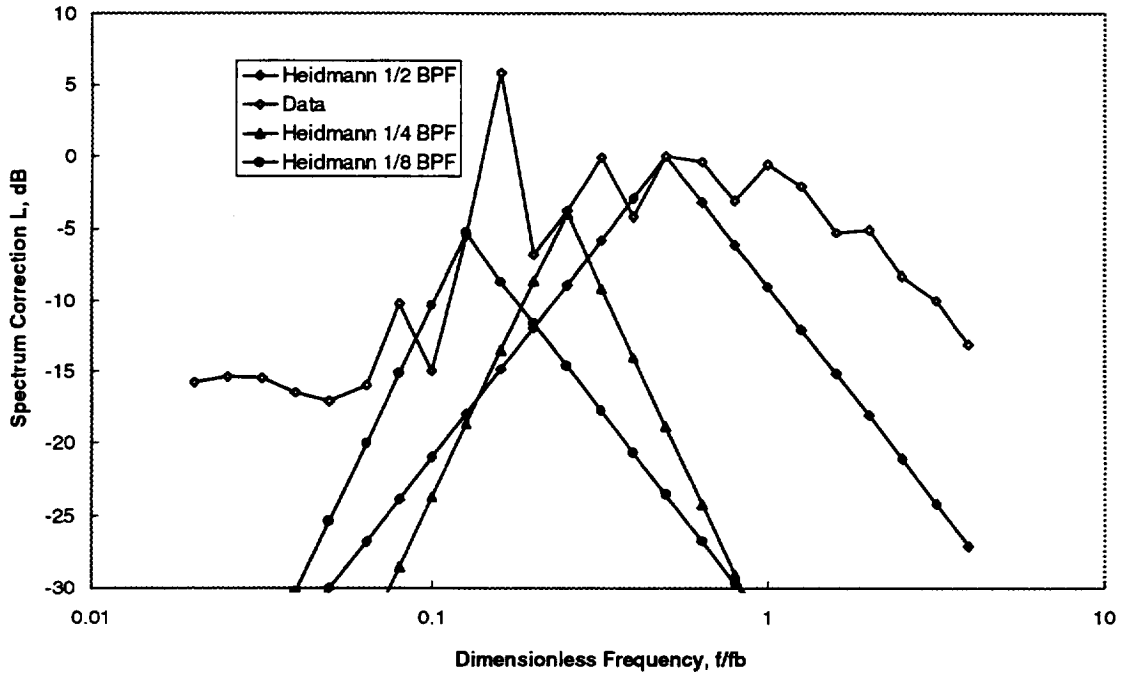
The changes recommended for the combination tone model are largely based on GE CFM56 data comparisons. Use of this data was required since the CF6-80C2 data contain relatively little combination tone noise. There is no discernible MPT noise in either the E<sup>3</sup> or QCSEE databases.

Figures 4.6.2, 4.6.3, and 4.6.4 show how well the spectral content of the combination tone noise is predicted by the modified Heidmann method, relative to the CFM56 data at various tip speeds. These charts indicate that the spectral distribution shapes with peaks at one-half, one-fourth, and one-eighth of the blade passage frequency ( $f/f_b = 1/2, 1/4,$  and  $1/8$ ) are not characteristic of the combination tone noise. In fact, there are no clear trends shown for the spectral distribution, and therefore no changes can be recommended.

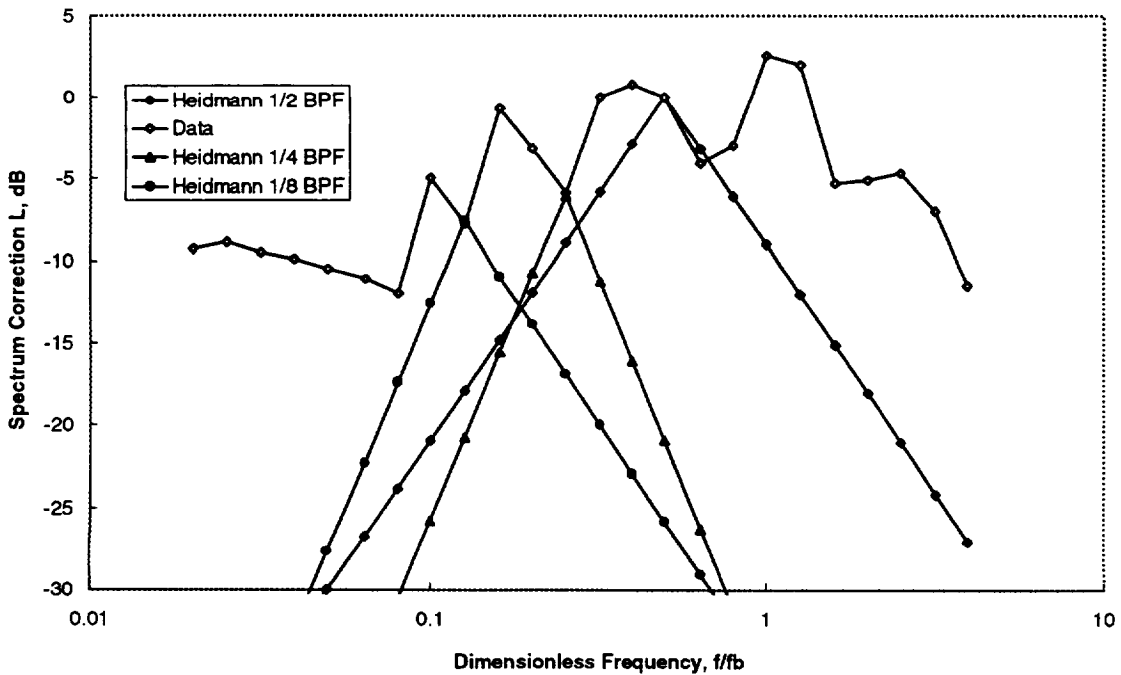
**Figure 4.6.2 Combination Tone Noise Spectrum, CFM56 engine,  $M_{tr} = 1.2$**



**Figure 4.6.3 Combination Tone Noise Spectrum, CFM56 engine,  $M_{tr} = 1.32$**



**Figure 4.6.4 Combination Tone Noise Spectrum, CFM56 engine,  $M_{tr} = 1.43$**



The levels of the three spectra are determined by a set of curves that are labeled "Heidmann" in Figures 4.6.5 - 4.6.7 (taken from "Figure 15", Heidmann, 1979). Figure 4.6.5 shows the new combination tone noise level curve that is recommended for  $f/f_b = 1/2$  (shown by the dashed line), based on the comparison made with the CFM56 and CF6-80C2 data. Similarly, Figures 4.6.6 and 4.6.7 show the recommended shapes for the  $f/f_b = 1/4$  and  $1/8$  curves. In the case of the  $1/2$  and  $1/4$  BPF curves, the modification was determined by a best fit with the CFM56 data (the CF6-80C2 data was ignored since the MPT content is relatively low in this engine). For the  $1/8$  BPF peak curve, the CFM56 and CF6-80C2 data agree, but there is not enough data to support definition of a new curve. In this case, the slope of the ascending curve was modified according to the data, and the slope of the descending curve was maintained.

Spectral comparisons of the old and new Heidmann method predictions relative to the GE data are given in Appendix L for the CFM56 and Appendix M for the CF6-80C2. Exact definition of the new normalized combination tone levels ( $F_1$ ) is given in Table 4.6.1.

**Figure 4.6.5 "Figure 15" Combination Tone Noise,  $f/f_b = 1/2$**

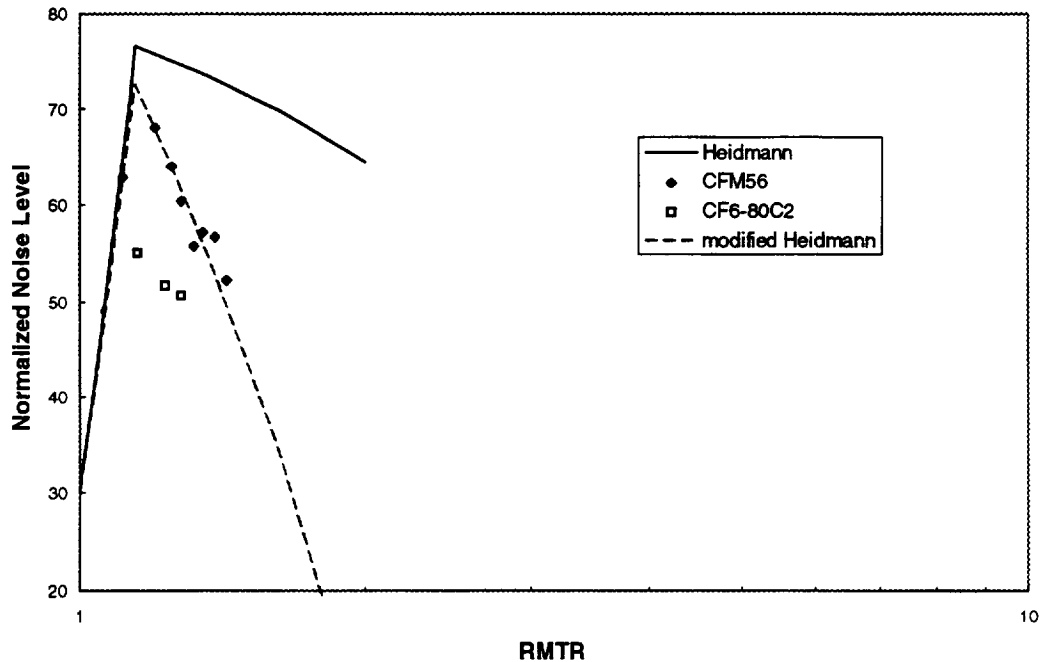


Figure 4.6.6 "Figure 15" Combination Tone Noise,  $f/f_b = 1/4$

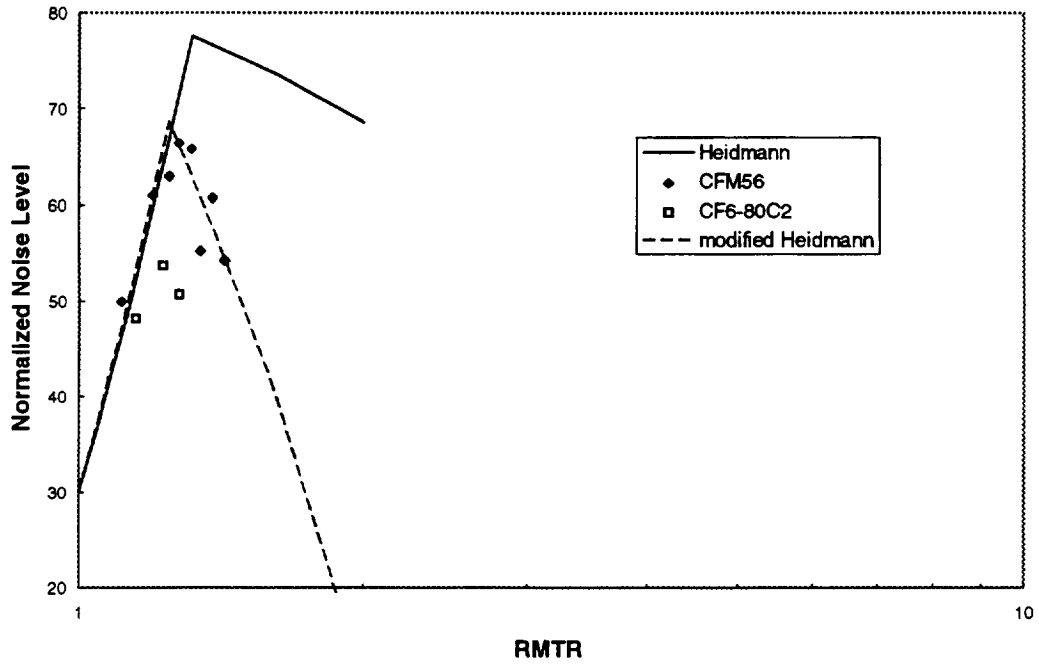
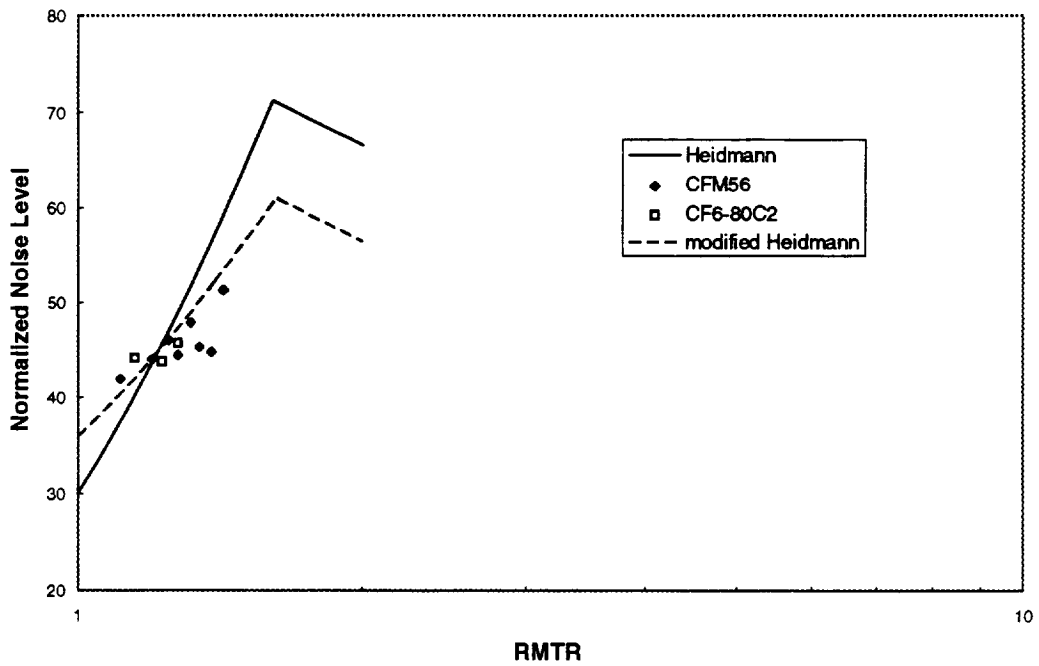


Figure 4.6.7 "Figure 15" Combination Tone Noise,  $f/f_b = 1/8$



**Table 4.6.1 Combination Tone Noise Levels**

<b>f/fb</b>	<b>MTR</b>	<b>Ln</b>
<b>1/2</b>	<b>1</b>	<b>30</b>
	<b>1.14</b>	<b>72.5</b>
	<b>2</b>	<b>4.4</b>
<b>1/4</b>	<b>1</b>	<b>30</b>
	<b>1.25</b>	<b>68.6</b>
	<b>2</b>	<b>10.5</b>
<b>1/8</b>	<b>1</b>	<b>36</b>
	<b>1.61</b>	<b>60.6</b>
	<b>2</b>	<b>56.5</b>

#### ***4.7 Summary of Fan Noise Methodology Changes***

The following section is an outline of all recommended changes to the Heidmann fan noise model, based on the results of correlations made with the CF6-80C2, E<sup>3</sup>, and QCSEE engine data.

##### ***Inlet Broadband Noise***

Inlet broadband noise is given by Heidmann as:

$$L_c = 20 \log(\Delta T/\Delta T_o) + 10 \log(m/m_o) + F_1(M_{trd}, M_{tr}) + F_2(RSS) + F_3(\theta)$$

Modify  $F_1$  such that:

$$F_1 = 58.5 + 20 \log(M_{trd}) - 50 \log(M_{tr}/0.9); M_{trd} > 1, M_{tr} > 0.9$$

Modify  $F_2$  such that:

$$F_2 = 0$$

##### ***Fan Exhaust Broadband Noise***

Fan exhaust broadband noise is given by Heidmann as:

$$L_c = 20 \log(\Delta T/\Delta T_o) + 10 \log(m/m_o) + F_1(M_{trd}, M_{tr}) + F_2(RSS) + F_3(\theta)$$

Modify  $F_1$  such that:

$$L_n = 63 + 20 \log(M_{trd}); M_{trd} > 1, M_{tr} \leq 1.0$$

$$L_n = 63 + 20 \log(M_{trd}) - 30 \log(M_{tr}); M_{trd} > 1, M_{tr} > 1.0$$

Always calculate  $F_2$  by:

$$F_2 = -5 \log(RSS/300)$$



***Inlet Tone Noise***

Fan inlet tone noise is given by Heidmann as:

$$L_c = 20 \log(\Delta T/\Delta T_o) + 10 \log(m/m_o) + F_1(M_{trd}, M_{tr}) + F_2(RSS) + F_3(\theta)$$

Modify  $F_1$  such that:

$$L_n = 64.5 + 80 \log(M_{trd}/M_{tr}); L_n = 60.5 + 20 \log(M_{trd}) + 50 \log(M_{tr}/0.72)$$

for  $M_{trd} > 1, M_{tr} > 0.72$  (choose lesser value)

Modify  $F_2$  such that:

$$F_2 = 0$$

***Cutoff Correction***

Increase the harmonic fall-off rate for cutoff correction and make it a function of  $M_{tr}$  as follows:

For  $M_{tr} < 1.15$ :

$$L = 6 - 6k; \delta > 1.05$$

$$L = -8; k = 1$$

$$L = 6 - 6k; k \geq 2$$

For  $M_{tr} \geq 1.15$ :

$$L = 9 - 9k; \delta > 1.05$$

$$L = -8; k = 1$$

$$L = 9 - 9k; k \geq 2$$

***Flight Cleanup***

Apply following suppressions to fan inlet fundamental (BPF) and second harmonic (2BPF) tones for “flight cleanup” effect:

Angle	Approach		Takeoff	
	BPF	2BPF	BPF	2BPF
10	5.6	5.4	4.8	5.8
20	5.8	4.3	5.5	3.8
30	4.7	3.4	5.5	5.3
40	4.6	4.1	5.3	6.4
50	4.9	2.0	5.3	3.5
60	5.1	2.9	5.1	3.0
70	2.9	1.6	4.4	2.1
80	3.2	1.3	3.9	2.1
90	1.6	1.5	2.6	1.1
100	1.6	1.1	2.3	1.4
110	1.8	1.4	1.8	0.9
120	2.1	1.5	2.1	0.7
130	2.4	1.0	1.7	0.7
140	2.2	1.8	1.7	0.4
150	2.0	1.6	2.6	0.6
160	2.8	1.6	3.5	0.8

### ***Fan Exhaust Tone Noise***

Always calculate  $F_2$  by:

$$F_2 = -10 \log(\text{RSS}/300)$$

### ***Combination Tone Noise***

Fan combination tone noise is given by Heidmann as:

$$L_c = 20 \log(\Delta T/\Delta T_o) + 10 \log(m/m_o) + F_1(M_{tr}) + F_2(\theta) + C$$

Revise normalized combination tone noise levels ( $F_1$ ) as follows:

<b>f/fb</b>	<b>MTR</b>	<b>Ln</b>
<b>1/2</b>	<b>1</b>	<b>30</b>
	<b>1.14</b>	<b>72.5</b>
	<b>2</b>	<b>4.4</b>
<b>1/4</b>	<b>1</b>	<b>30</b>
	<b>1.25</b>	<b>68.6</b>
	<b>2</b>	<b>10.5</b>
<b>1/8</b>	<b>1</b>	<b>36</b>
	<b>1.61</b>	<b>60.6</b>
	<b>2</b>	<b>56.5</b>

## ***5.0 Concluding Remarks***

The fan noise model in ANOPP is based on noise correlations developed from fan rig tests at NASA Lewis. The recommendations that have been made relative to commercial engine data have now helped the method to achieve results that are a better indication of full-scale fan noise from large commercial turbofan engines. No assessments related to multiple stage fans or fans with inlet guide vanes were made, since this is outside of the task of developing ANOPP as a tool for advanced UHB studies.

The recommendations intentionally are structured to retain the form of the Heidmann model. Generally, no need to change the structure of the models was demonstrated, since many of the original correlations showed some relationship to the engine data. An exception to this was the combination tone noise model. In this case, it was demonstrated that the structure of the model did not reflect the nature of the data, both in magnitude and in frequency. The engine combination tone noise data does not fit the one-half, one-fourth, and one-eighth blade passage frequency spectrum model. It is therefore suggested that the current Heidmann method for combination tone noise prediction be replaced with a new methodology.

The assessment of the other components of engine noise (jet, combustor, and turbine) identified some other areas for potential model improvements, especially to the turbine noise method. This model was shown to give tremendously high predictions of turbine noise, and a spectral content that was much different from that of the engine data.

Follow-on work to this task is in progress to add fan inlet and fan exhaust noise models of acoustic treatment suppression. This will be an enhancement to the current Heidmann model, which predicts only hardwall fan noise. Such a tool will enable comparisons of engine configurations with different treatment designs.



***Appendix A***  
***Sample ANOPP Input***

```

ANOPP JECHO=.TRUE.  JLOG=.FALSE.  NLPPM=60  $
STARTCS  $
SETSYS JECHO=.FALSE.  JCON=.TRUE.  $
CREATE SCRATCH ATM HDNFAN STNJET GECOR GETUR SFIELD  $
CREATE FANIN FANEX  $
$
$ DEFINE FREQUENCY AND DIRECTIVITY ANGLE ARRAYS
$
UPDATE NEWU=SFIELD SOURCE=* $
  -ADDR OLDM=*  NEWM=FREQ  FORMAT=5H24RS$  $
    50. 63. 80. 100. 125. 160. 200. 250. 315. 400. 500. 630. 800. 1000
    1250. 1600. 2000. 2500. 3150. 4000. 5000. 6300. 8000. 10000. $
  -ADDR OLDM=*  NEWM=THETA  FORMAT=5H17RS$  $
    10. 20. 30. 40. 50. 60. 70. 80. 90. 100. 110. 120. 130. 140.
    150. 160. 170. $
  -ADDR OLDM=*  NEWM=PHI  FORMAT=3HRS$  $
    90. $
END* $
$
PARAM IUNITS=7HENGLISH $
PARAM RS = 150.  $ RADIAL DISTANCE FROM SOURCE TO OBSERVER, M
PARAM IOUT=1  $ REQUEST dB OUTPUT
PARAM AE=33.2  $ ENGINE REFERNCE AREA, ft**2
PARAM NENG=1  $ NUMBER OF ENGINES
PARAM IPRINT=2  $ INPUT PRINT ONLY
$
$ LOAD SYSTEM PROCEDURE LIBRARY
$
LOAD /LIBRARY/STNTBL $
LOAD /LIBRARY/ LIB=PROCLIB $
$
$ BUILD ATMOSPHERIC AND ATMOSPHERIC ABSORPTION TABLES
$
PARAM DELH=100.  $ ALTITUDE INCREMENT FOR OUTPUT, M
PARAM H1=0.  $ GROUND LEVEL ALTITUDE
PARAM NAI=1  $
PARAM NHO=11  $ NUMBER OF ALTITUDES FOR OUTPUT
PARAM P1=1936.08  $ ATMOSPHERIC PRESSURE AT GROUND LEVEL, LB/FT^2
PARAM ABSINT=10  $ # OF INTEGRATION STEPS FOR ABS
$
$ DEFINE MEMBER ATM(IN) - ALTITUDE.  TEMPERATURE.  RELATIVE HUMIDITY
$
UPDATE NEWU=ATM SOURCE=* LIST=ES $
  -ADDR OLDM=*  NEWM=IN  FORMAT=4H3RS$  $
    0.  536.67  70.  $
END*  $
$
$ EXECUTE ATM $
$ EXECUTE ABS $
$
$ SET UP INPUT FOR GEO
$
PARAM DELT=0.5  $ RECEPTION TIME INCREMENT
PARAM ENGAM=3HXXX  $ MATCH DEFAULT NAMES IN OTHER MODULES
PARAM START=0.0  $ START TIME FOR GEOMETRY
PARAM STOP=40.  $ STOP TIME FOR GEOMETRY
PARAM ICOORD=1  $ REQUEST BODY AXIS ONLY

```

```

PARAM DIRECT=.FALSE. $ INTERPOLATE FROM FLI (TAKOFF) OBSERVER RECEPTION
$ TIMES AND GEOMETRY BASED ON USER PARAMS
PARAM DELTH=10. $ MAXIMUM POLAR DIRECTIVITY ANGLE
PARAM CTK=1. $ CHARACTERISTIC TIME CONSTANT
PARAM DELDB=10. $ LIMITING NOISE LEVEL DOWN FROM PEAK
$
$
$ PUT OBSERVER AT LOCATION 0,0,0
$
UPDATE NEWU=OBSERV SOURCE=* $
-ADDR OLDM=* NEWM=COORD FORMAT=4H3RS$ $
0.0.0.$
END* $
$
$
PARAM RHOA=.00222 $
PARAM MA=0.00 $
$
$
$ DEFINE ENGINE CYCLE PARAMETERS FOR FAN NOISE
$
PARAM CA= 1135.6 $ AMBIENT SPEED OF SOUND
PARAM DIAM=1.2 $ FAN ROTOR DIAMETER, RE AE
PARAM MDOT=.443 $ MASS FLOW RATE, RE RHOA*CA*AE
PARAM N=0.320 $ ROTATIONAL SPEED, RE CA/DIAM
PARAM DELTAT=0.123 $ TOTAL TEMPERATURE RISE ACROSS FAN, RE TA
PARAM NB=32 $ NUMBER OF BLADES
PARAM MD=0.989 $ FAN ROTOR REL. TIP MACH NO. AT DESIGN POINT
PARAM AFAN=1.0 $ FAN INLET X-SECT AREA, RE AE
PARAM RSS=2.600 $ ROTOR-STATOR SPACING, RE MEAN BLADE CHORD
PARAM NV=34 $ NUMBER OF VANES
PARAM IGV=1 $ NO INLET GUIDE VANES
PARAM DIS=2 $ INLET FLOW DISTORTION
PARAM INRS=.TRUE. $ ROTOR STATOR INTERACTION TONES ON
PARAM INCT=.FALSE. $ COMBINATION TONES ON
PARAM INDIS=.TRUE. $ INLET DISTORTION TONES OFF
PARAM IDRS=.FALSE. $ DISCHARGE ROTOR-STATOR TONES ON
PARAM IDBB=.FALSE. $ DISCHARGE BROADBAND ON
PARAM INBB=.TRUE. $ INLET BROADBAND ON
$
EXECUTE HDNFAN HDNFAN=FANIN $
$
PARAM IDBB=.TRUE. IDRS=.TRUE. INBB=.FALSE. INCT=.FALSE. INRS=.FALSE. $
PARAM INDIS=.FALSE. $
$
EXECUTE HDNFAN HDNFAN=FANEX $
$
$
$ DEFINE INPUT PARAMETERS FOR JET NOISE MODULE
$
PARAM CIRCLE=.TRUE. $ IMPLIES CIRCULAR NOZZLE
PARAM PLUG=.TRUE. $ EXHAUST PLUG OPTION ON
PARAM SUPER=.FALSE. $ SUPERSONIC JET OPTION OFF
PARAM DELTA=0. $ ANGLE BETWEEN FLIGHT VECTOR AND ENGINE AXIS
PARAM M1=.707 $ PRIMARY STREAM MACH NO
PARAM V1=0.783 $ " " JET VELOCITY, RE CA
PARAM T1=1.341 $ " " TOTAL TEMP, RE TA
PARAM MA=0.0 $ AIRCRAFT MACH NO.
PARAM RHO1=.819 $ PRIMARY STREAM JET DENSITY, RE RHOA
PARAM DE1=.912 $ ACTUAL PRIMARY STREAM EQUIVALENT DIAMETER

```

```

PARAM DH1=DE1          $ PRIMARY STREAM HYDRAULIC DIAMETER
PARAM A1=.653          $ PRIMARY STREAM FULLY EXPANDED JET AREA
$
EXECUTE STNJET $
$
$ DEFINE PARAMETERS FOR COMBUSTION NOISE MODULE
$
PARAM MDOT=.037        $ COMBUSTOR ENTRANCE MASS FLOW RATE, RE RHOA*CA*AE
PARAM PI=25.09         $ " " TOTAL PRESSURE, RE TA
PARAM TI=2.709         $ " " TEMPERATURE, RE TA
PARAM TCJ=5.707       $ " EXIT TOTAL TEMPERATURE, RE TA
PARAM TDDELTA=2.8     $ DESIGN TURBINE TEMPERATURE RISE, RE TA
PARAM A=.01           $ COMBUSTOR ENTRANCE AREA, RE AE
$
EXECUTE GECOR $
$
$ DEFINE PARAMETERS FOR TURBINE NOISE MODULE
$
PARAM AREA=.213        $ TURBINE INLET CROSS-SECTIONAL AREA, RE AE
PARAM NBLADE=48       $ # OF ROTOR BLADES
PARAM D= .351         $ TURBINE ROTOR DIAMETER, RE SQRT AE
PARAM ROTSPD=.32     $ ROTATIONAL SPEED, RE CA/D
PARAM TTI=3.786       $ ENTRANCE TOTAL TEMPERATURE, RE TA
PARAM TSJ=2.875       $ EXIT STATIC TEMPERATURE, RE TA
$
EXECUTE GETUR $
$
$
PARAM PROPRT=2 $
$
ENDCS $

```



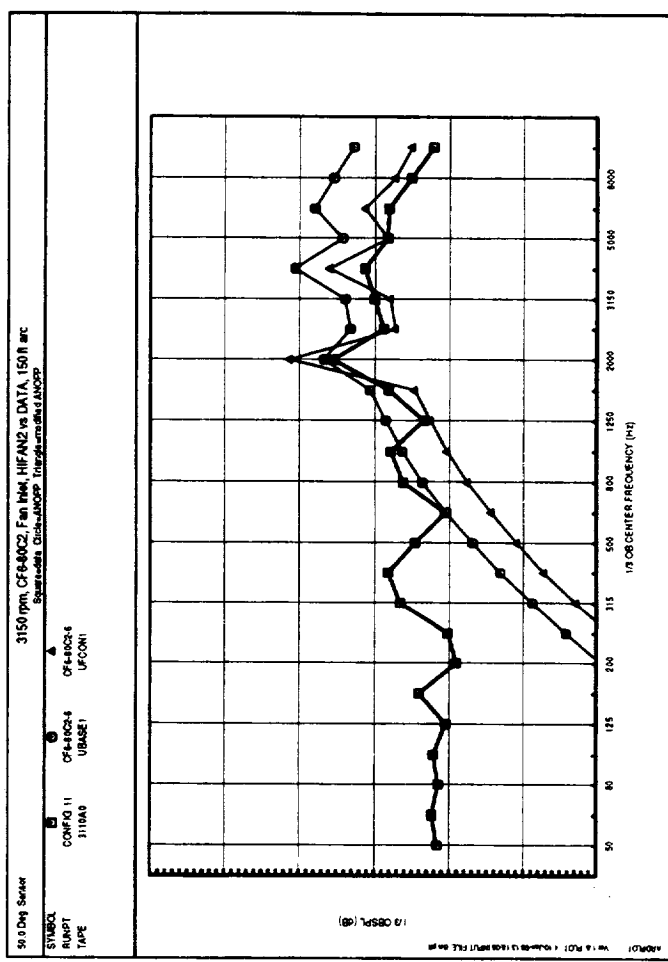
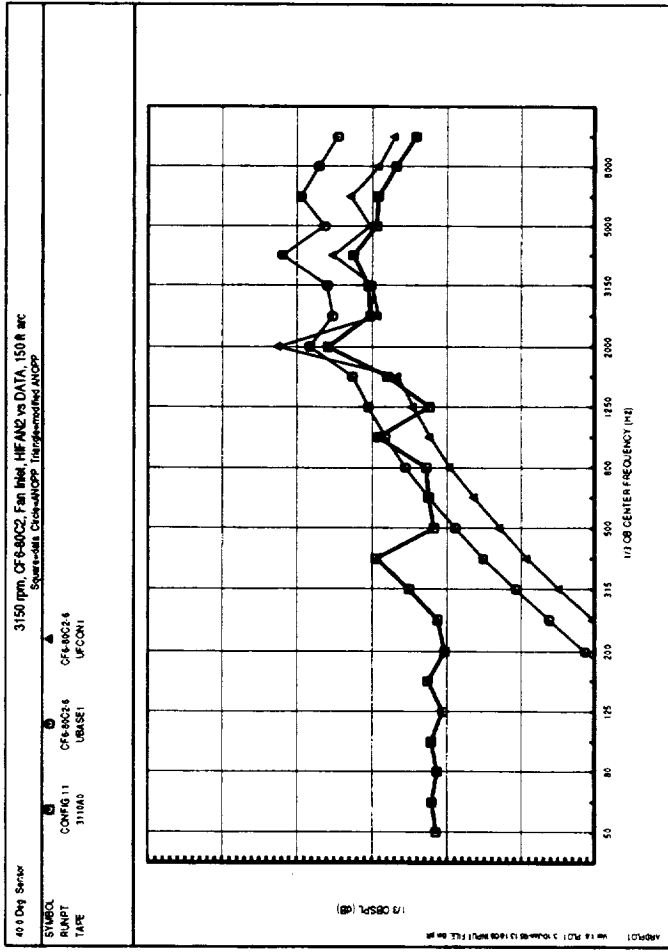
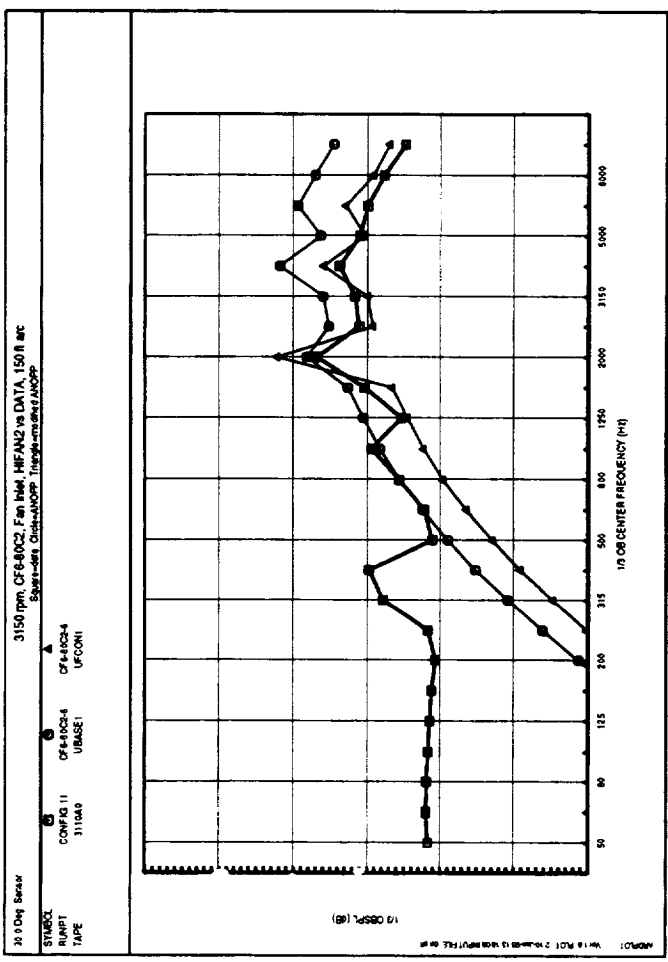
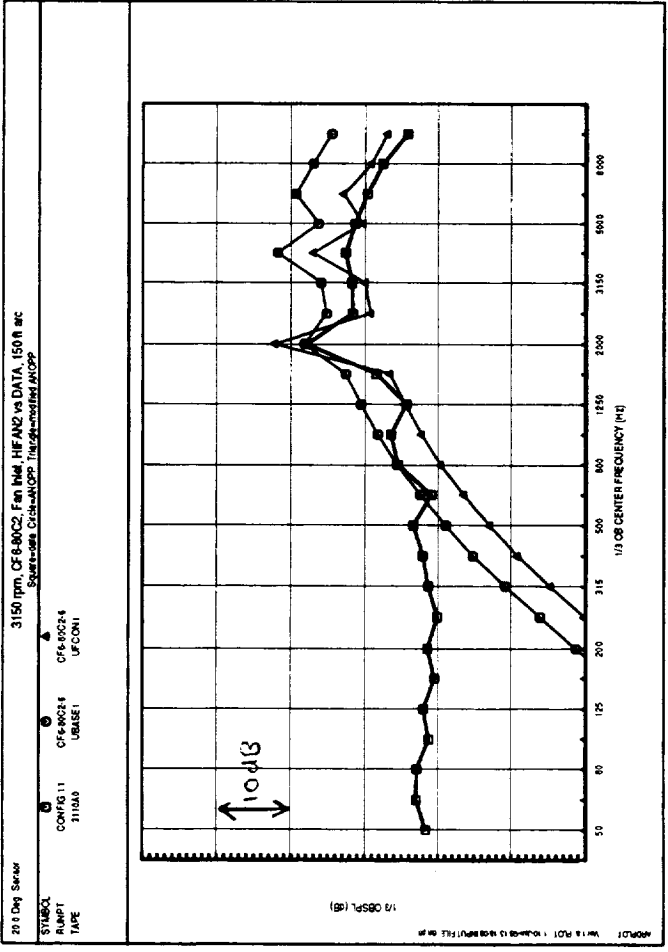
**Appendix B**  
**Fan Inlet Noise Spectral Comparisons - CF6-80C2**

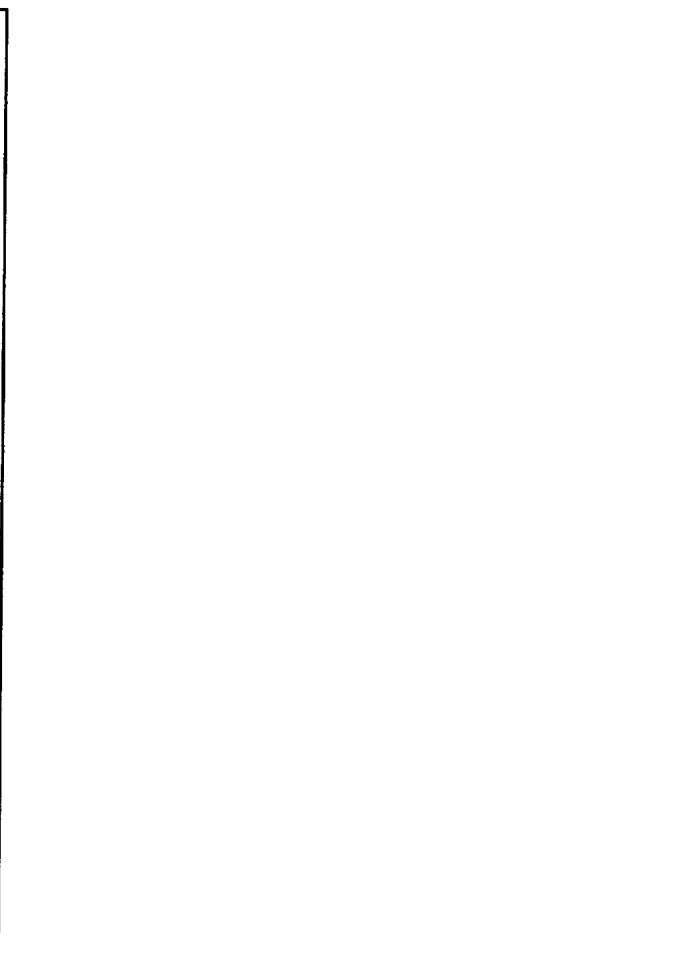
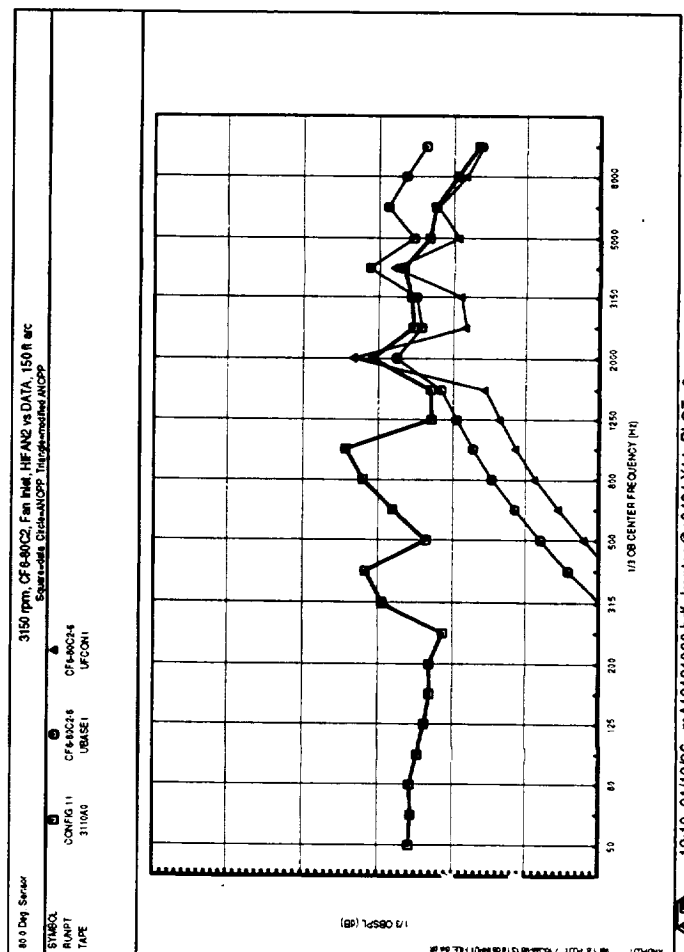
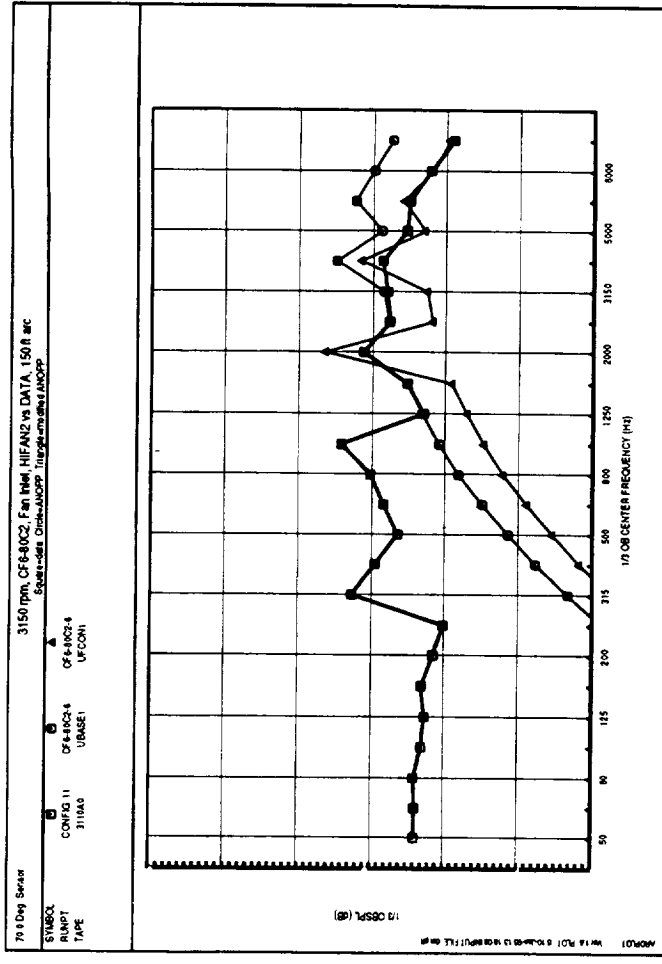
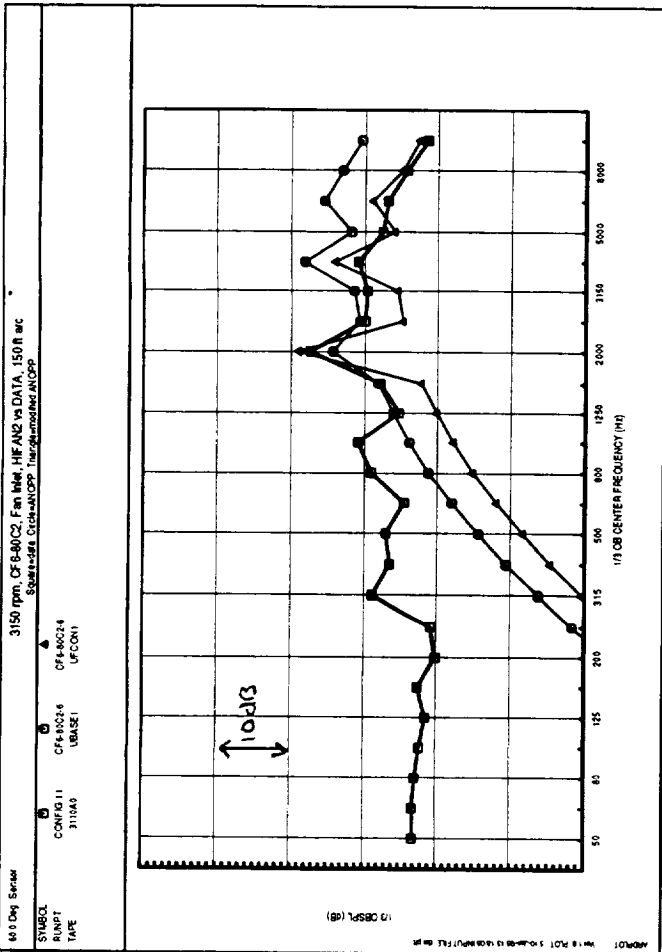
**Appendix B Contents**

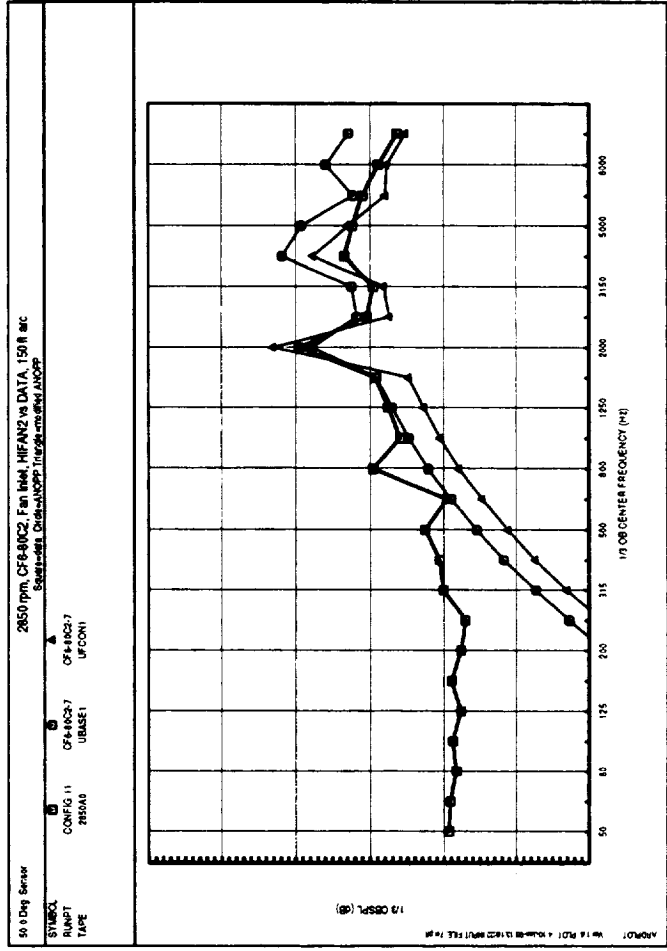
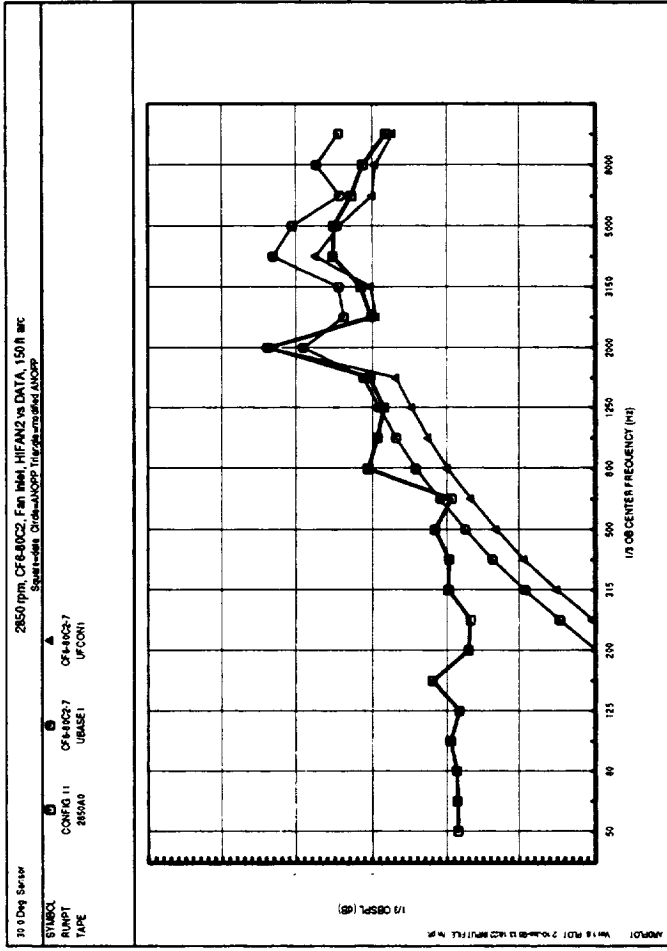
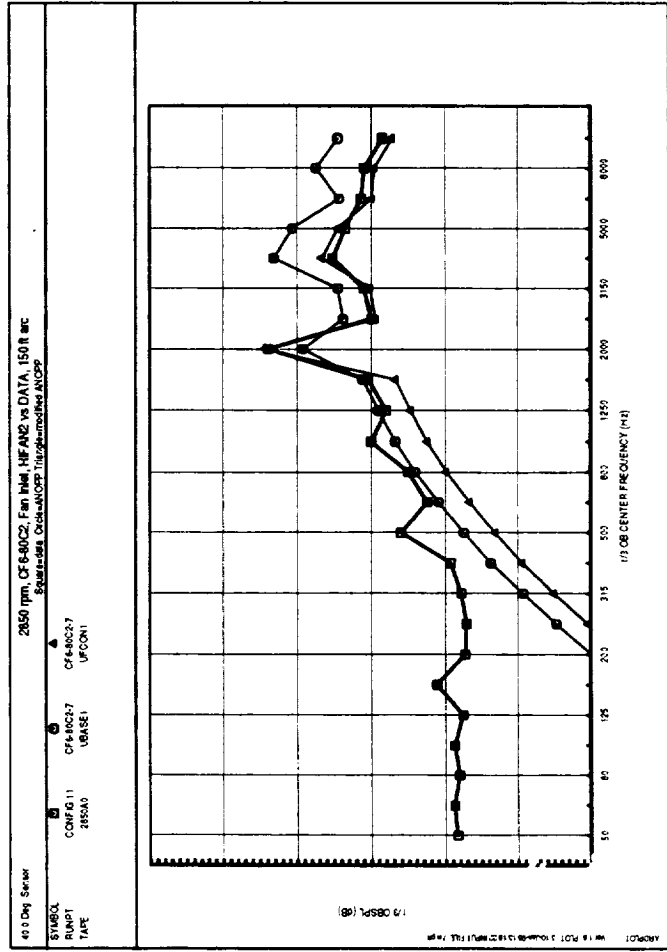
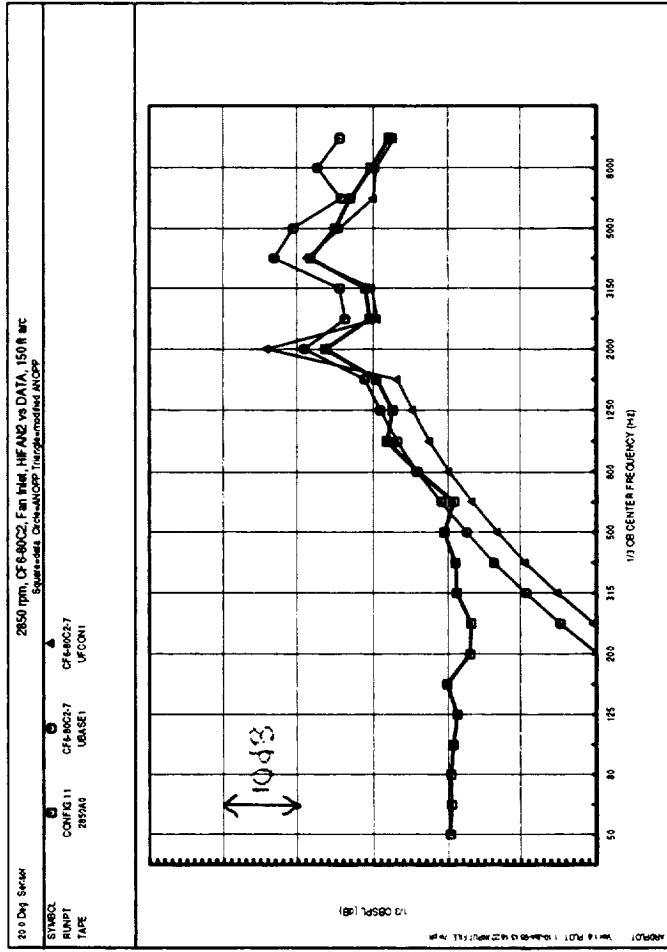
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52	3150 (takeoff)	60-80
53	2850 (cutback)	20-50
54	2850 (cutback)	60-80
55	2700	20-50
56	2700	60-80
57	2550	20-50
58	2550	60-80
59	2250	20-50
60	2250	60-80
61	2100 (approach)	20-50
62	2100 (approach)	60-80

**Key to Plots:**

- squares = total measured engine data
- circles = Heidmann method prediction
- triangles = modified Heidmann method prediction (see Section 4)

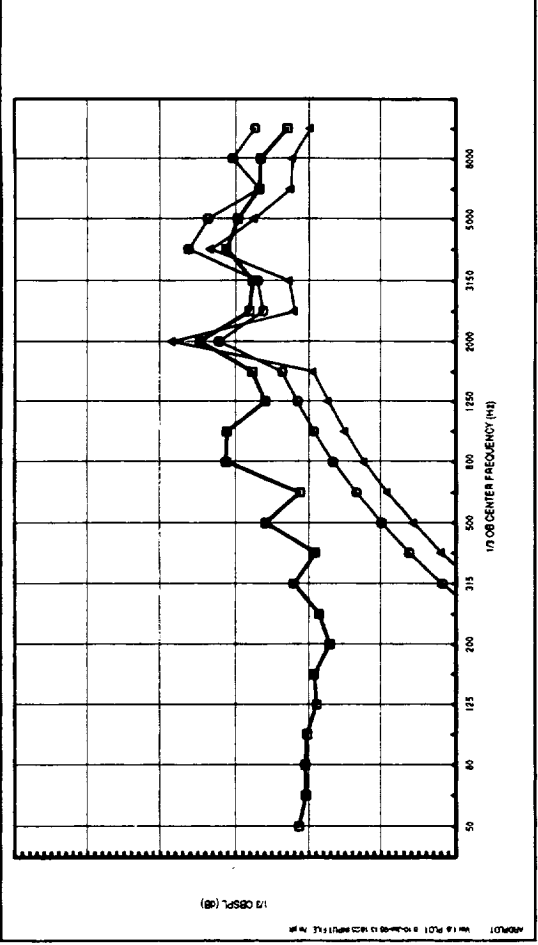






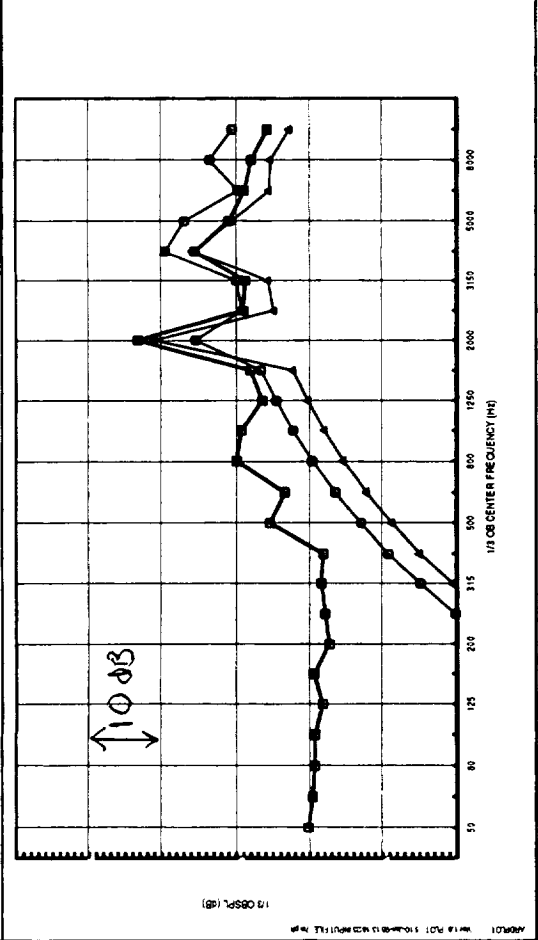
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 Square data, Circle ANOPP Through-modified ANOPP

RUNPT 2850A0  
 TAPE CF-80C2-7  
 UBASE1 UFCO11



800 Dry Sewer  
 SYMBOL 2850 rpm, CF-80C2, Fan Inlet, HF AN2 vs DATA, 150 ft ac  
 Square data, Circle ANOPP Through-modified ANOPP

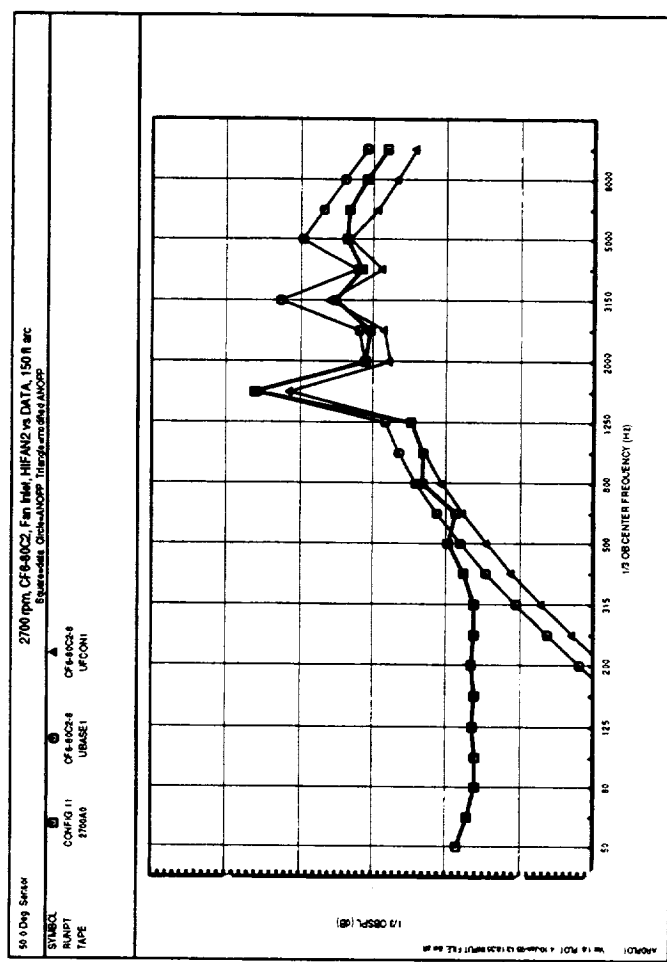
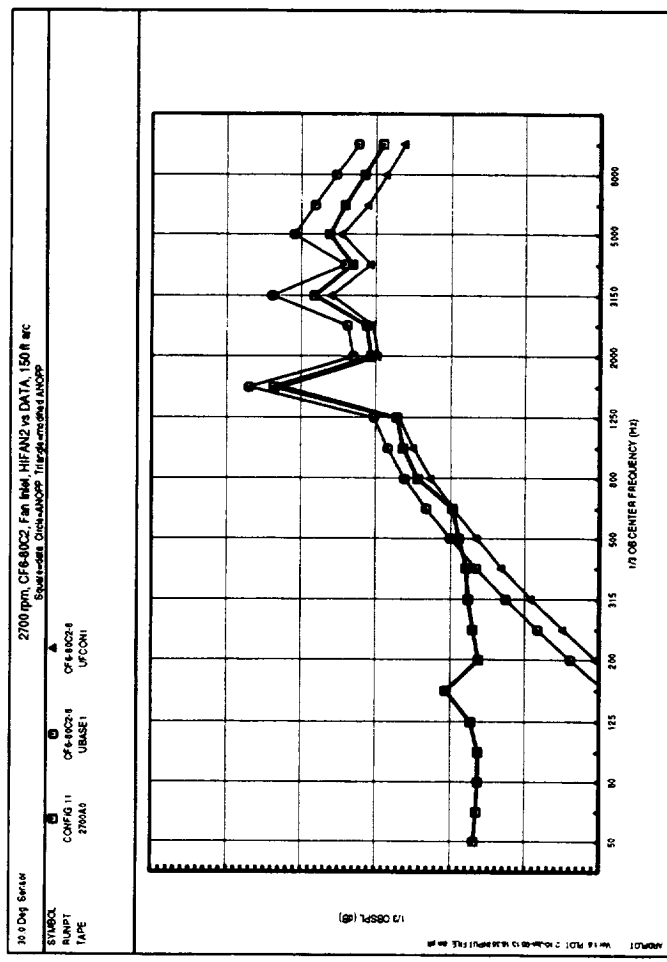
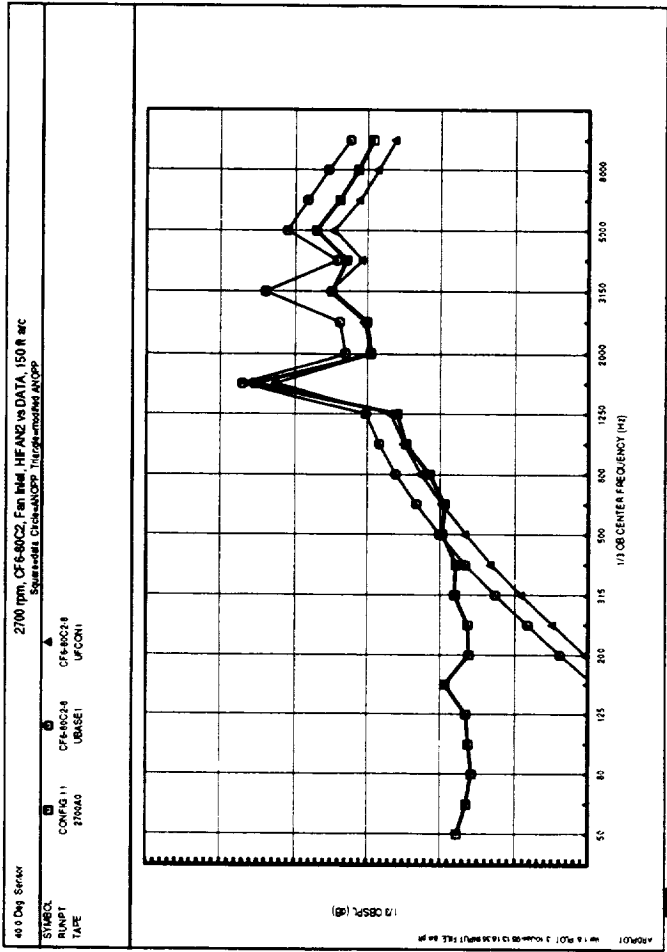
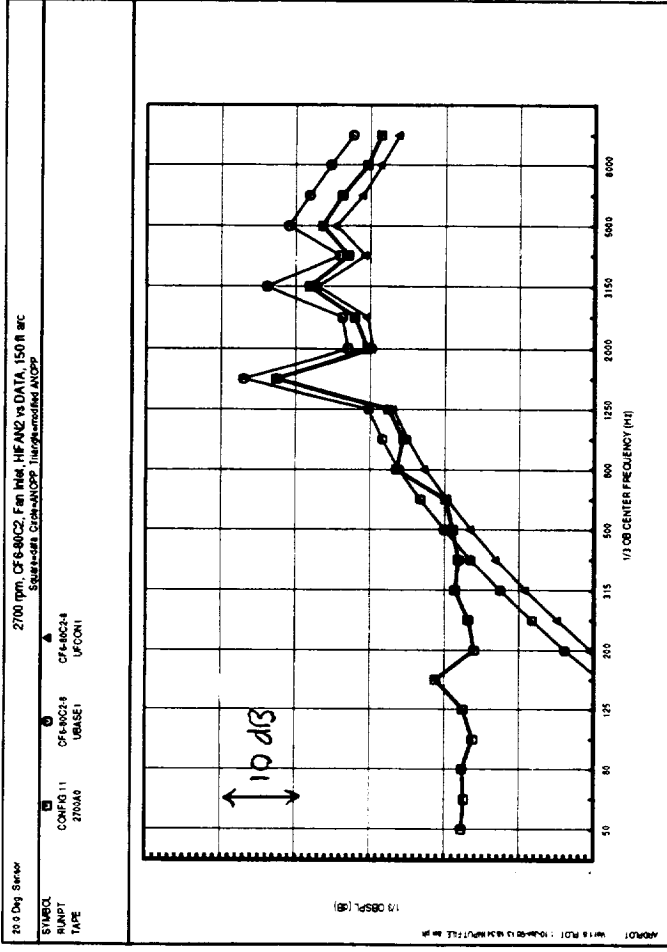
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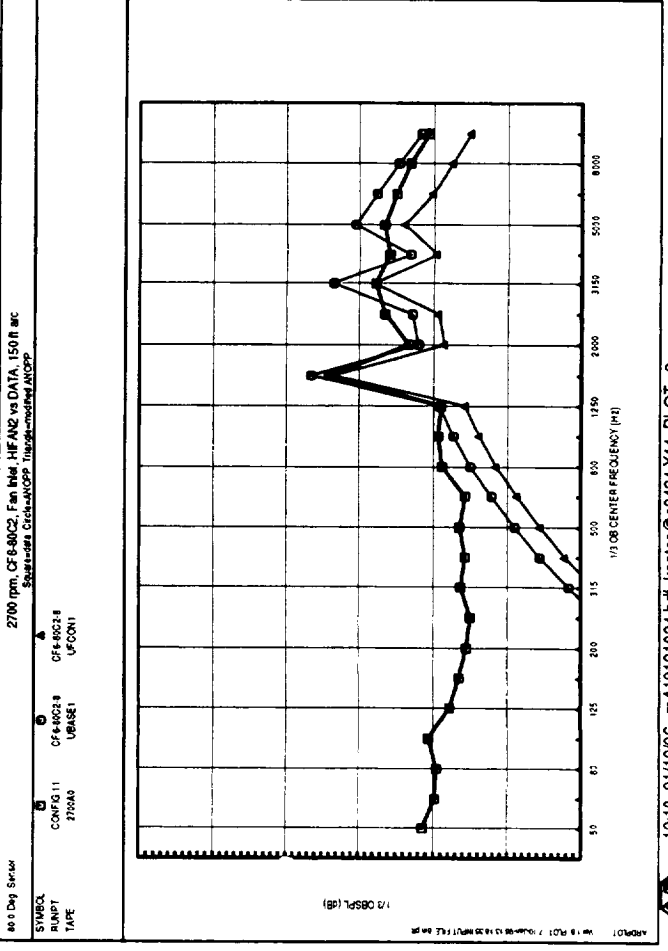
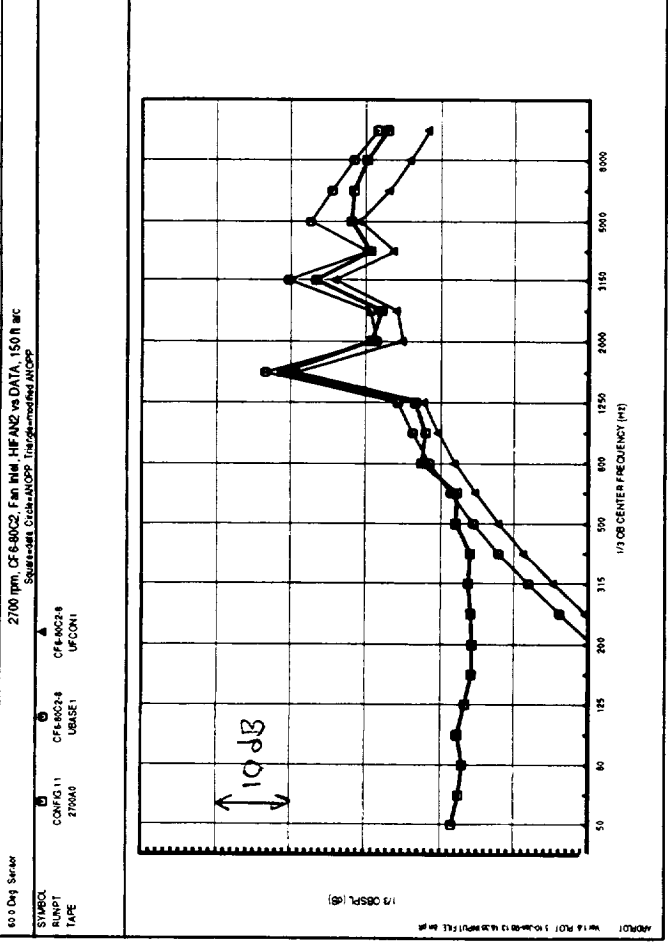
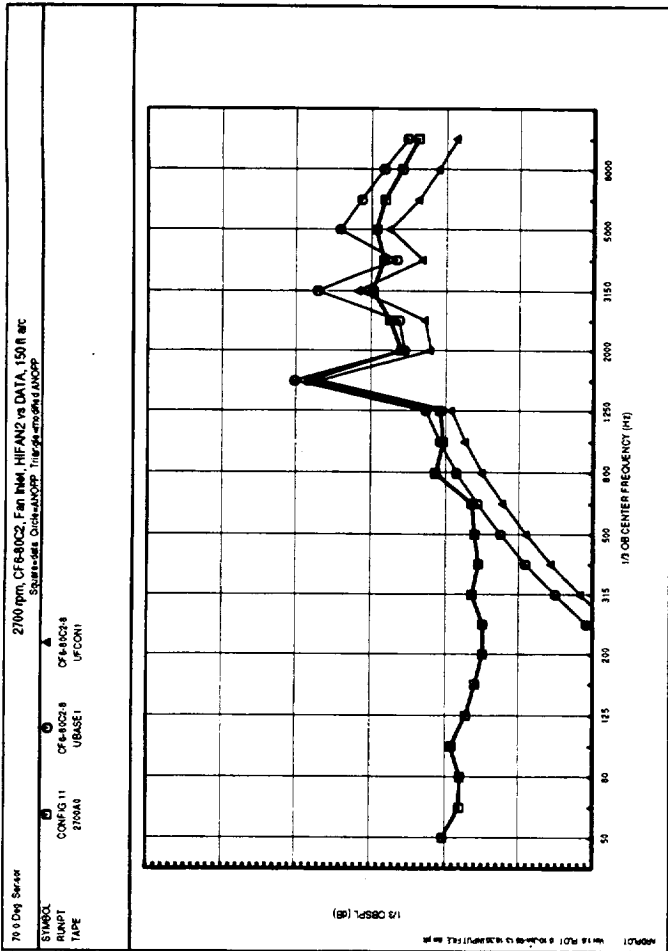


800 Dry Sewer  
 SYMBOL 2850 rpm, CF-80C2, Fan Inlet, HF AN2 vs DATA, 150 ft ac  
 Square data, Circle ANOPP Through-modified ANOPP

RUNPT 2850A0  
 TAPE CF-80C2-7  
 UBASE1 UFCO11

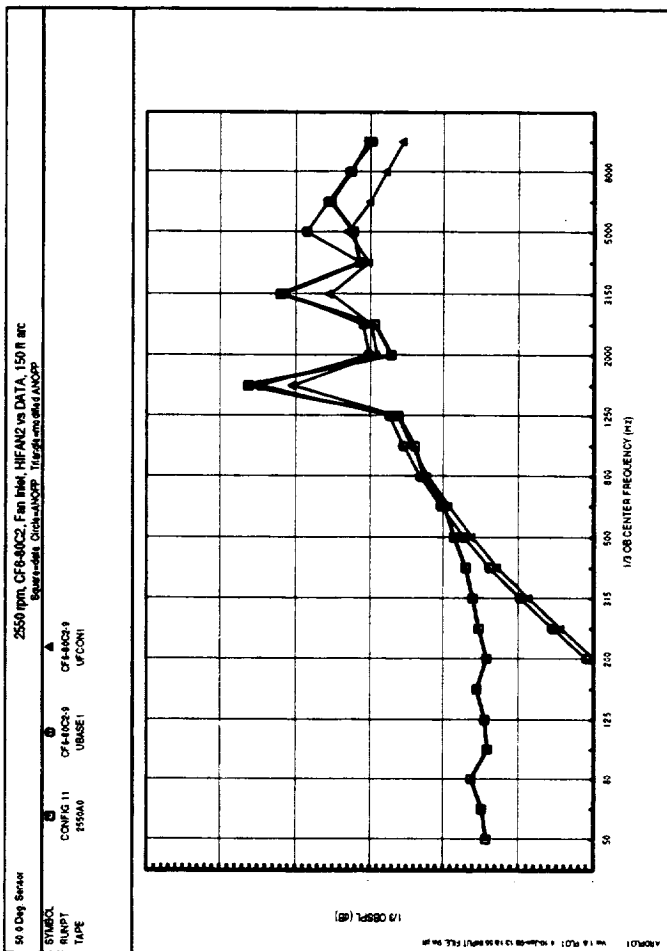
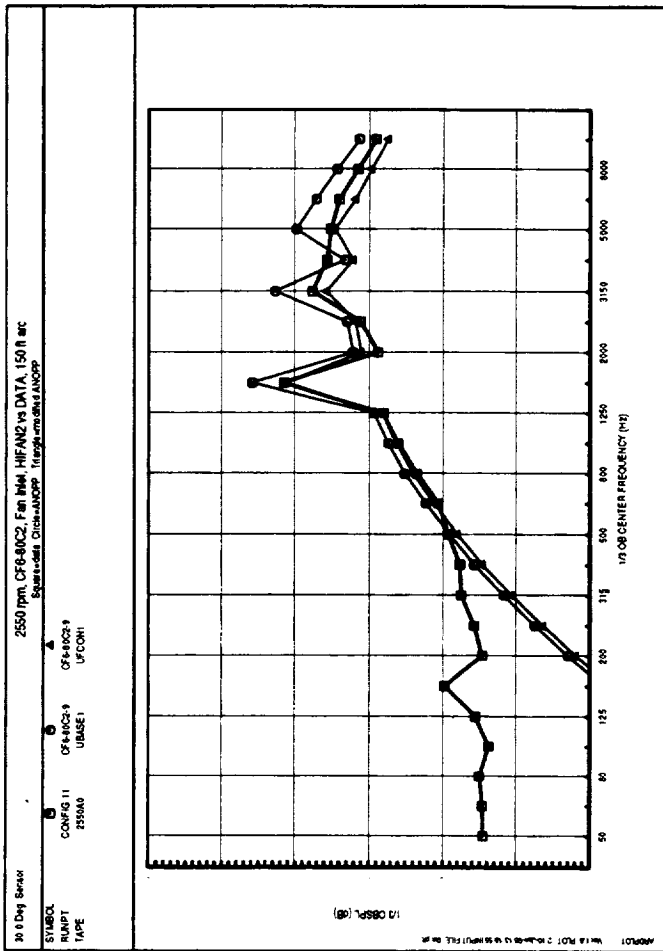
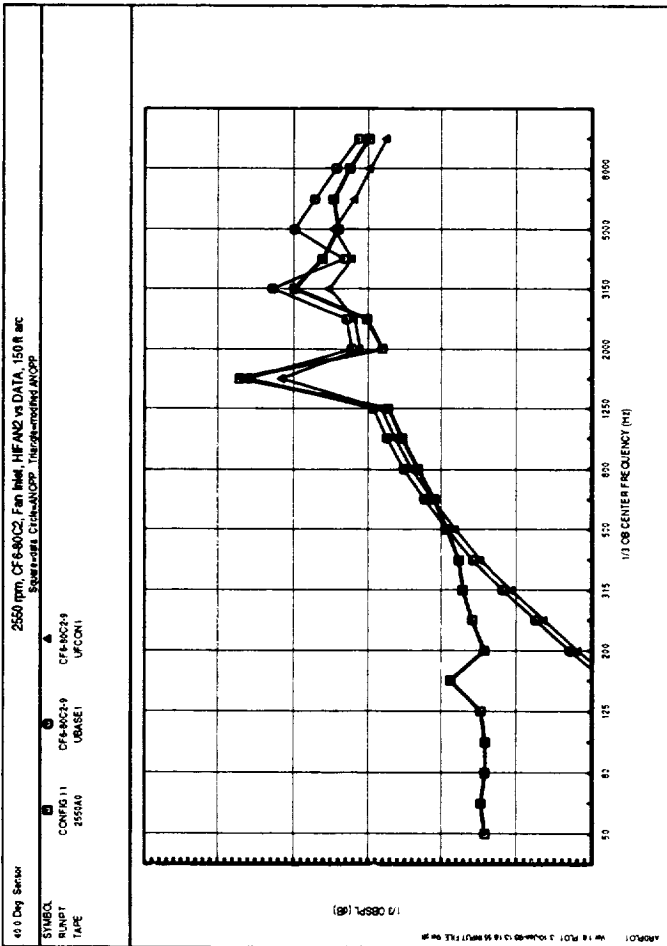
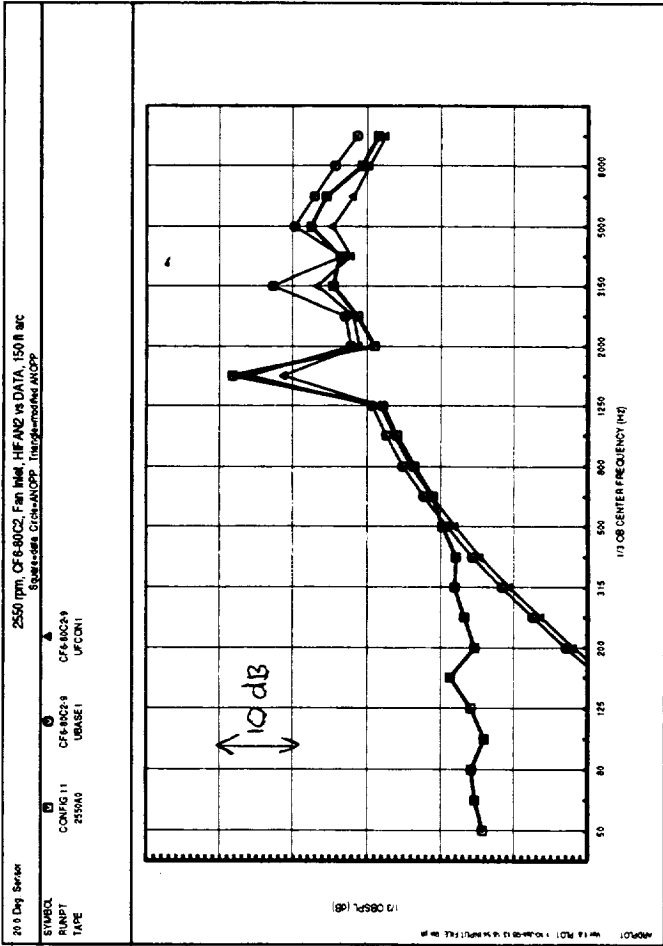




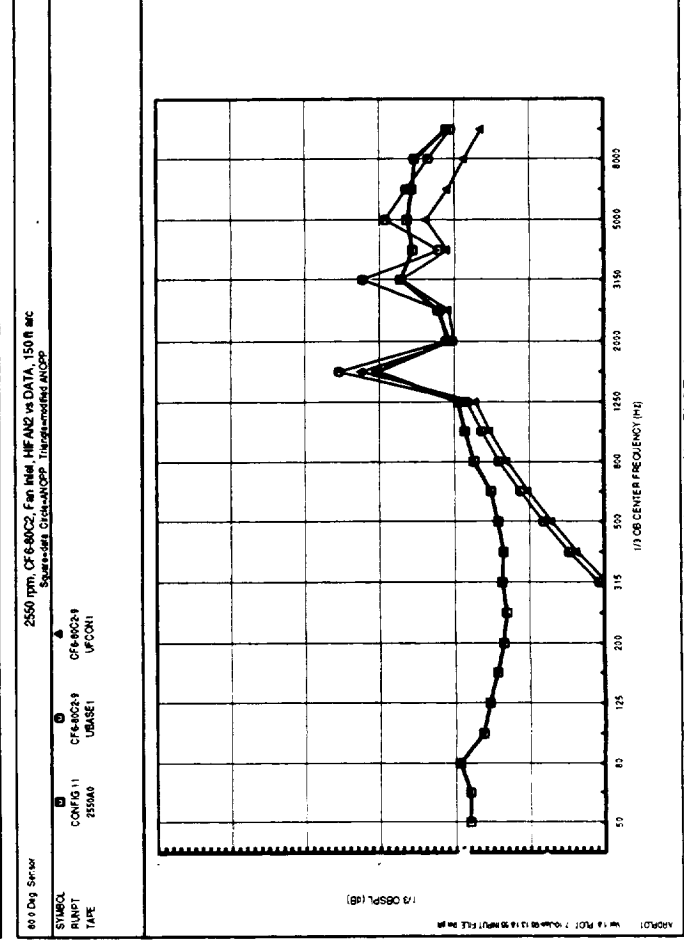
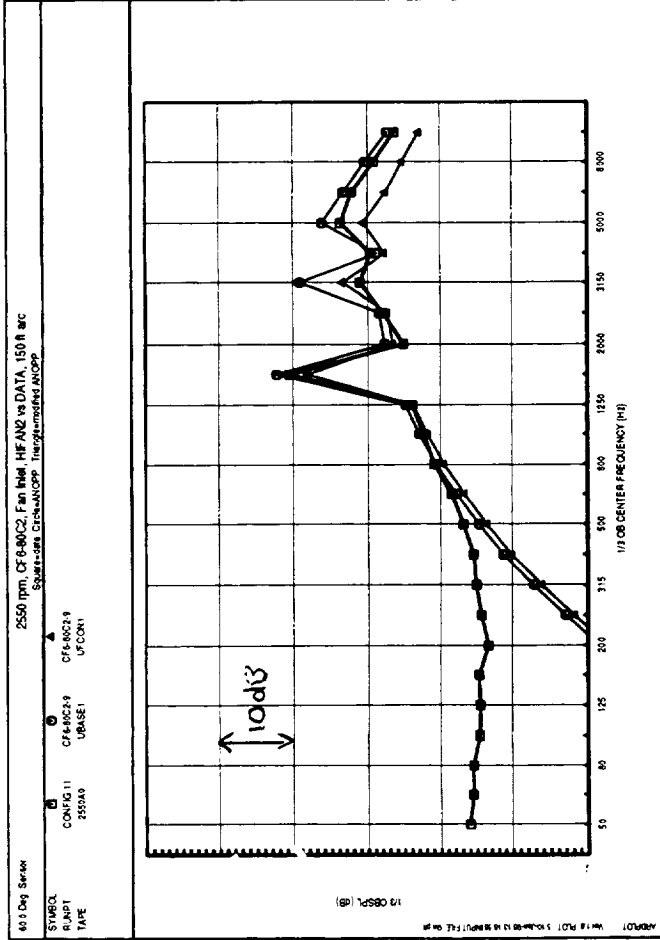
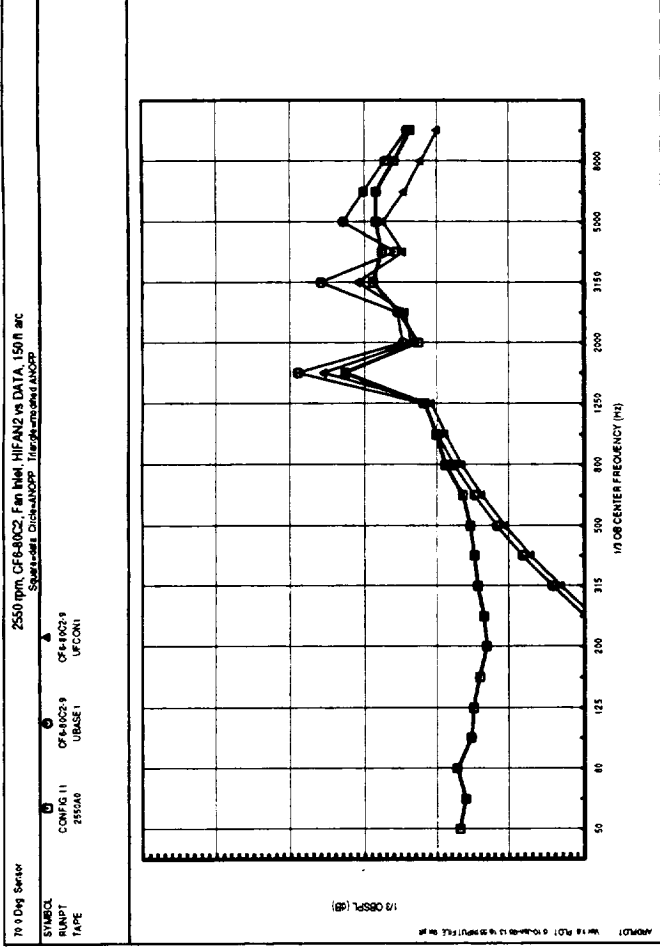


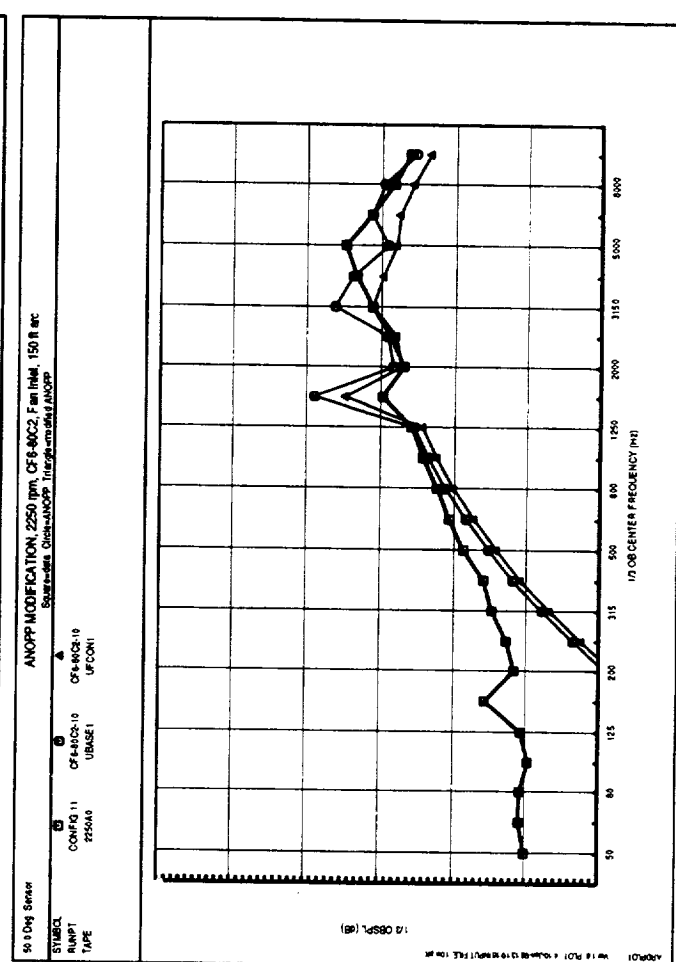
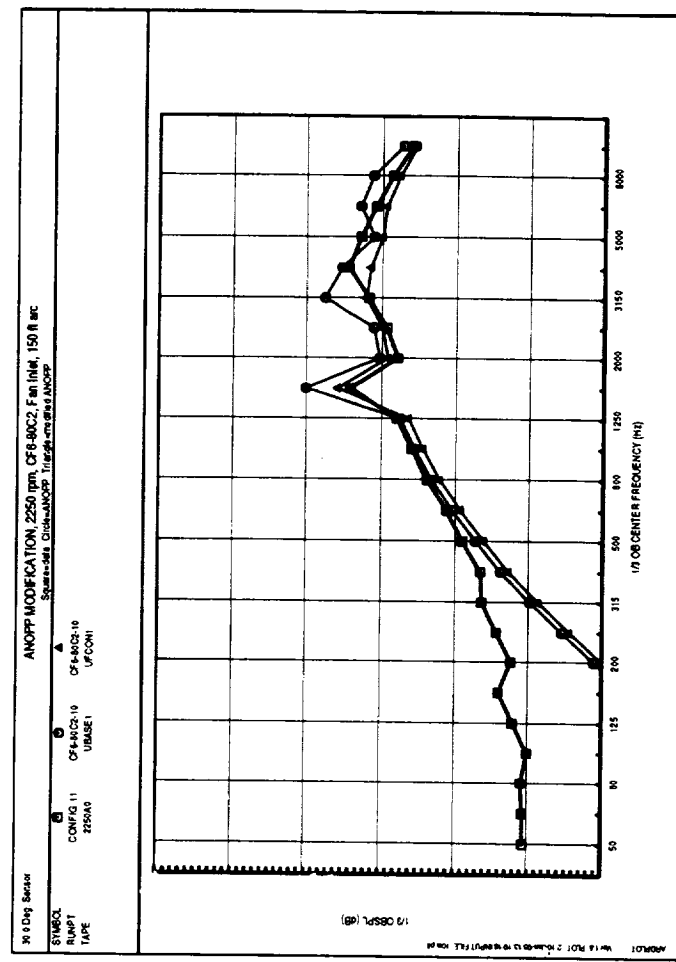
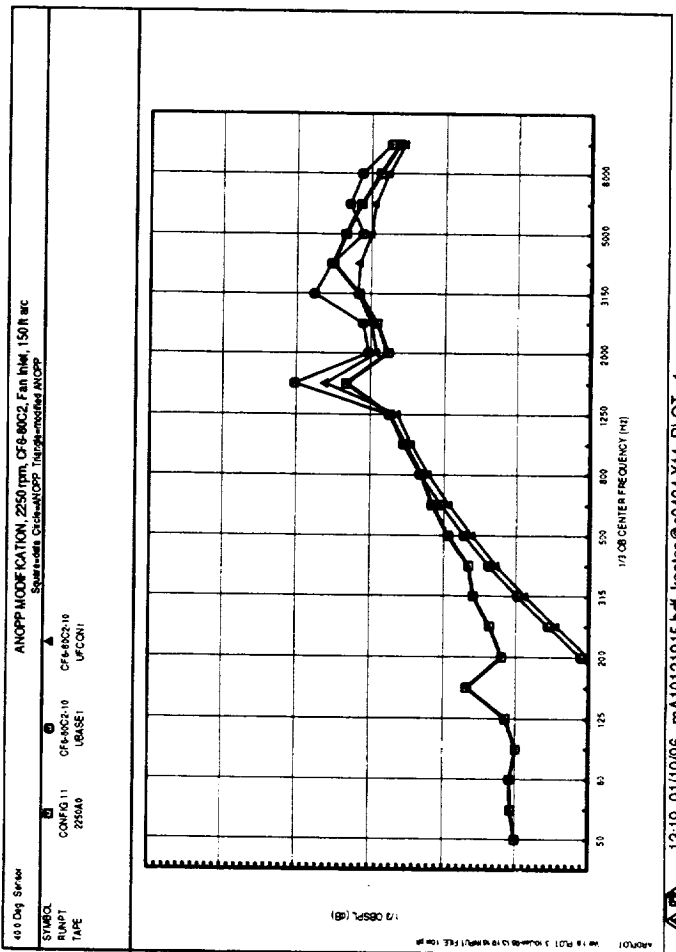
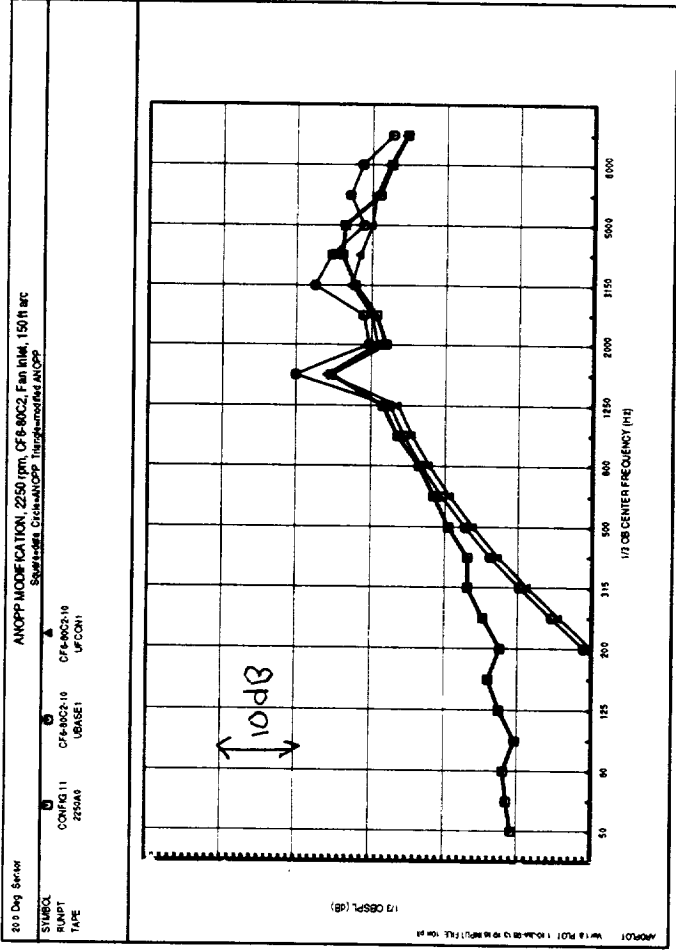
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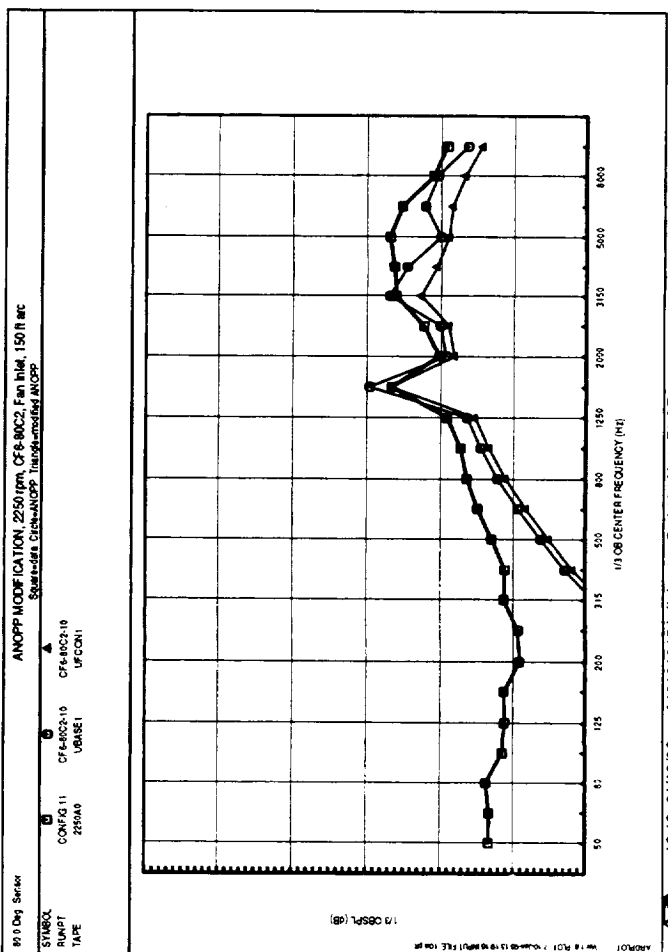
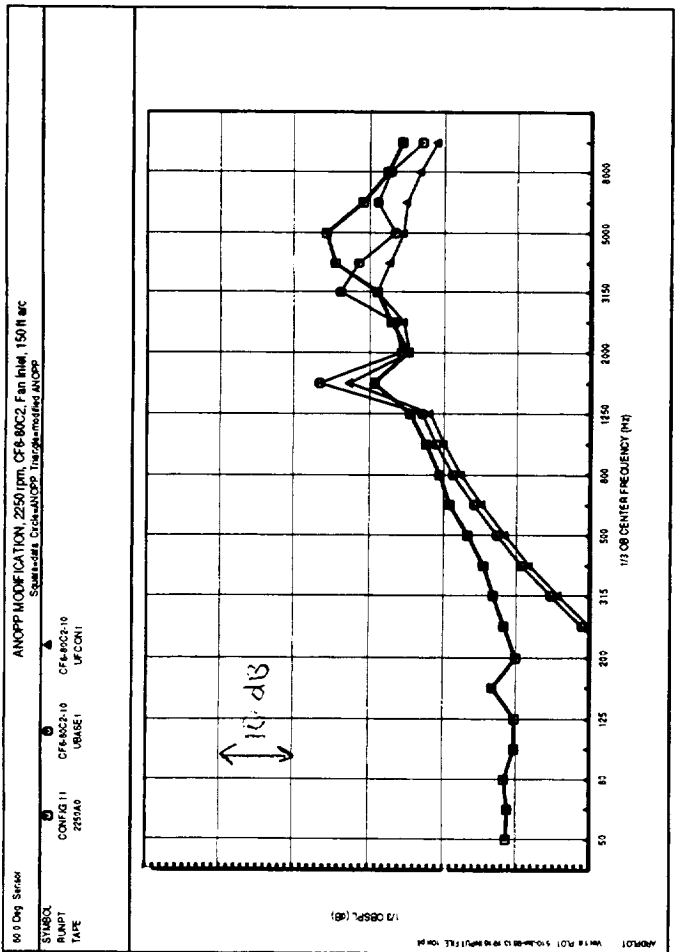
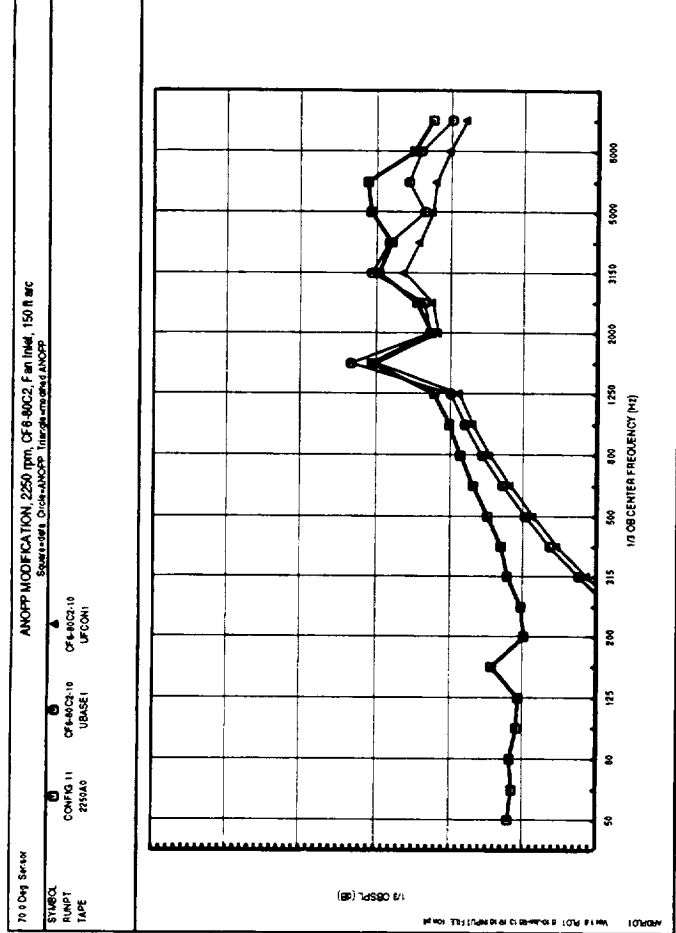


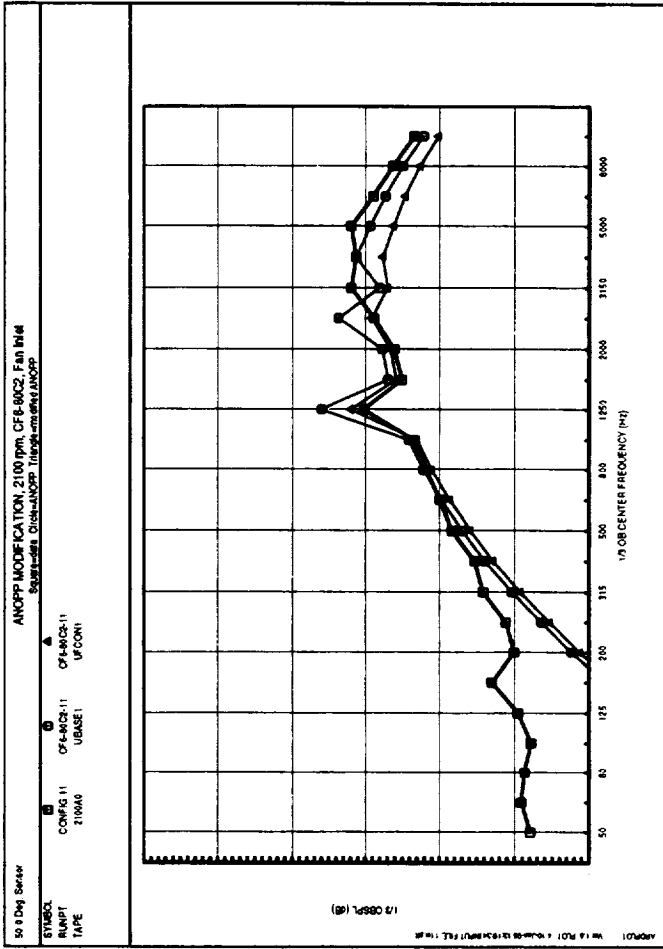
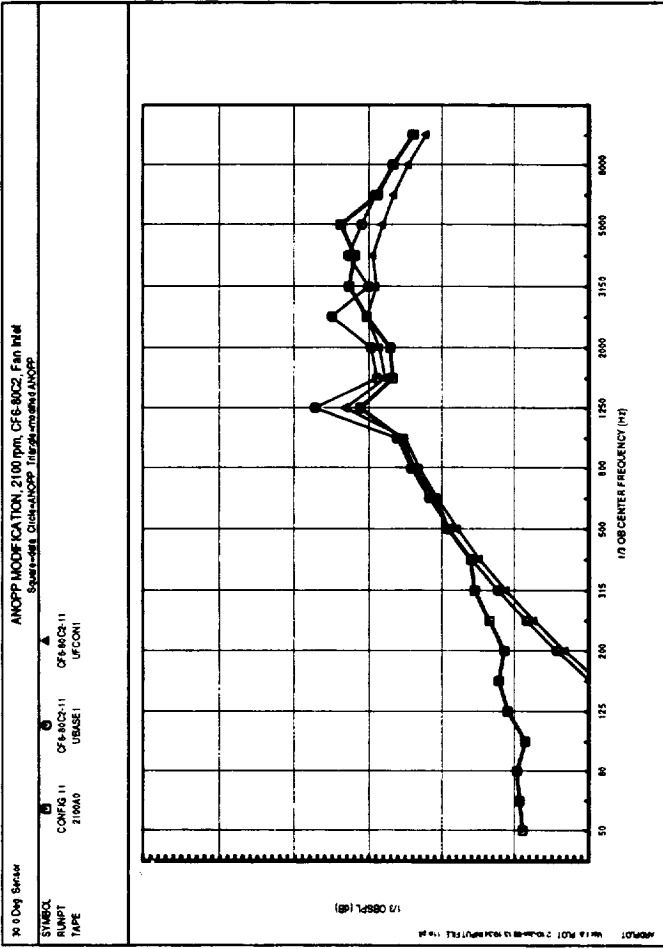
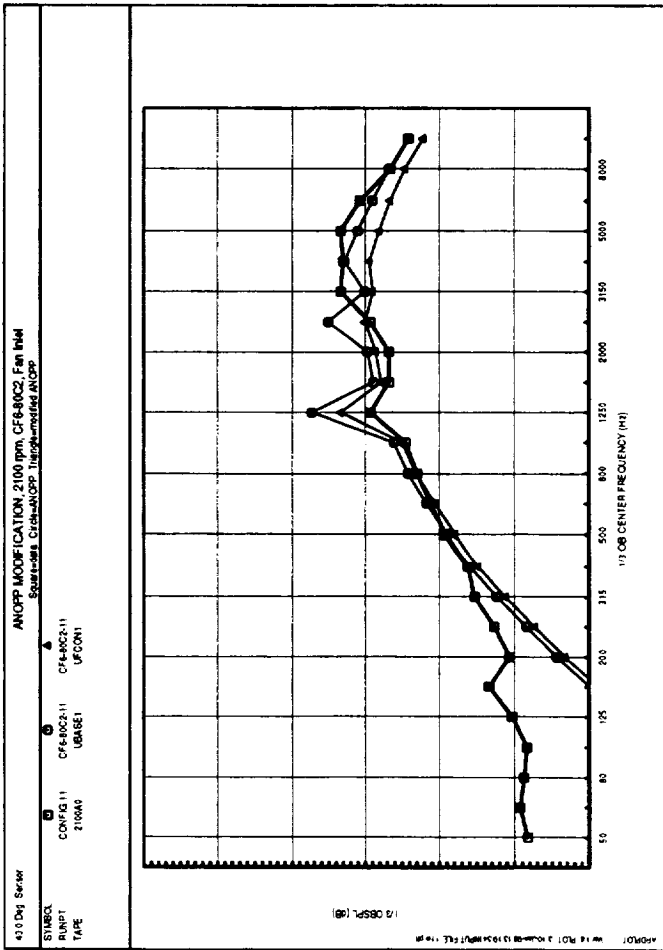
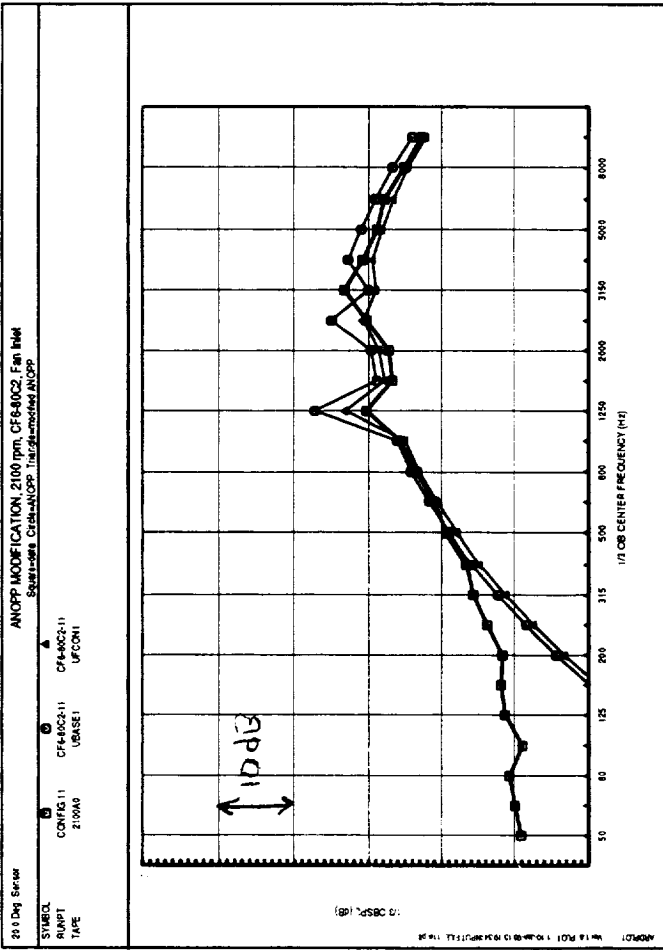


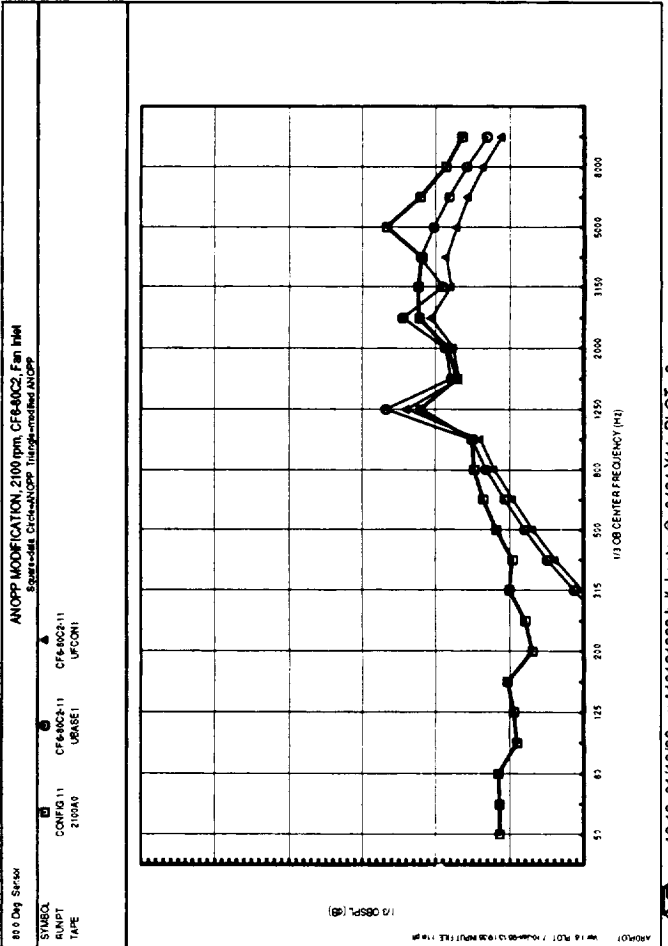
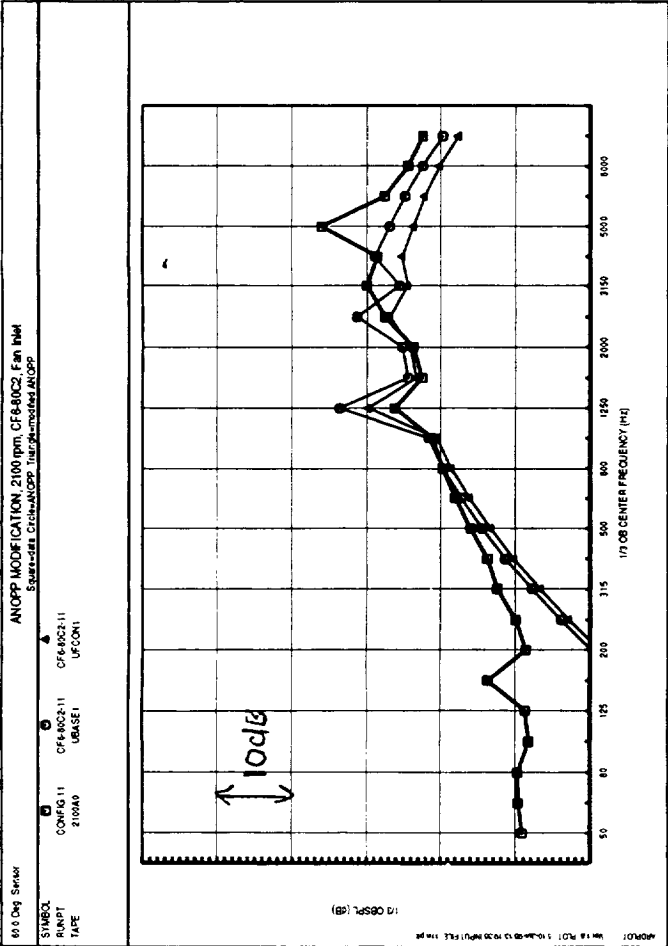
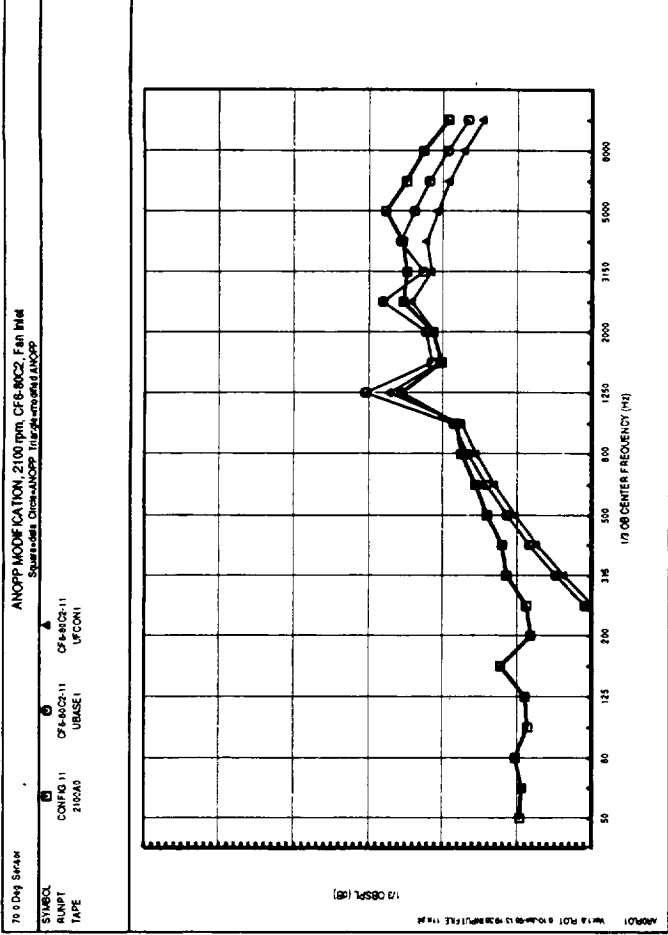












13:19 01/10/96 MA10131933.bdf Konlos@c0424.X11.PLOT\_2  
 EGS LIB 5.1 12/14/95 EGSREP.XPOST 5.1 12/14/95 on c0424)  
 (NO PROG. VER. SPECIFIED)



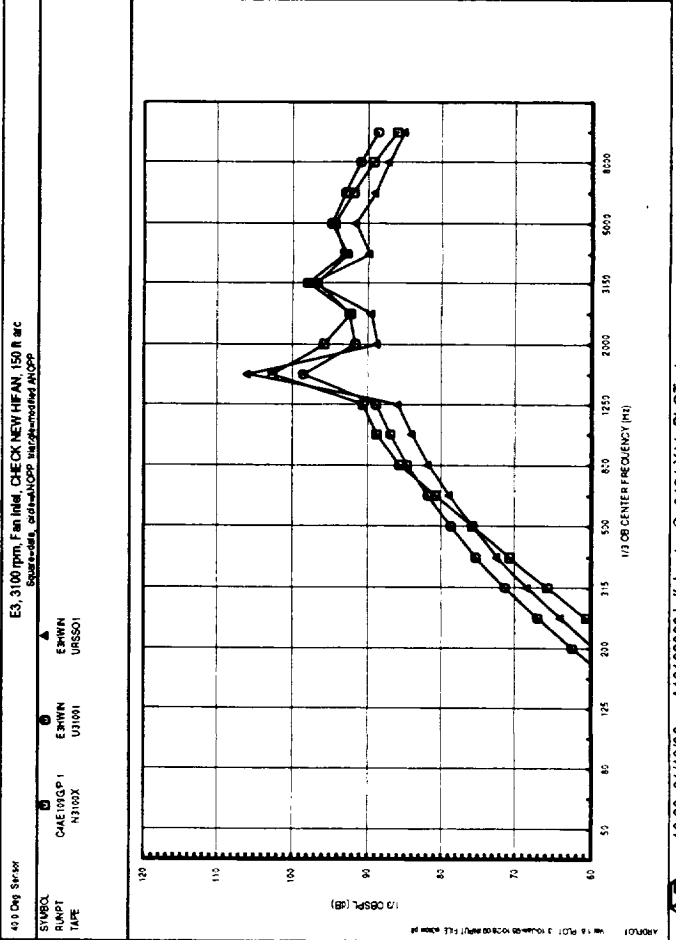
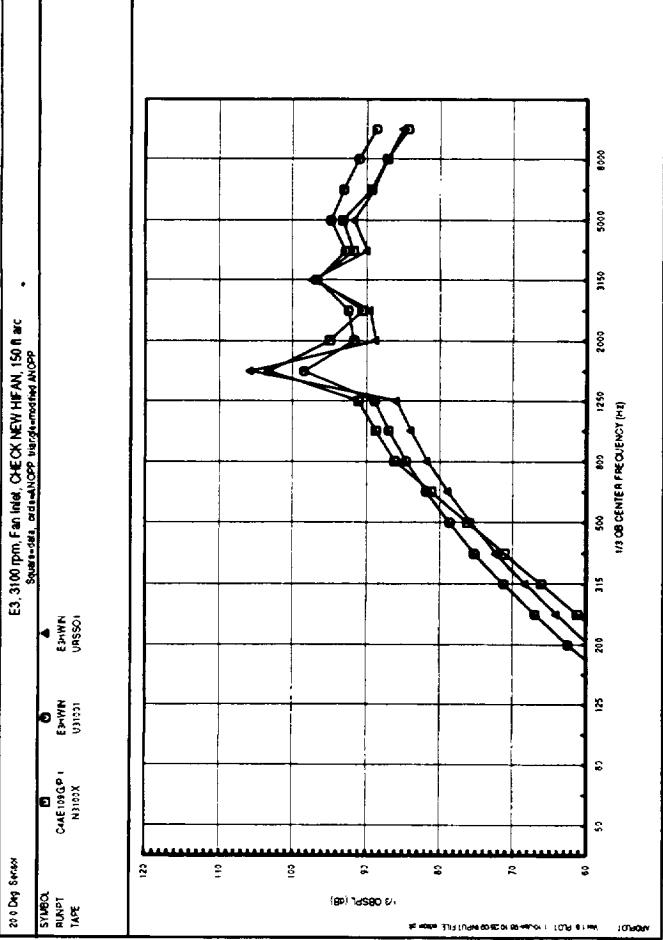
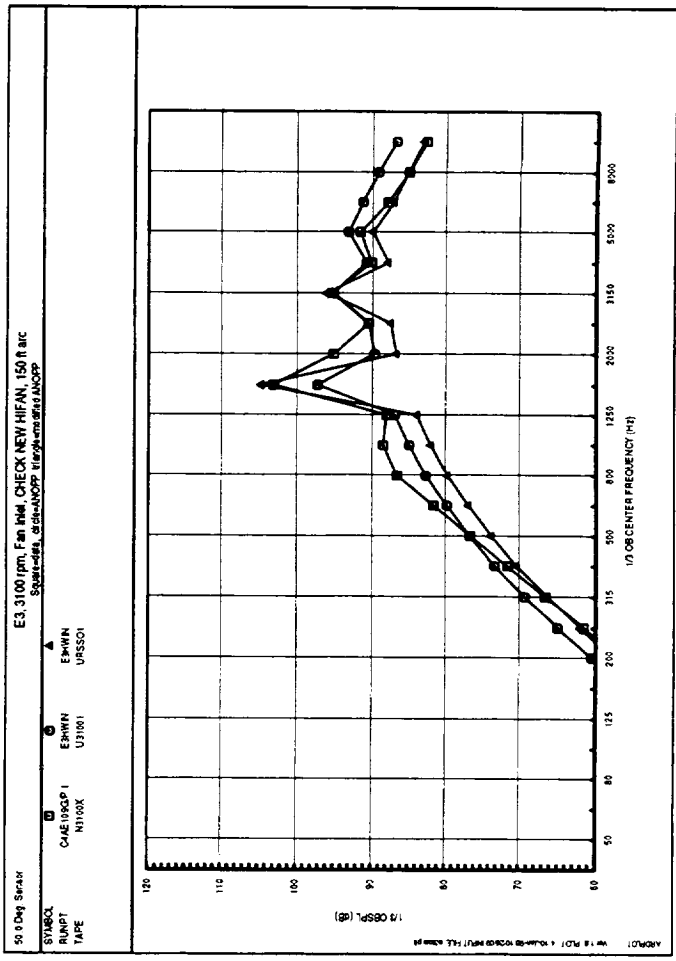
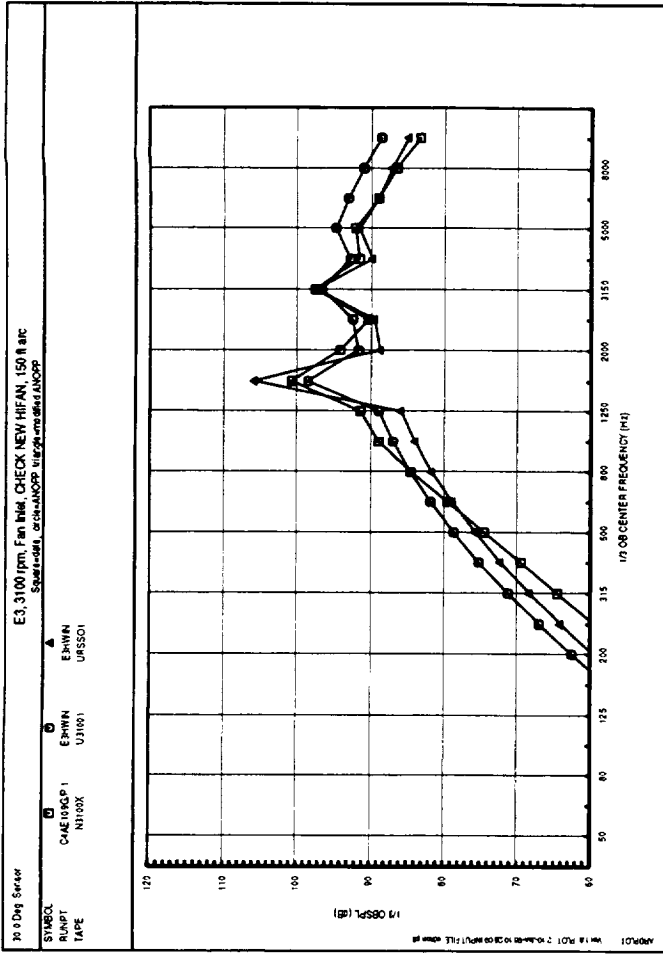
**Appendix C**  
**Fan Inlet Noise Spectral Comparisons - E<sup>3</sup>**

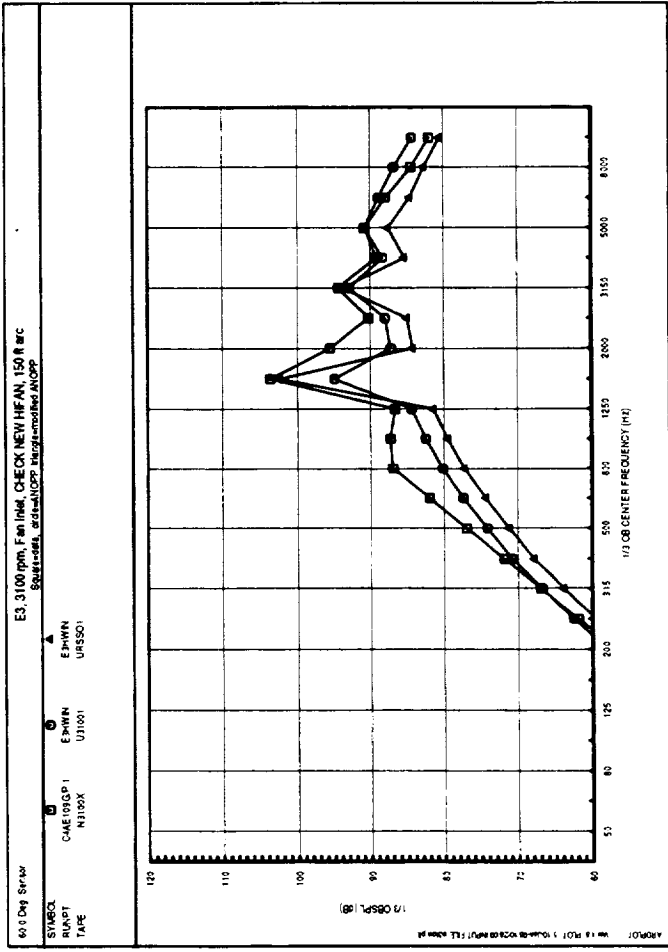
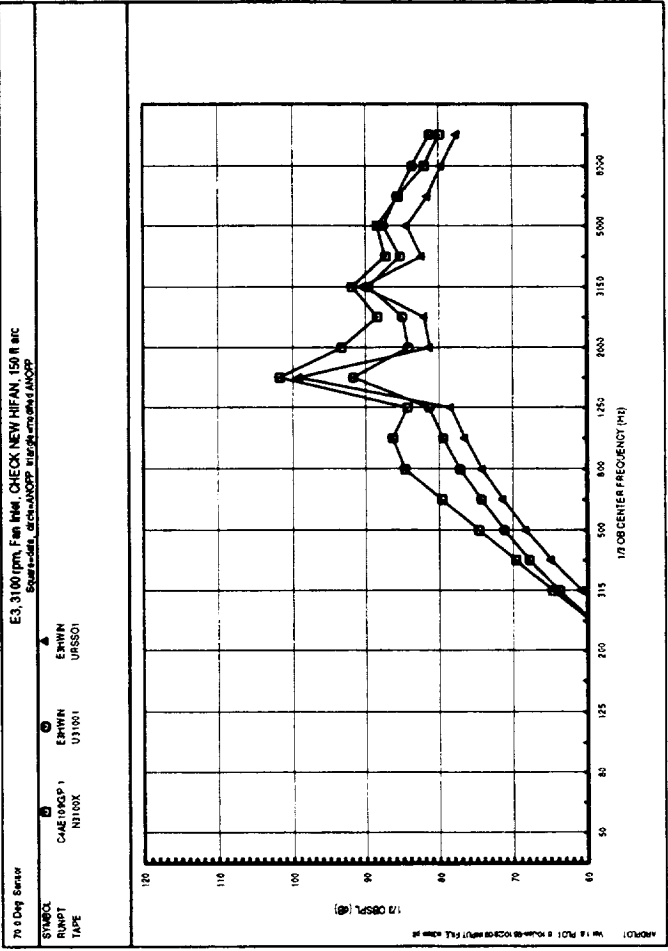
**Appendix C Contents**

<b>Page</b>	<b>Fan Speed, rpm</b>	<b>Angles, deg</b>
64	3100 (takeoff)	20-50
65	3100 (takeoff)	60-70
66	2800 (cutback)	20-50
67	2800 (cutback)	60-70
68	1820 (approach)	20-50
69	1820 (approach)	60-70

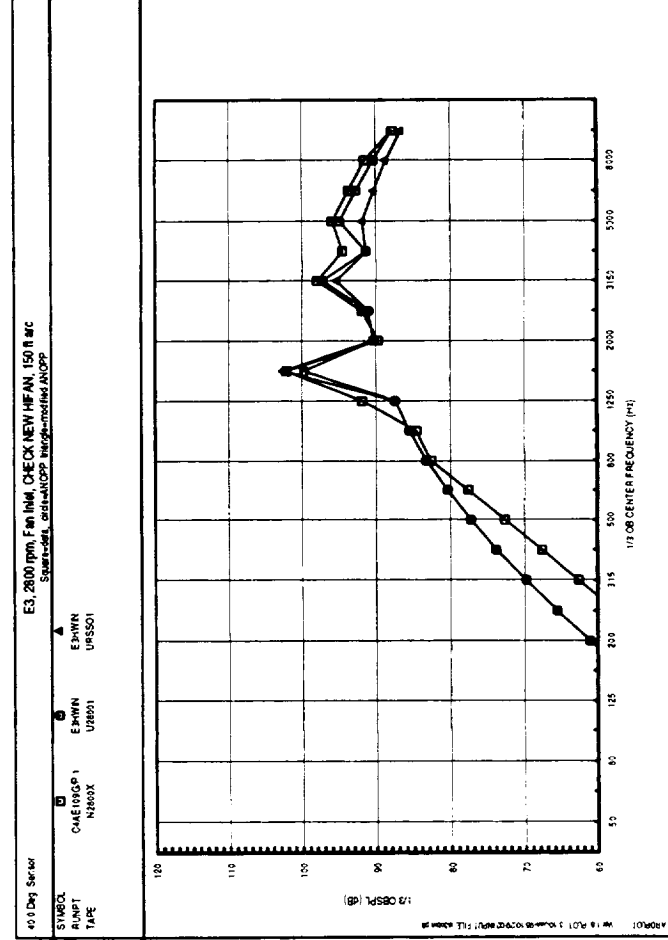
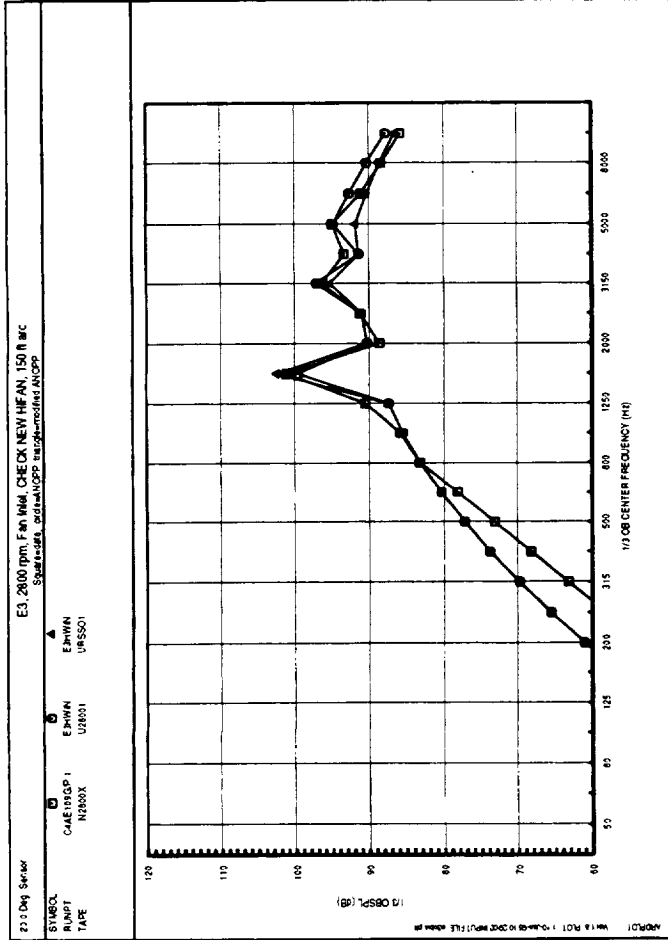
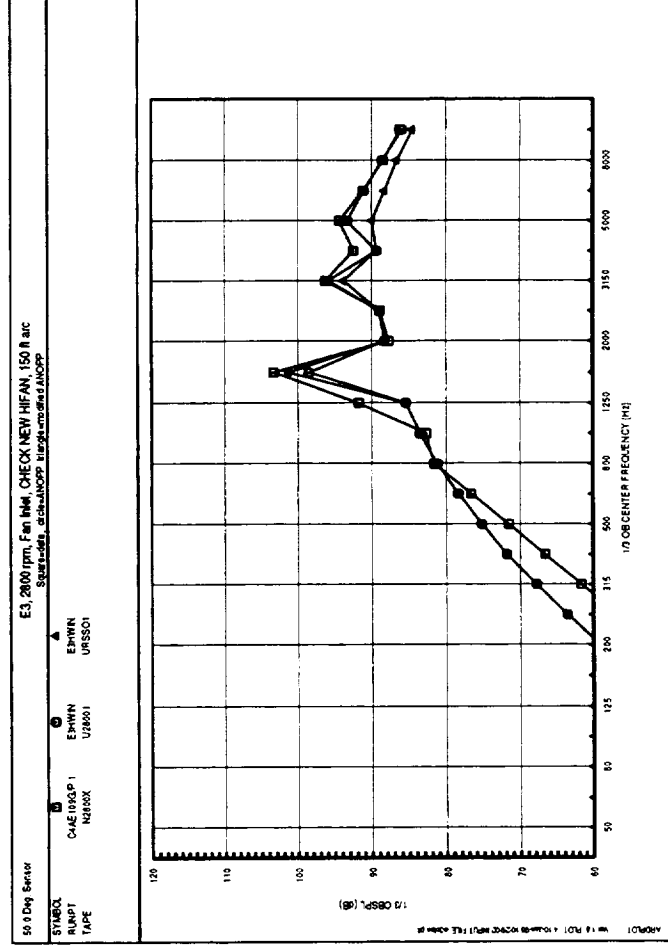
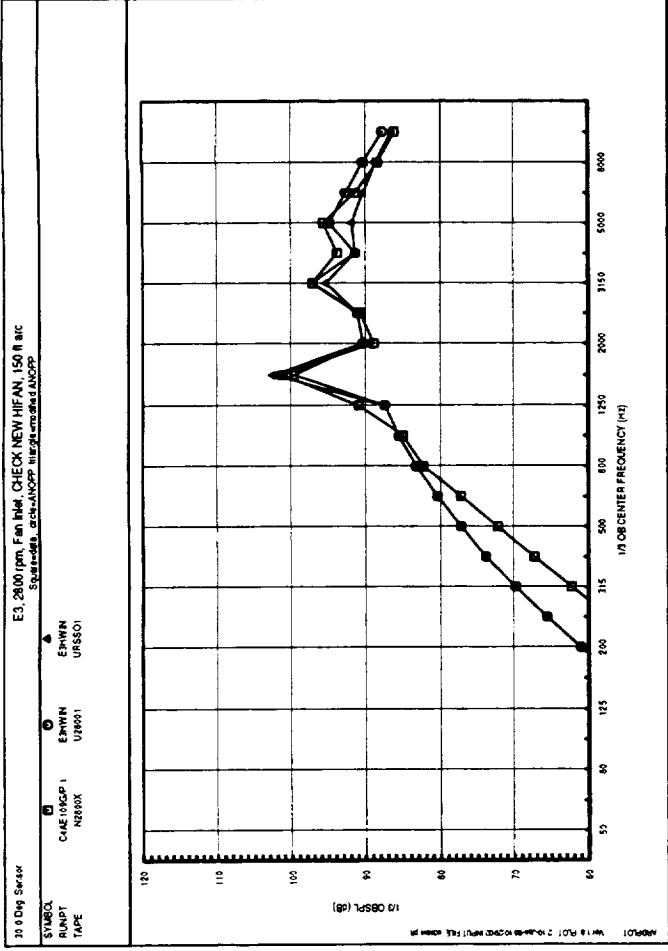
**Key to Plots:**

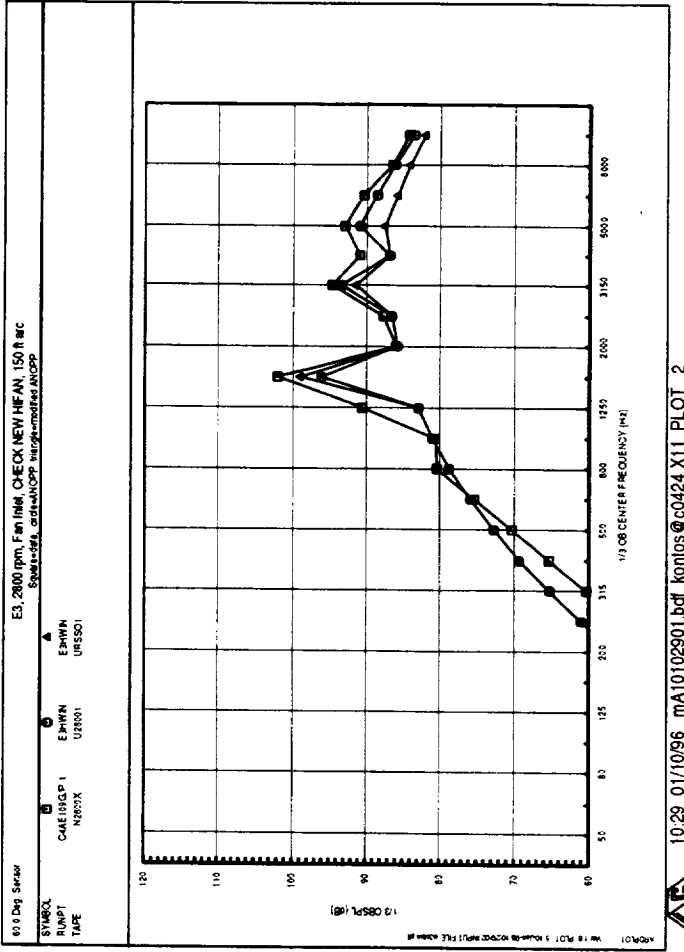
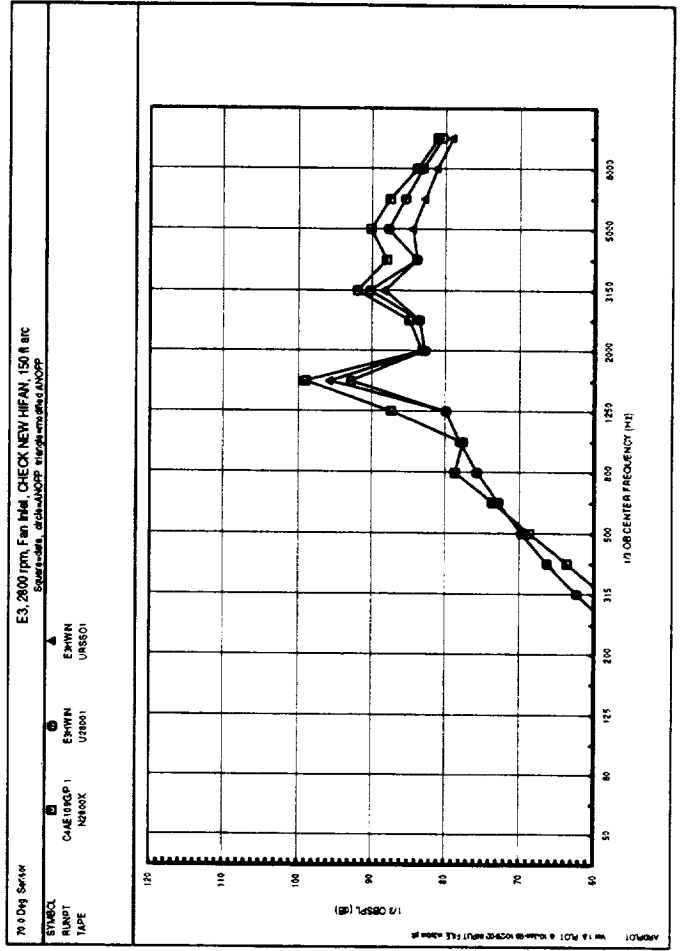
squares = total measured engine data  
circles = Heidmann method prediction  
triangles = modified Heidmann method prediction (see Section 4)

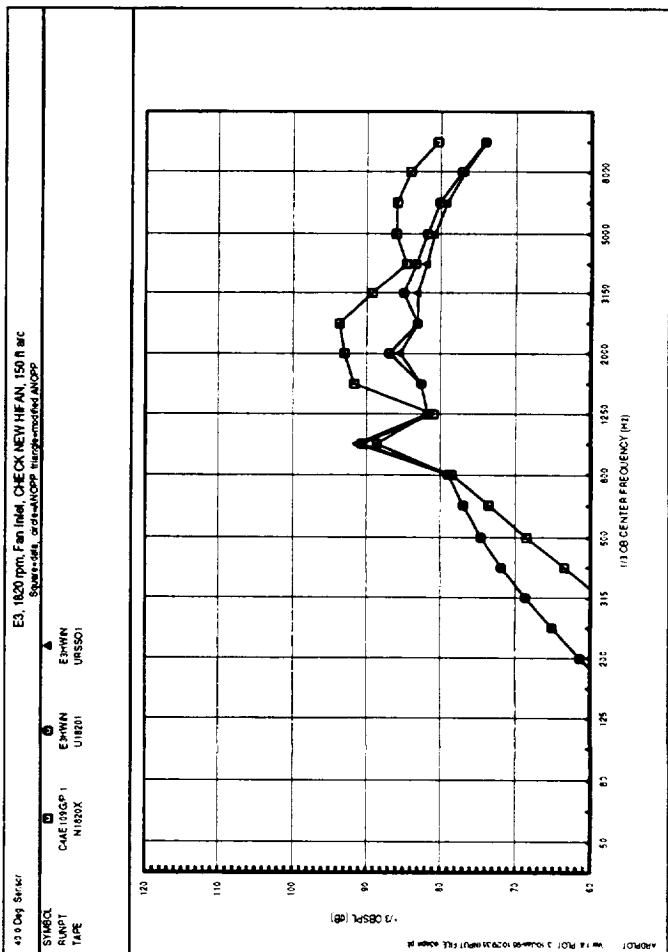
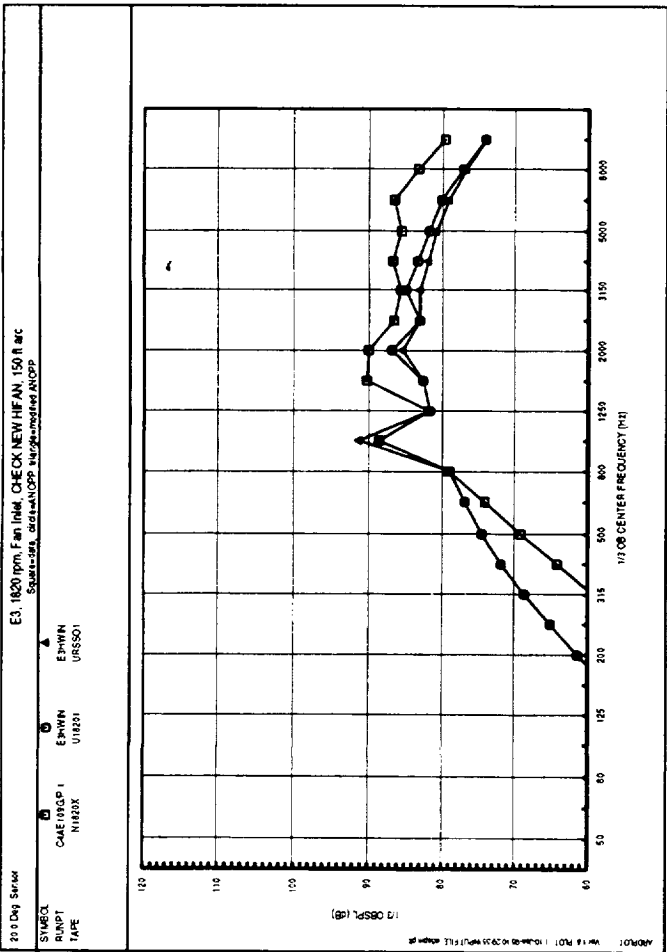
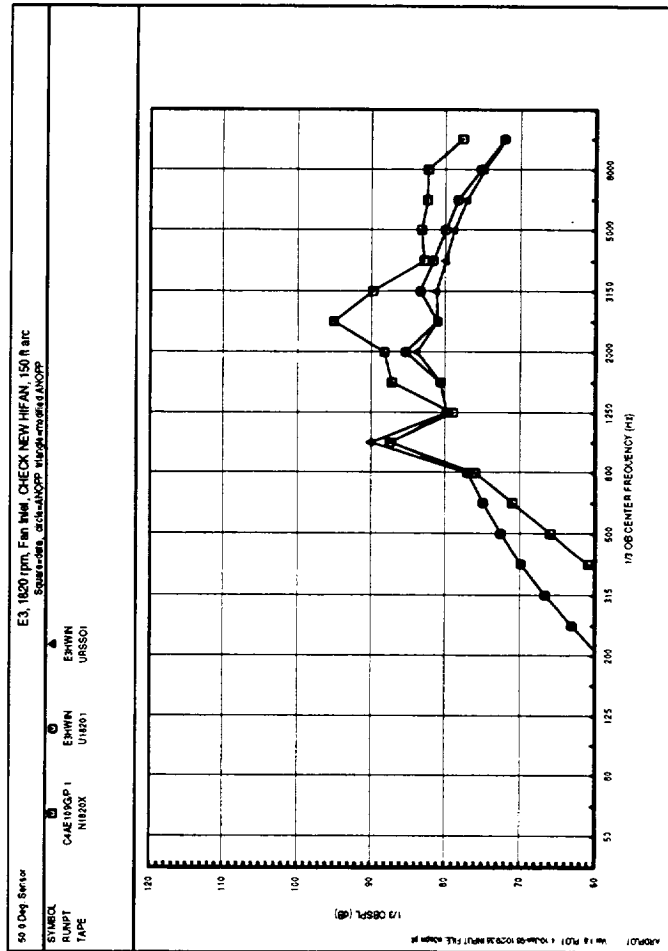
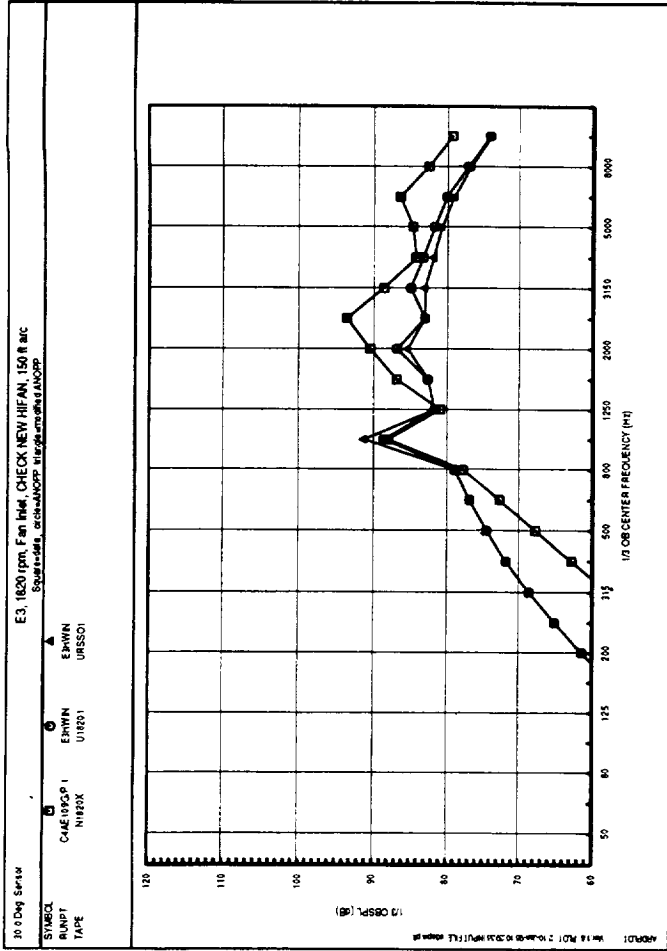






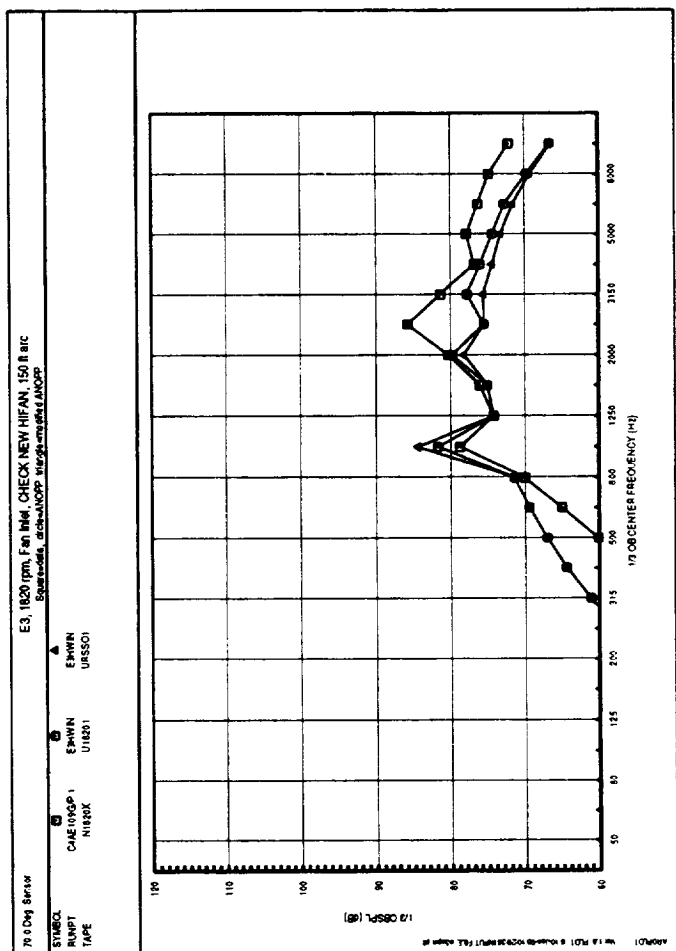
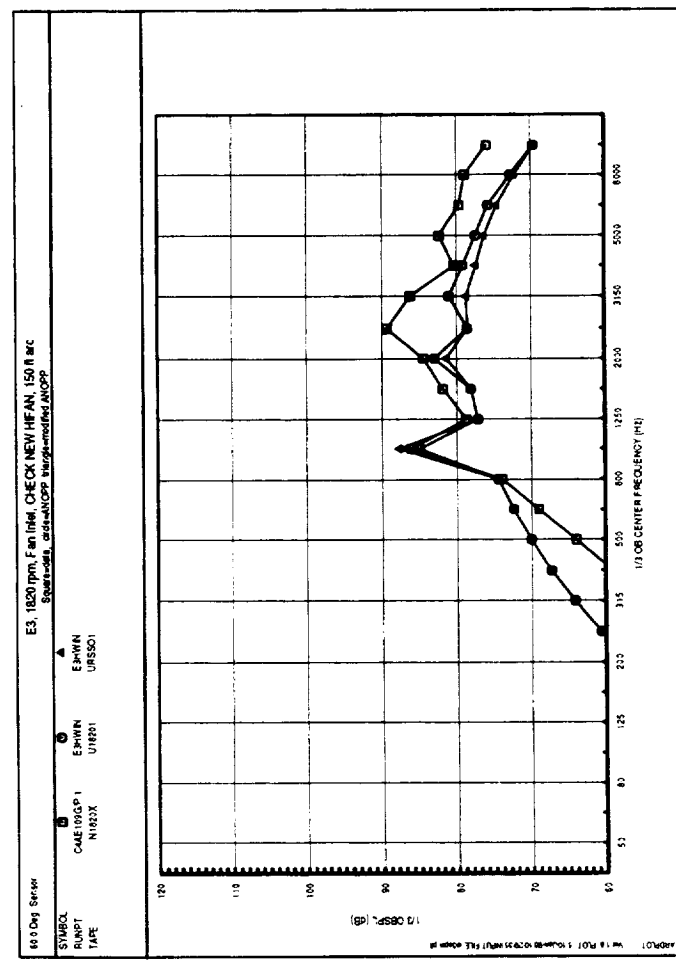






10-20 01/10/95 ma10102024 bdf kontus@c0424 X11 PLOT 1  
 EGS LIB 5.1 12/14/95 LEGSREP.XPOST 5.1 12/14/95 on c0424)  
 (NO PROG. VER. SPECIFIED)





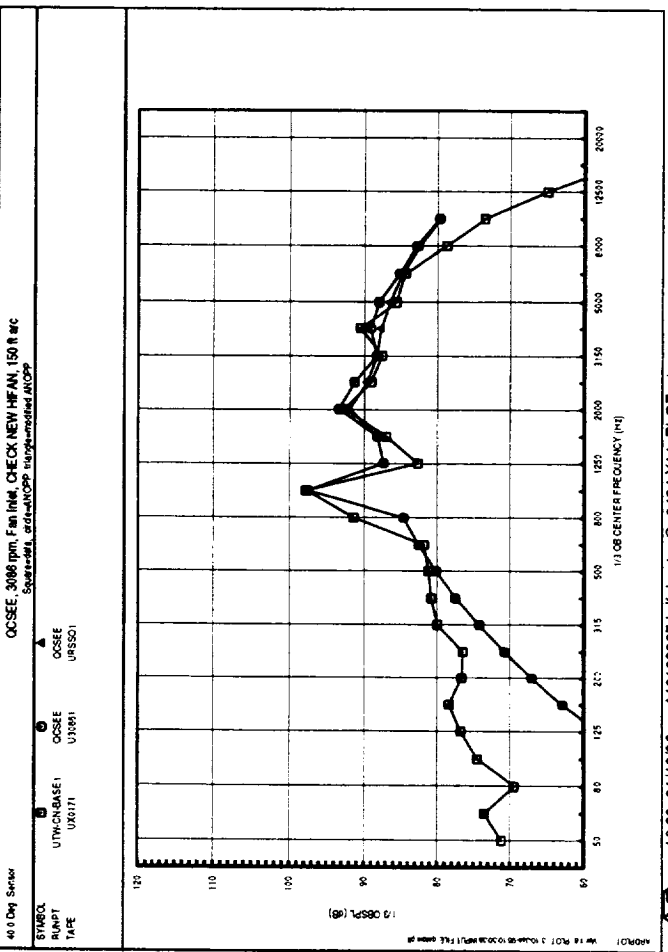
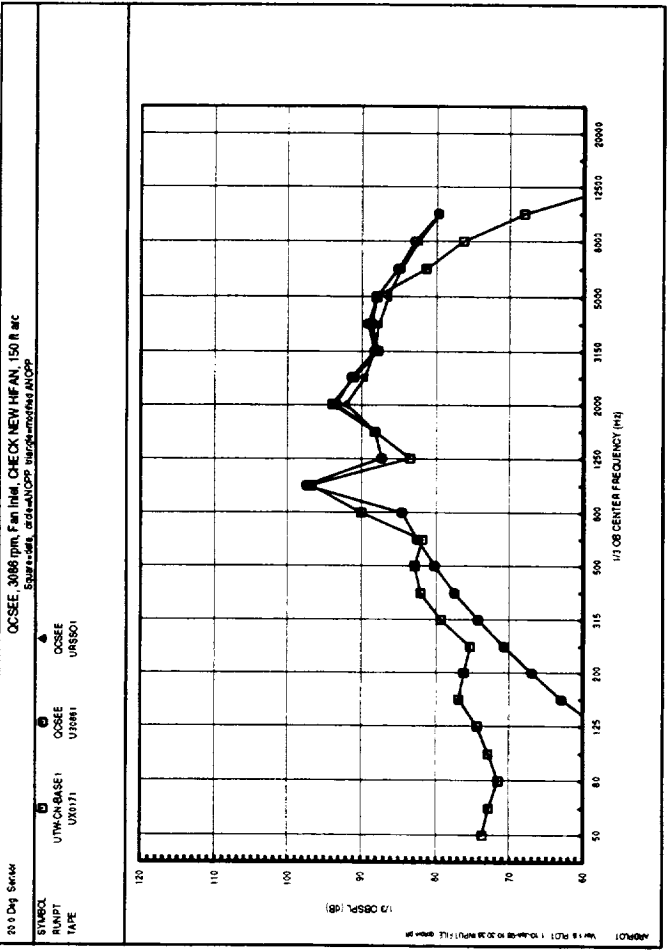
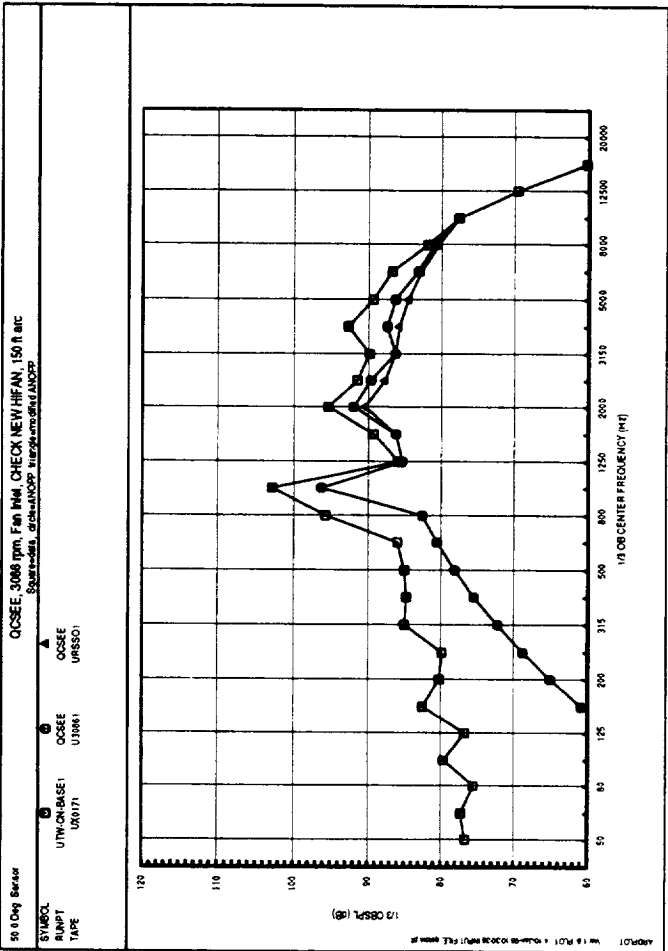
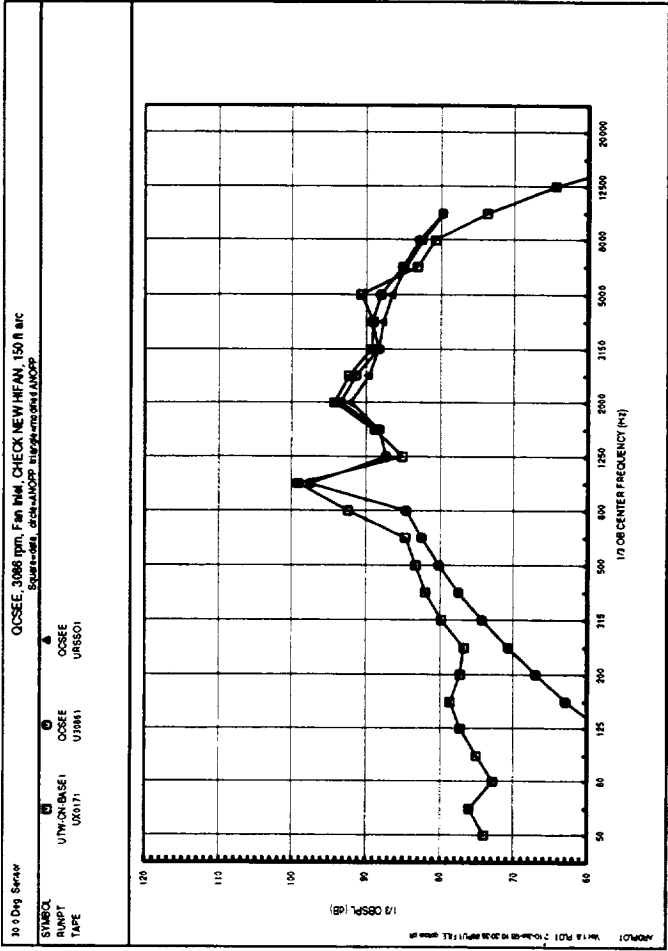
**Appendix D**  
**Fan Inlet Noise Spectral Comparisons - QCSEE**

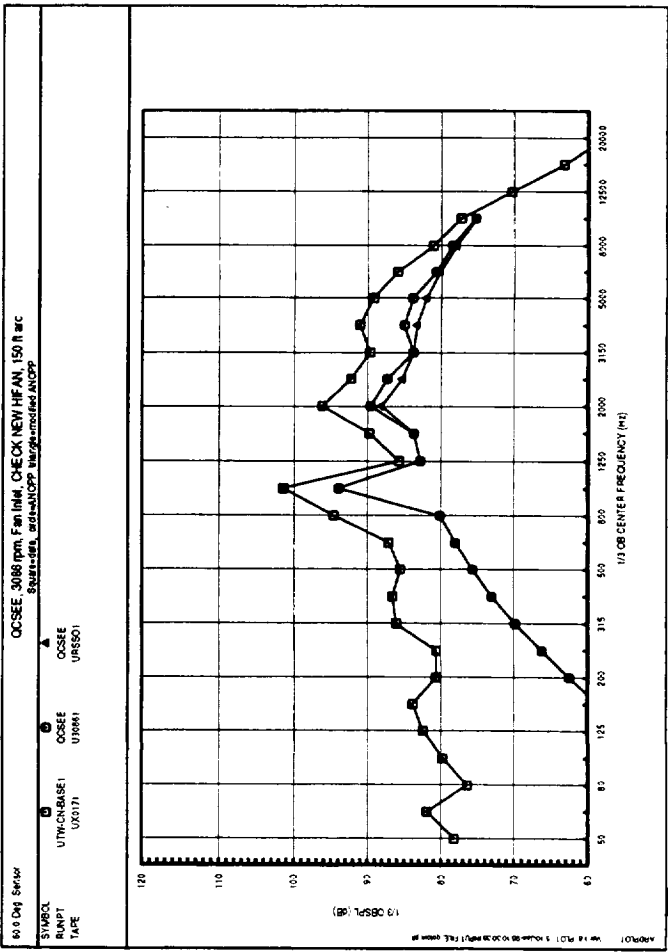
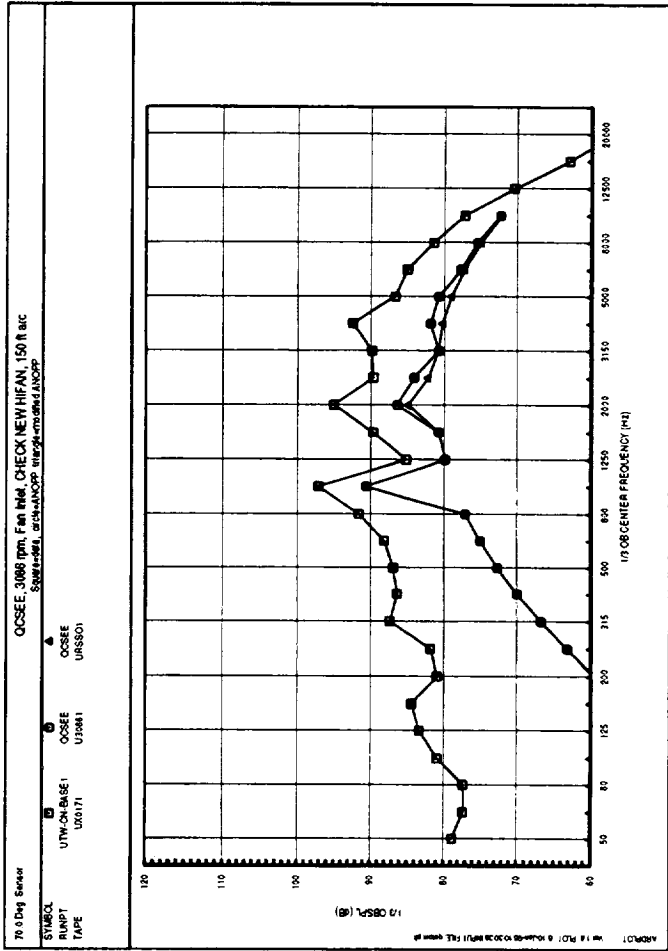
**Appendix D Contents**

<b>Page</b>	<b>Fan Speed, rpm</b>	<b>Angles, deg</b>
71	3086 (takeoff)	20-50
72	3086 (takeoff)	60-70
73	2931 (cutback)	20-50
74	2931 (cutback)	60-70
75	2759 (approach)	20-50
76	2759 (approach)	60-70

**Key to Plots:**

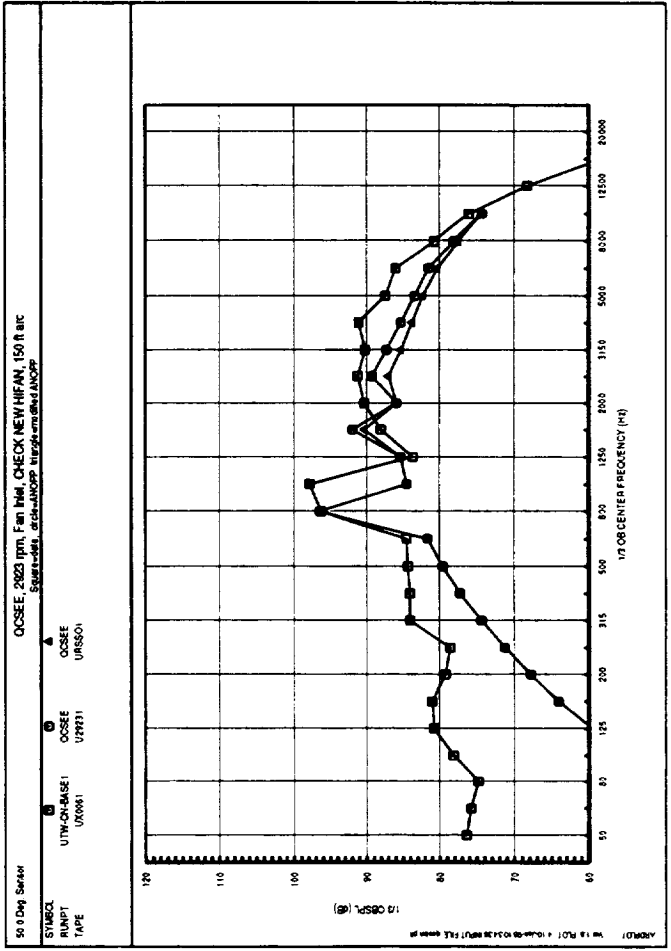
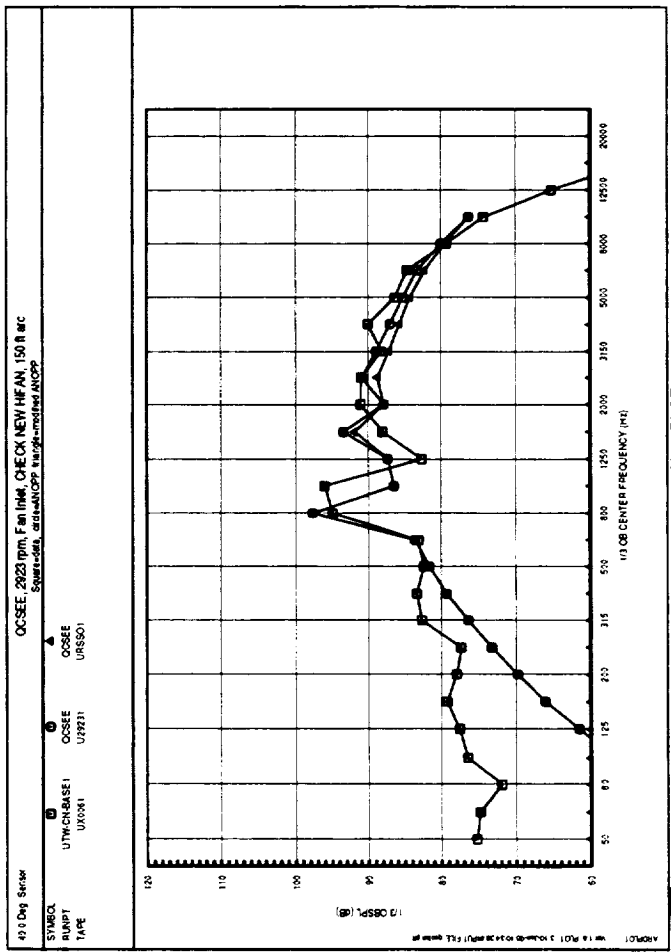
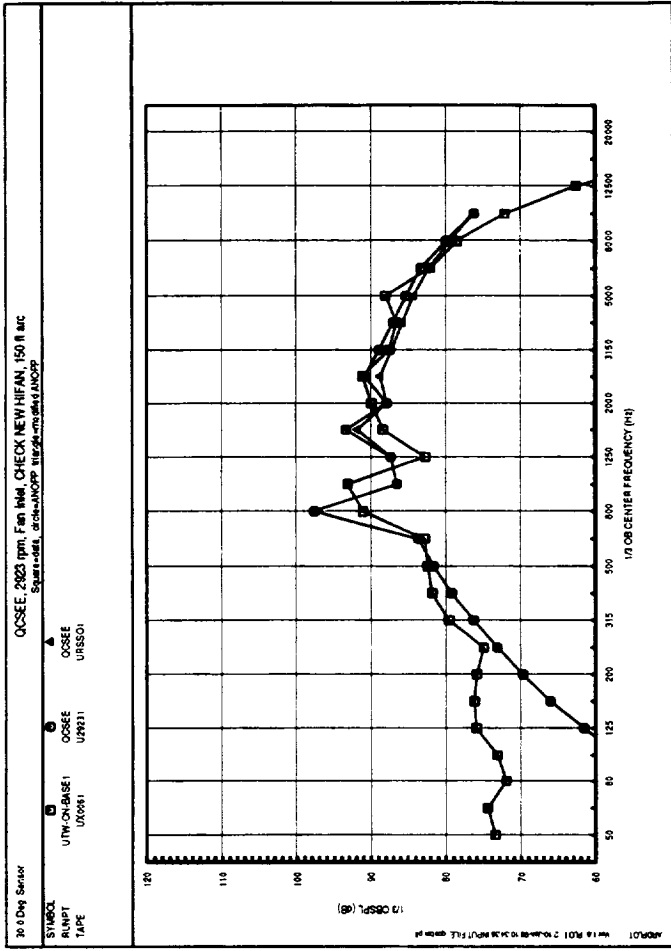
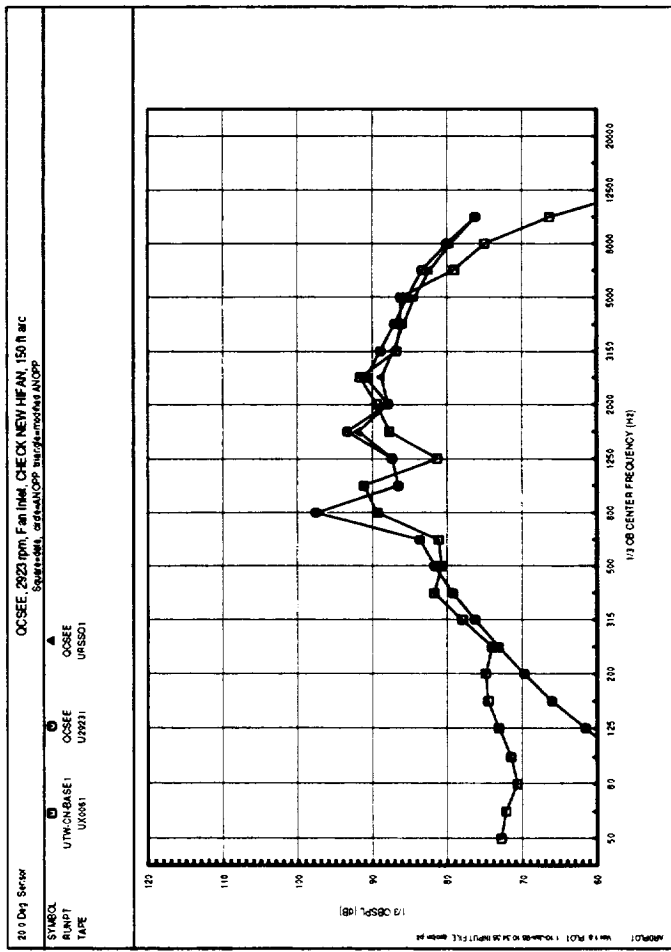
squares = total measured engine data  
circles = Heidmann method prediction  
triangles = modified Heidmann method prediction (see Section 4)



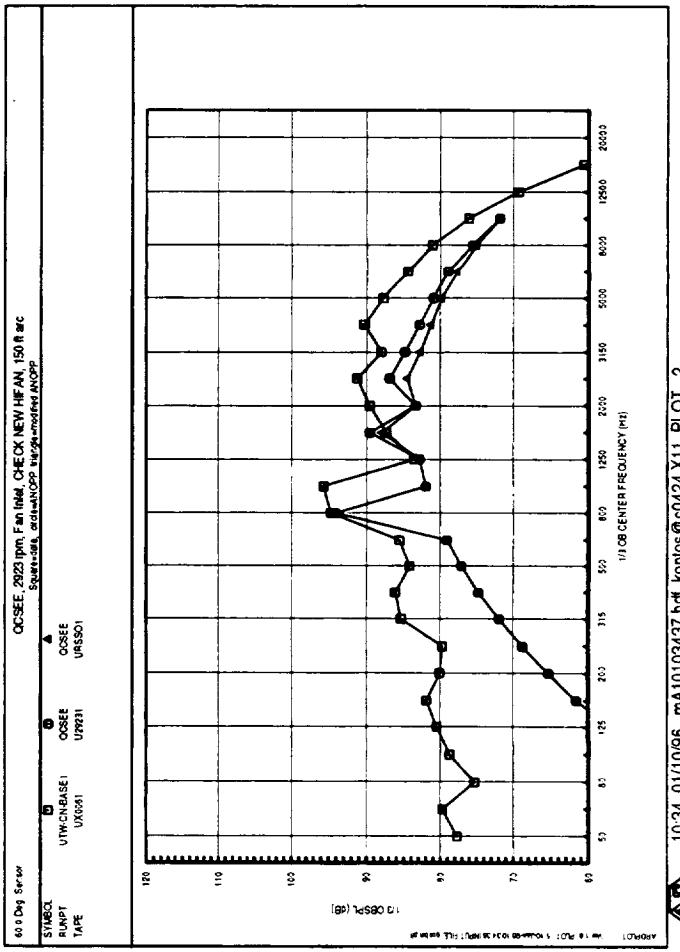
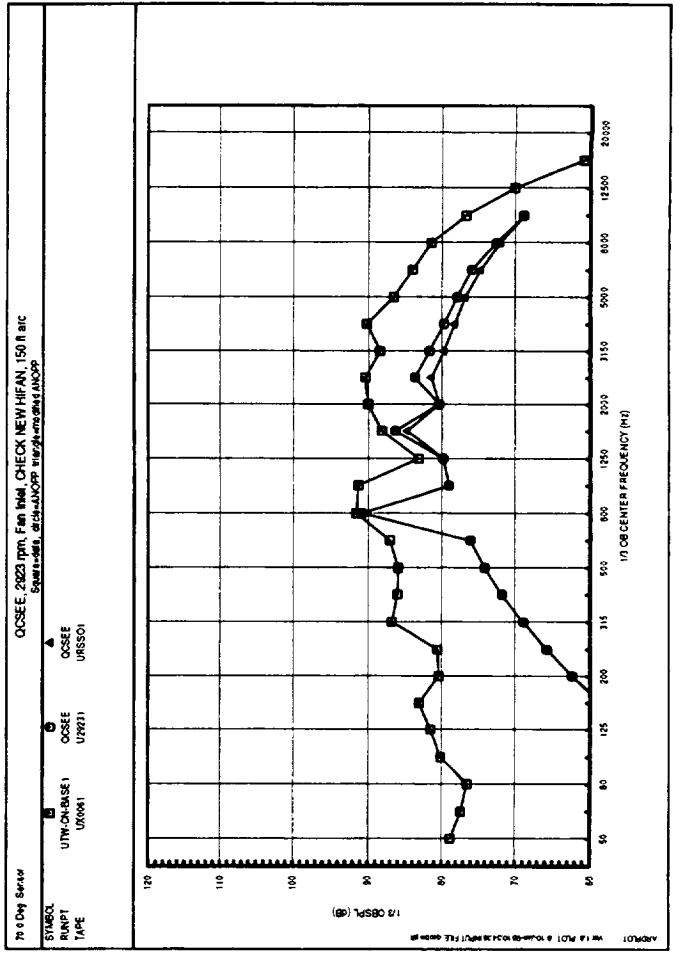


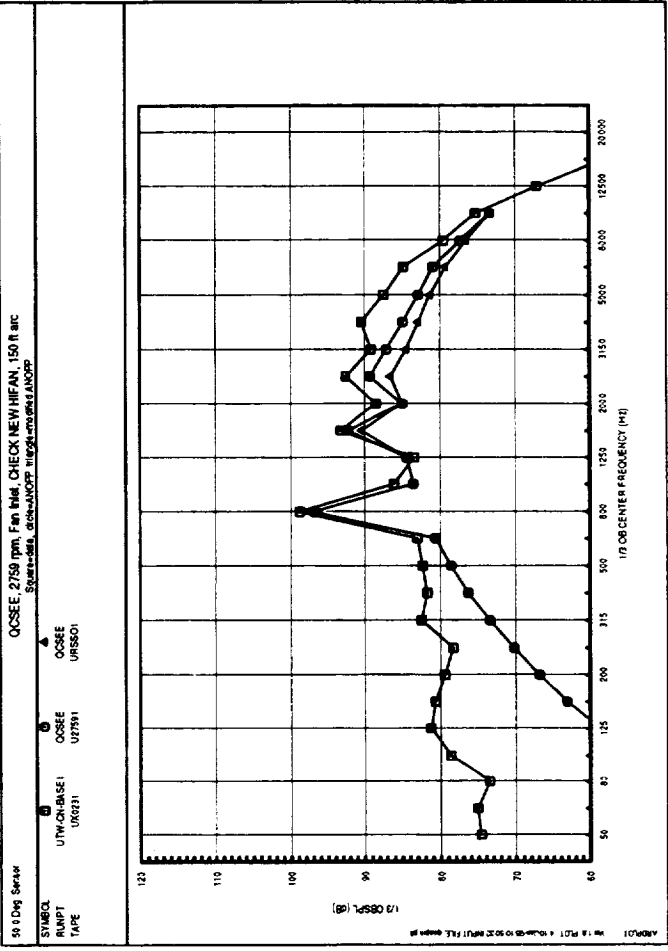
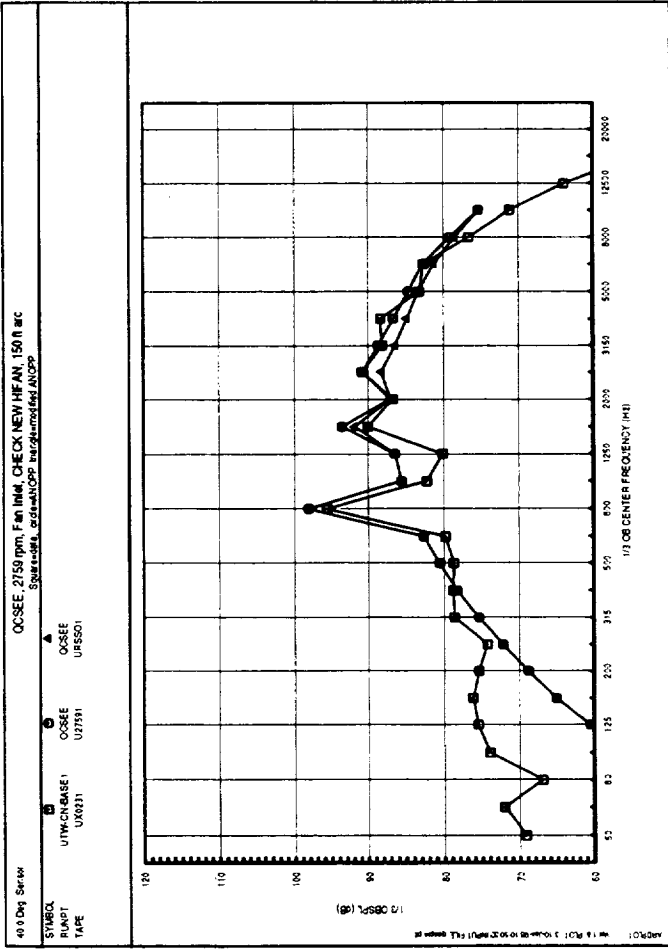
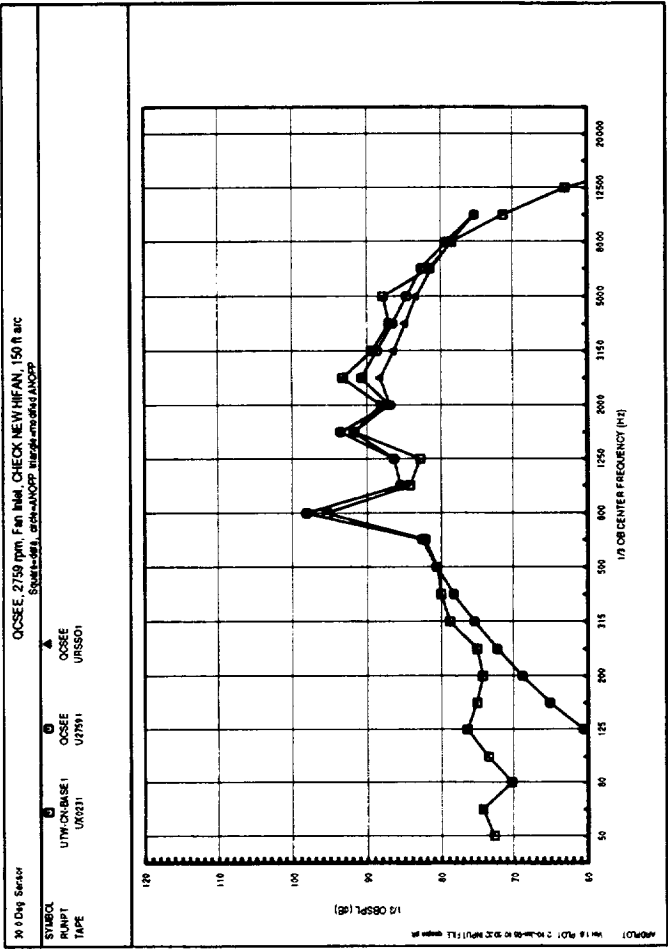
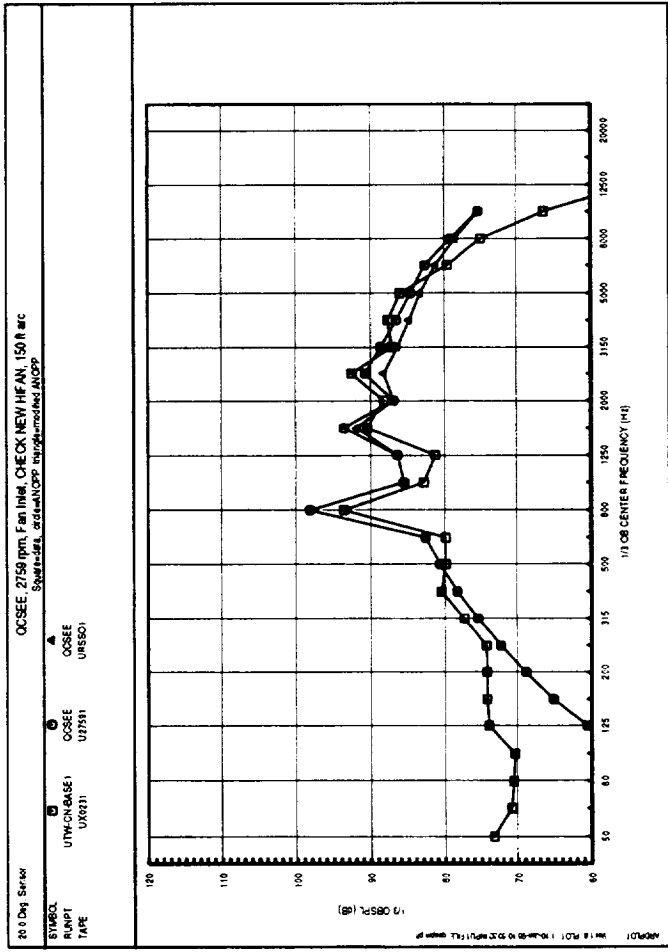
10:30 01/10/96 MA10103037 bdf konlos@c0424.X11 PLOT\_2  
 EGS LIB 5.1 12/14/95 EGSREP XPOST 5.1 12/14/95 on c0424  
 (NO PROG. VER. SPECIFIED)



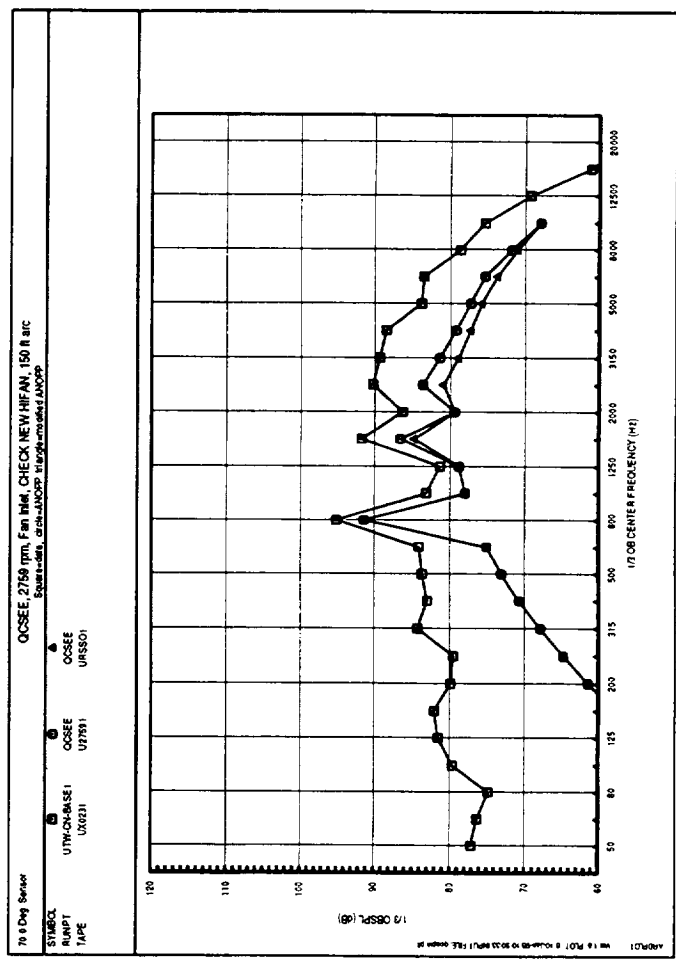
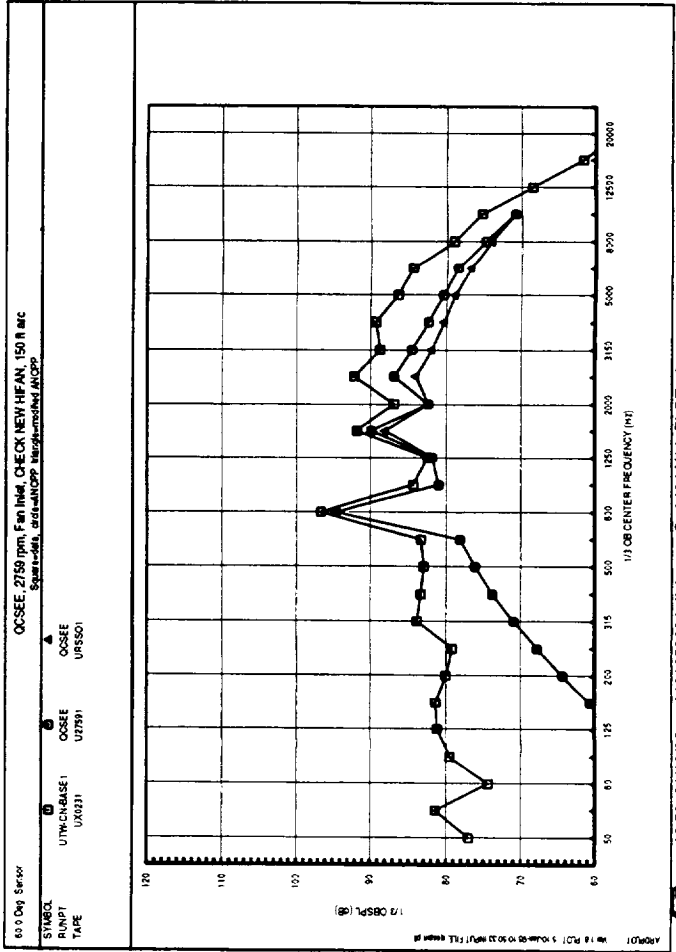








6



10:50 01/10/96 m\A10105032.bdf komlos@c0424.X11 PLOT 2  
EGS LIB 5.1 12/14/95 (EGSREP.XPOST 5.1 12/14/95 on c0424)  
(NO PROG. VER. SPECIFIED)



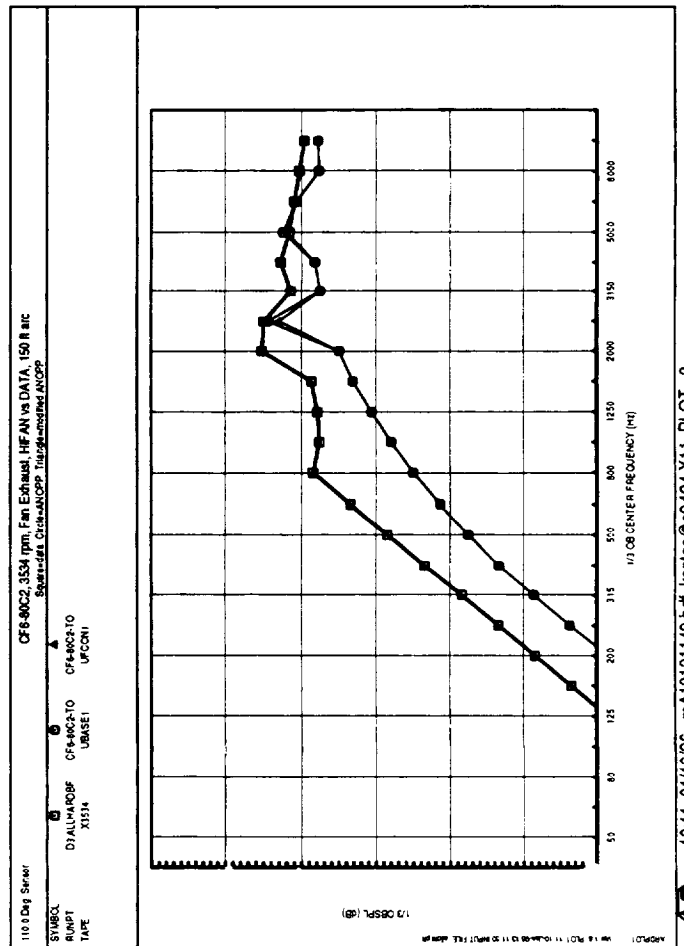
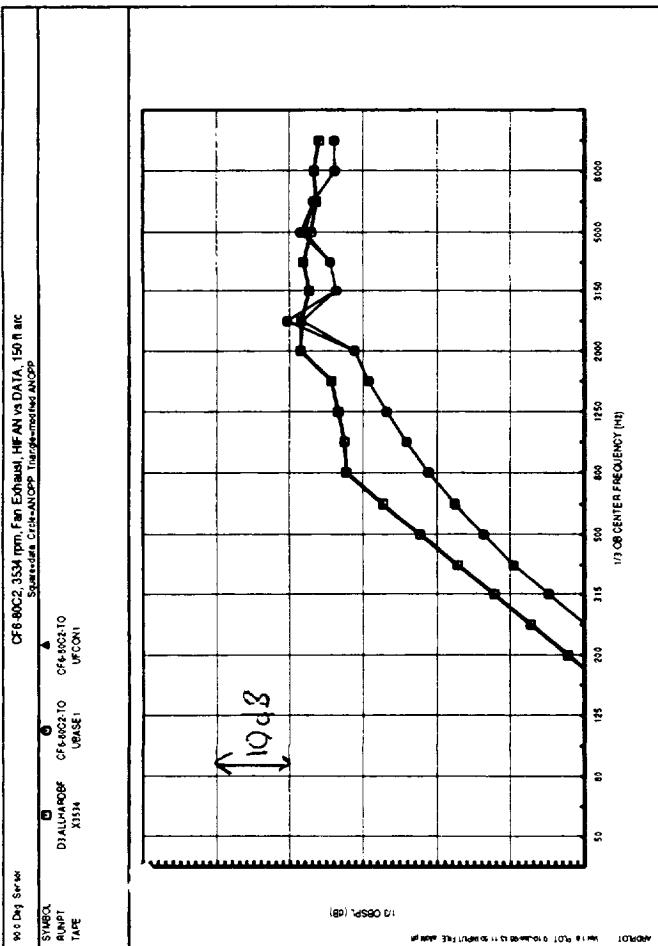
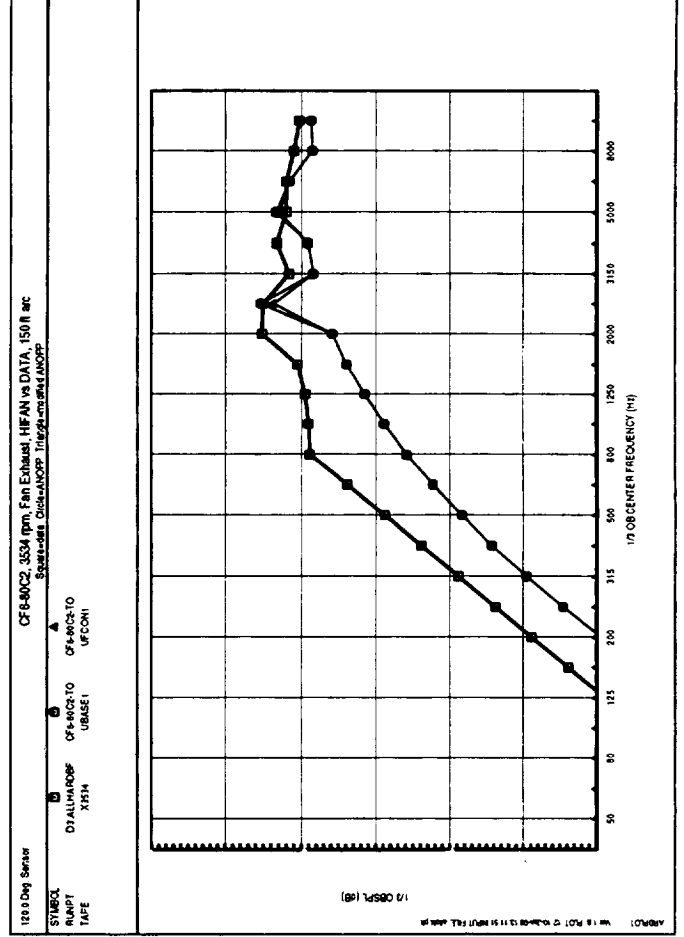
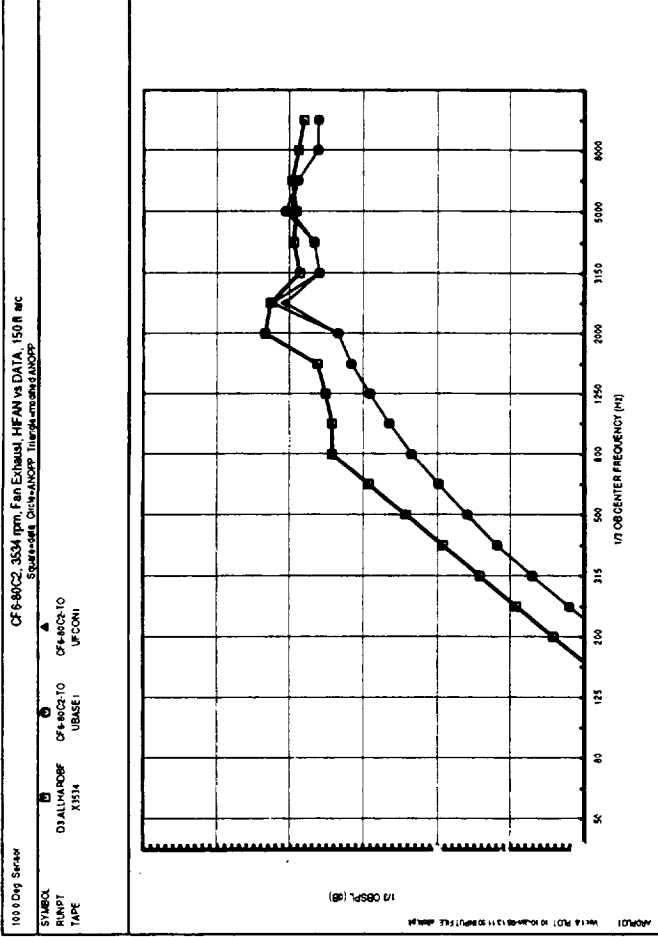
**Appendix E**  
**Fan Exhaust Noise Spectral Comparisons - CF6-80C2**

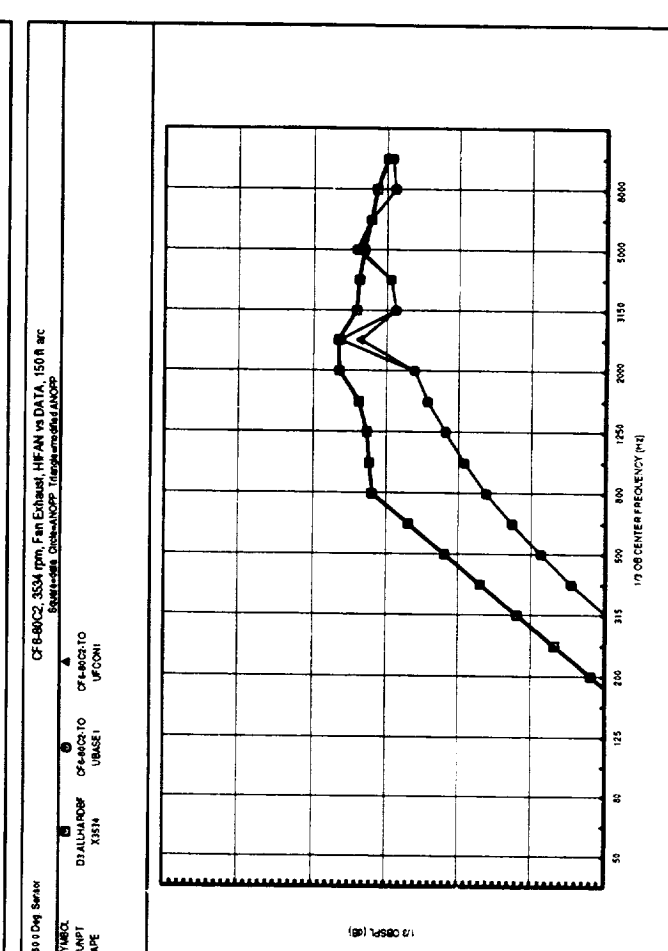
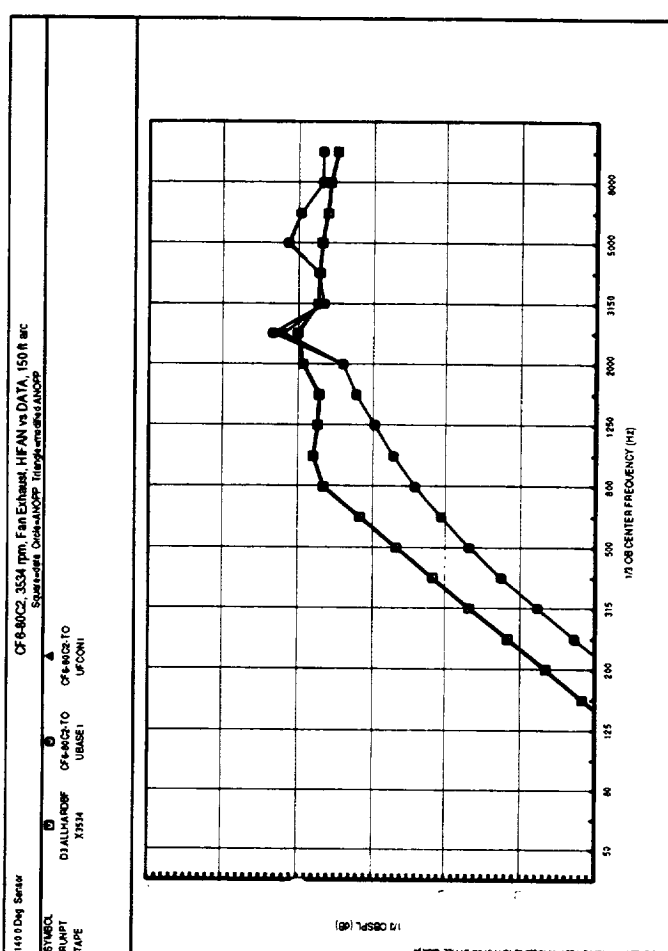
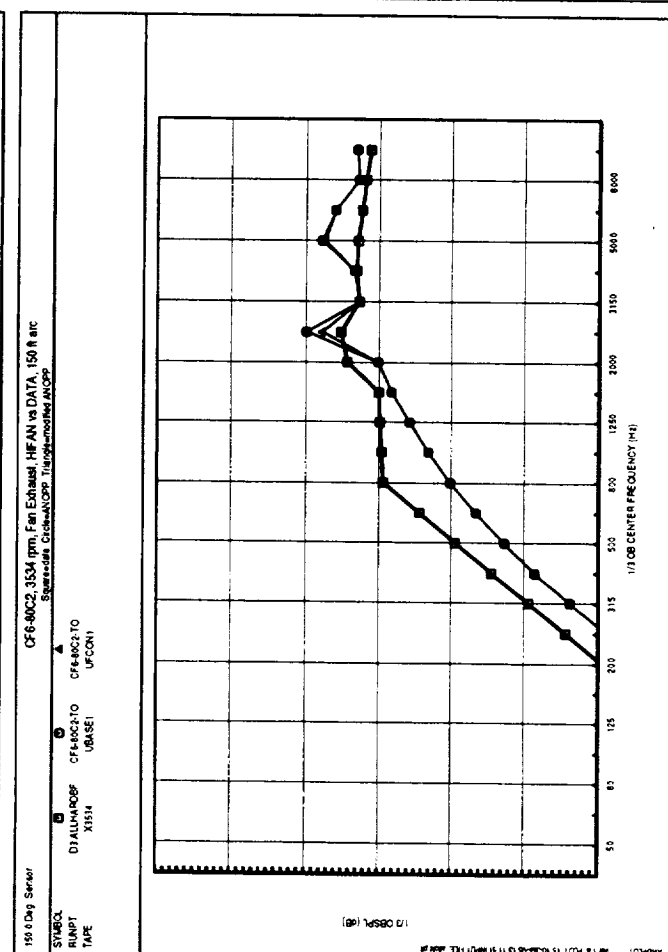
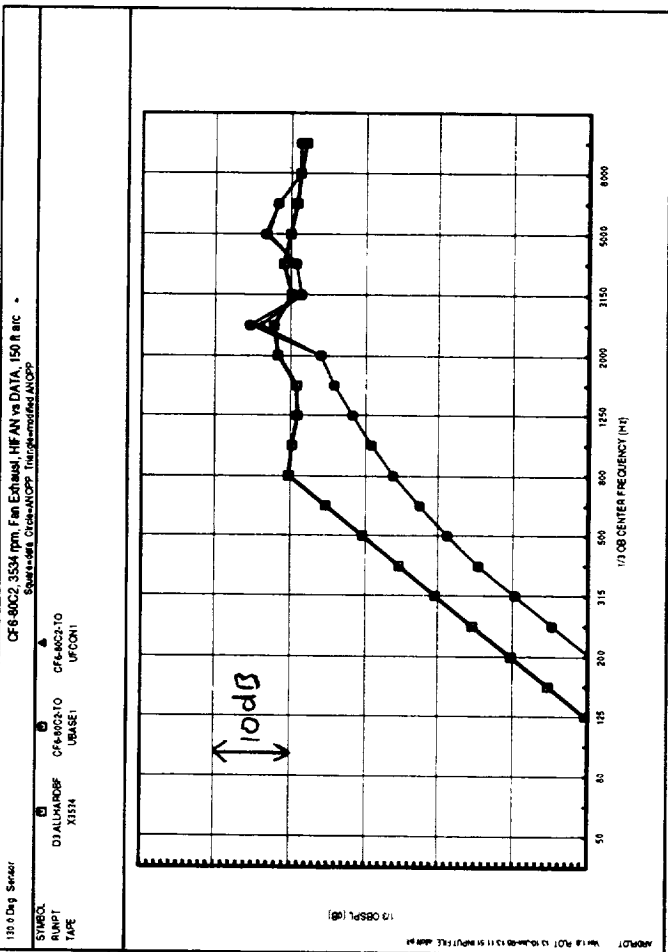
**Appendix E Contents**

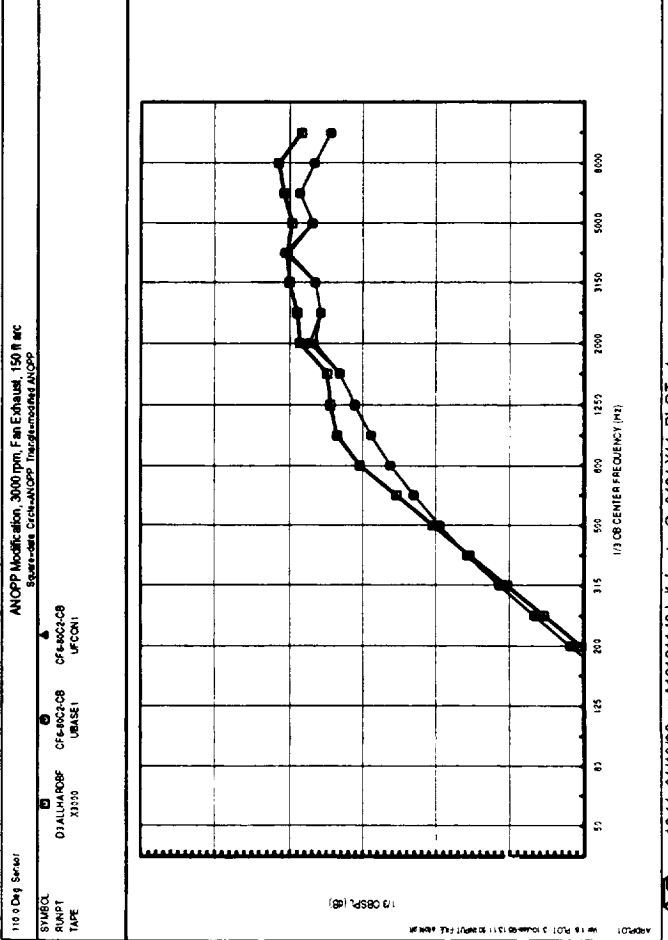
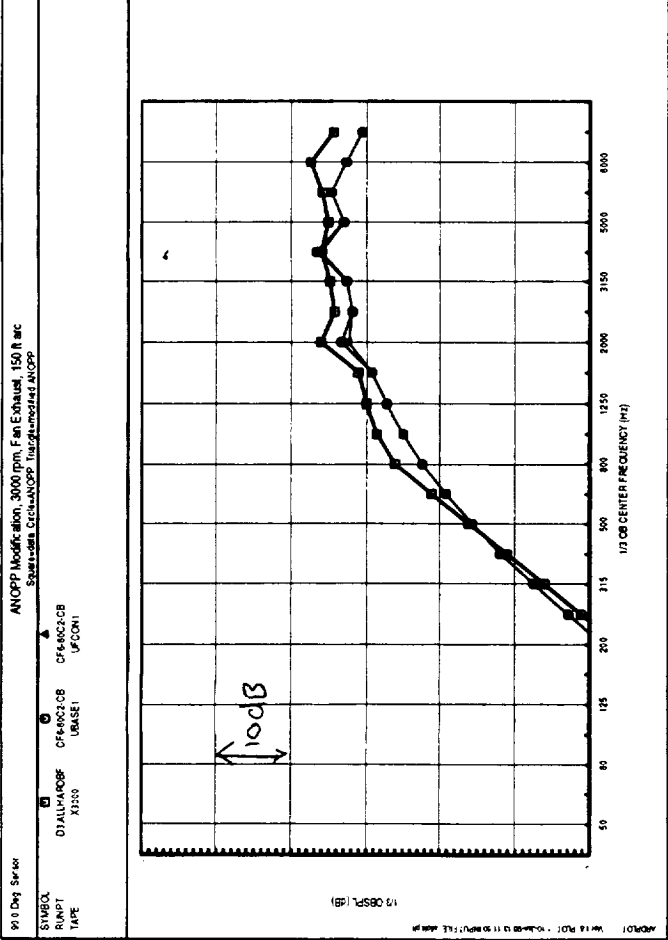
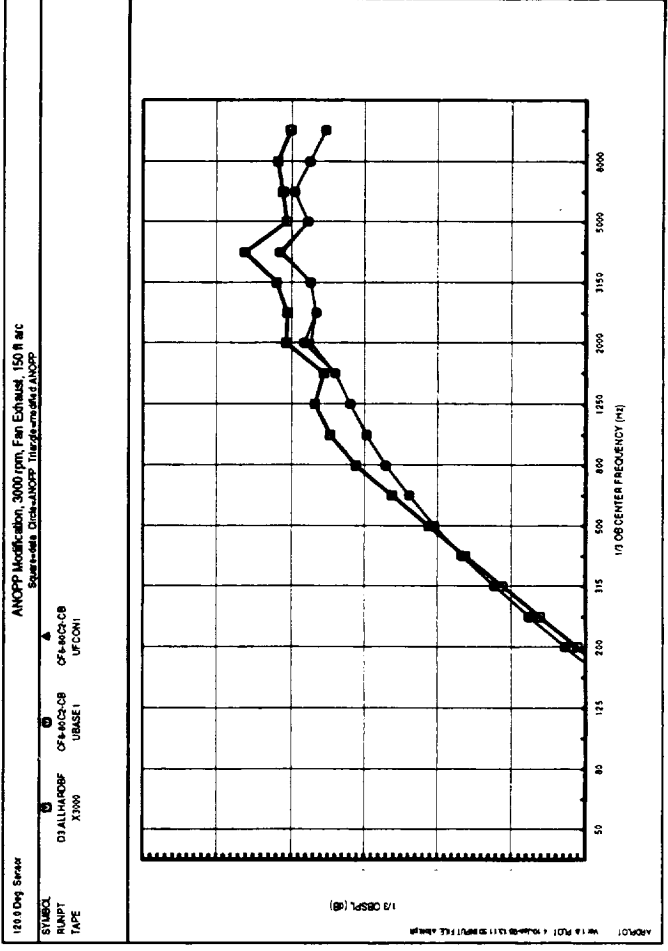
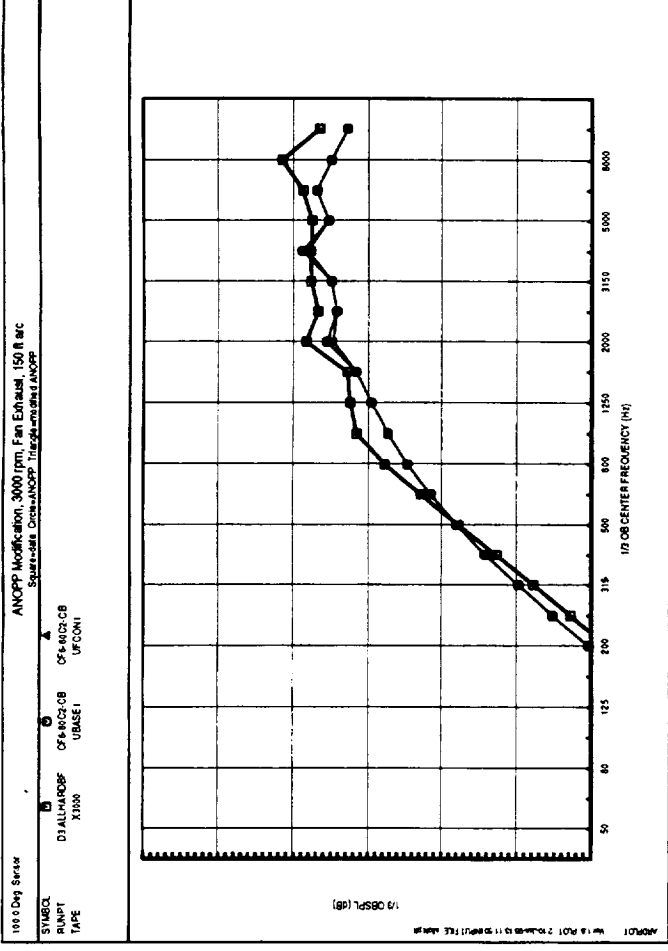
<b>Page</b>	<b>Fan Speed, rpm</b>	<b>Angles, deg</b>
78	3534	90-120
79	3534	130-160
80	3000	90-120
81	3000	130-160
82	2400	90-120
83	2400	130-160
84	3450	90-120
85	3450	130-160
86	3300	90-120
87	3300	130-160
88	3150	90-120
89	3150	130-160
90	2850	90-120
91	2850	130-160
92	2700	90-120
93	2700	130-160
94	2100	90-120
95	2100	130-160
96	1950	90-120
97	1950	130-160
98	1800	90-120
99	1800	130-160
100	1650	90-120
101	1650	130-160

**Key to Plots:**

- squares = total measured engine data
- circles = Heidmann method prediction
- triangles = modified Heidmann method prediction (see Section 4)

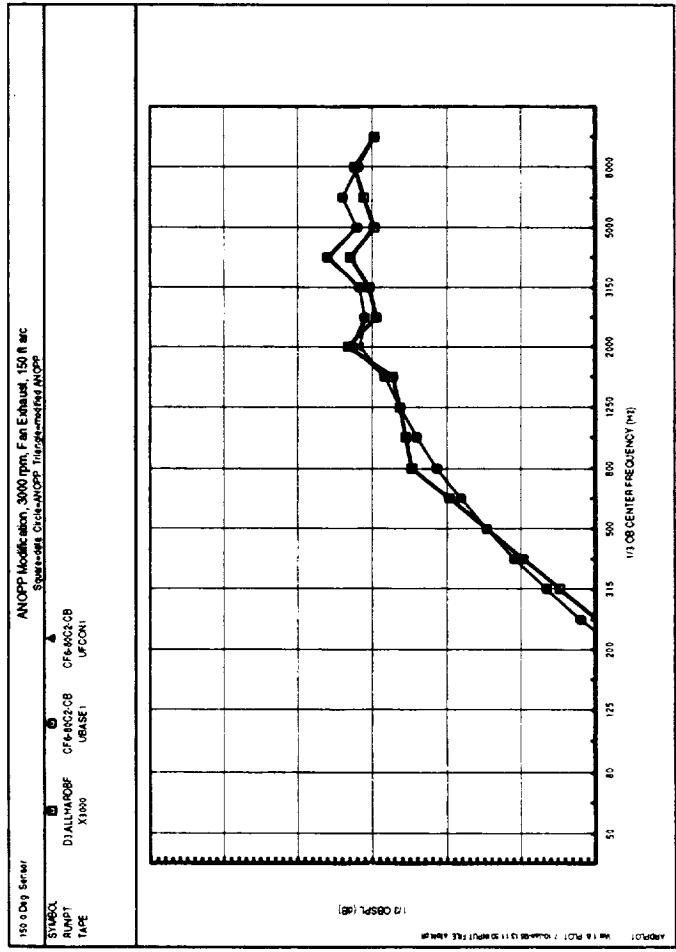
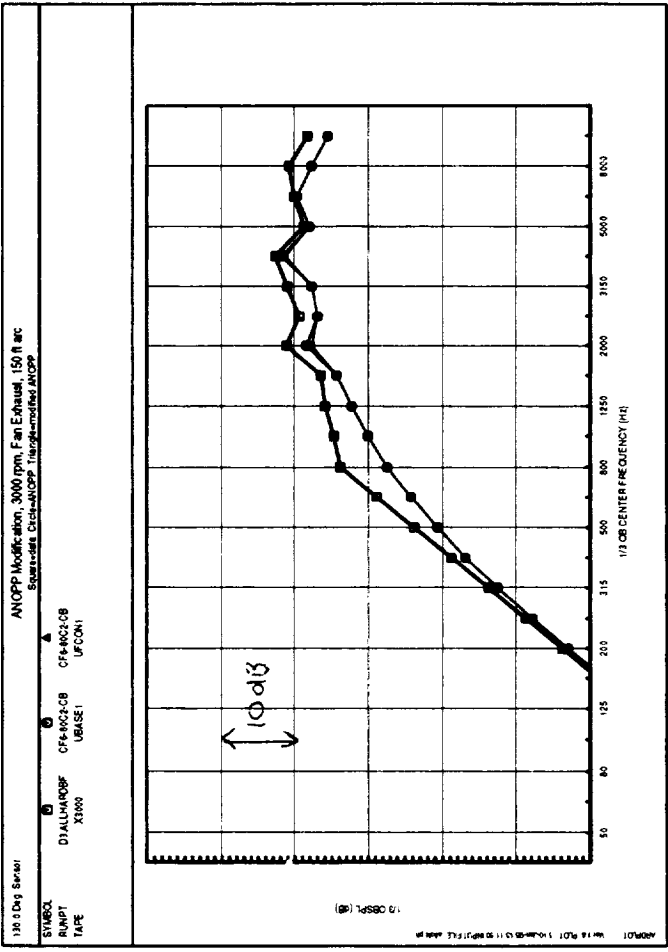
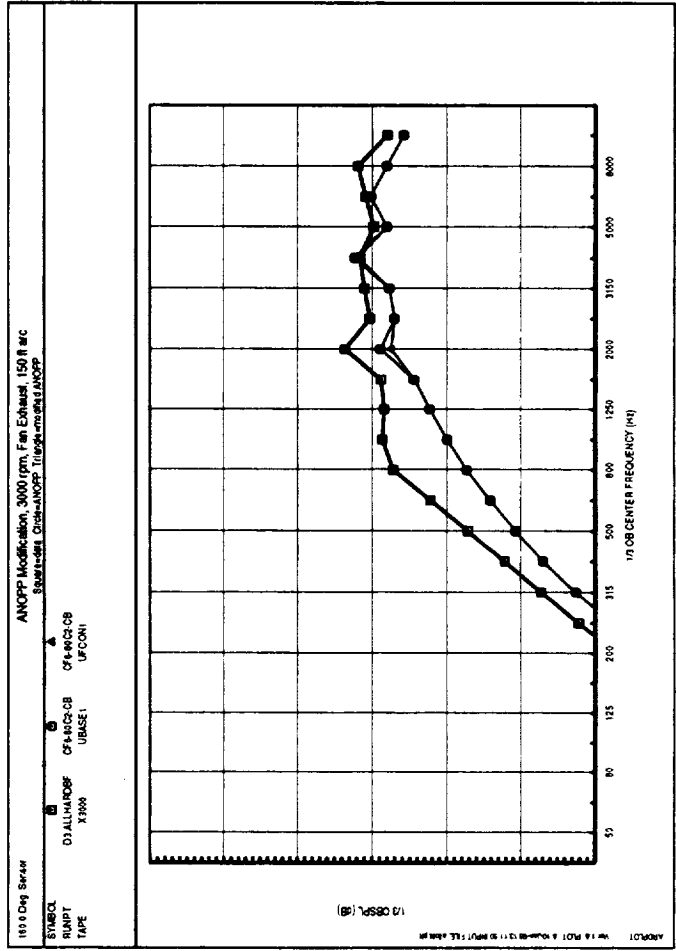
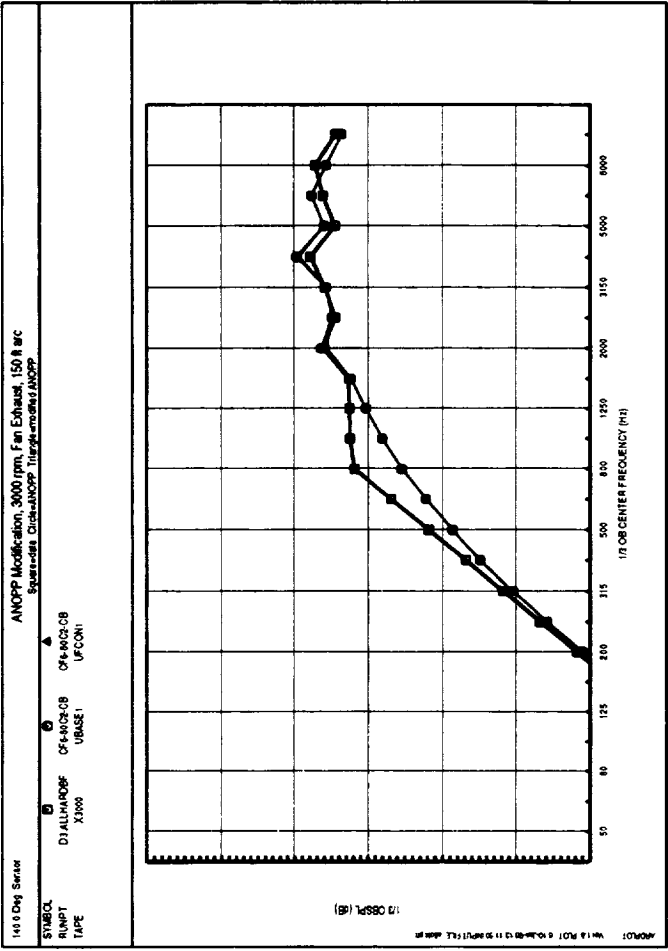




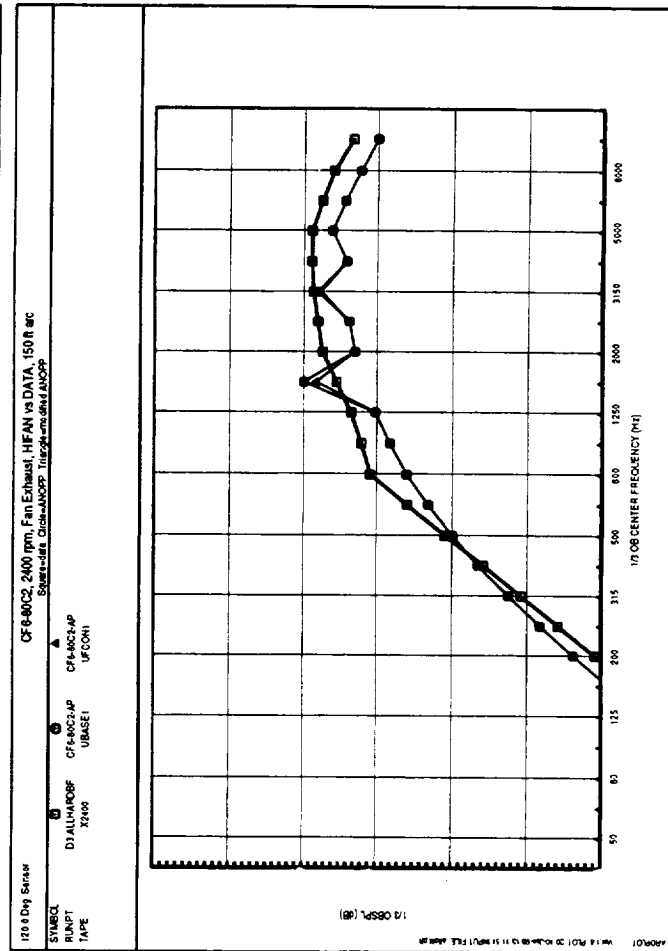
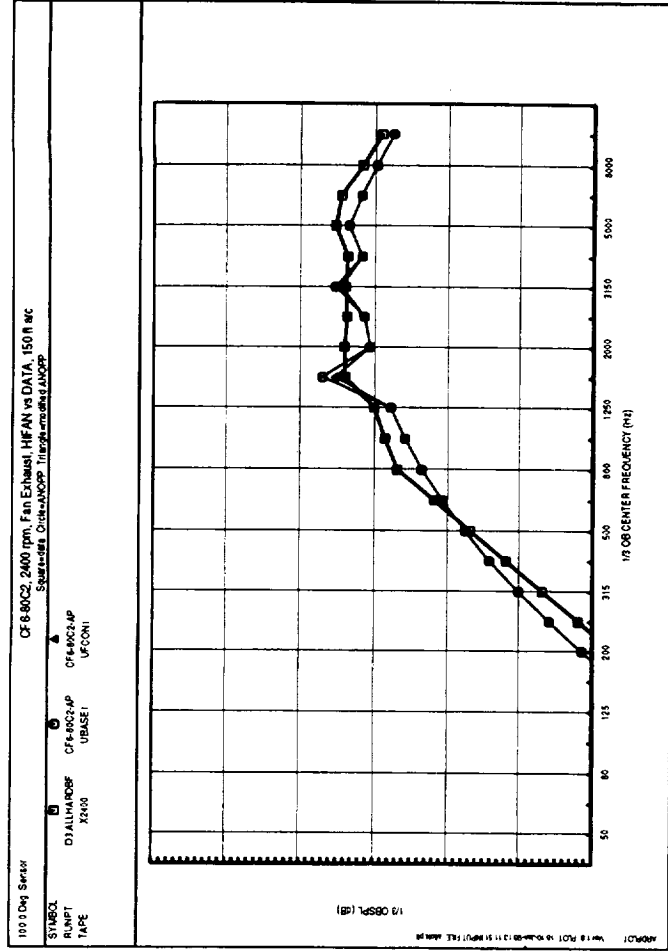
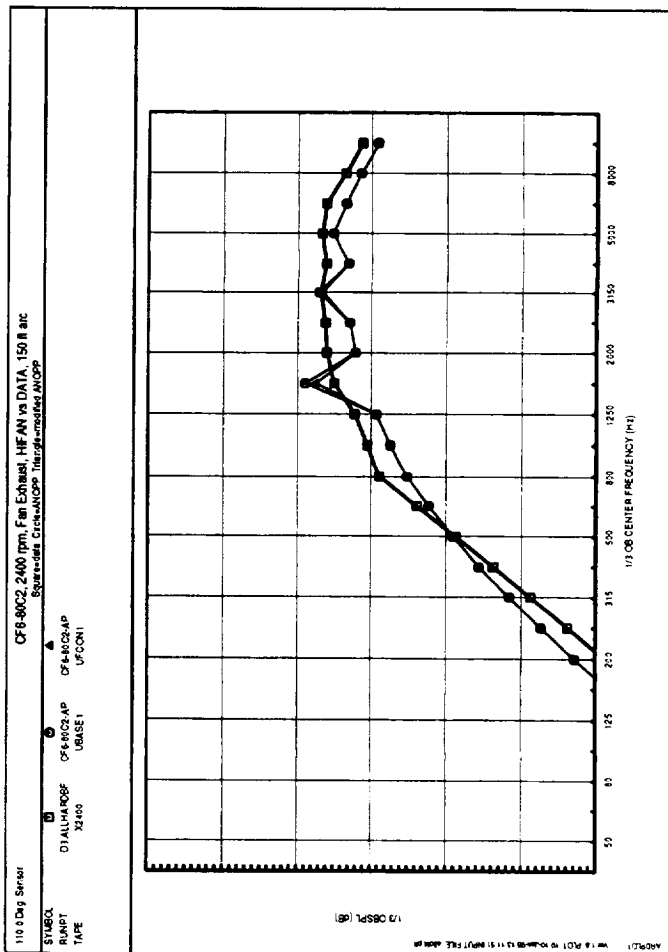
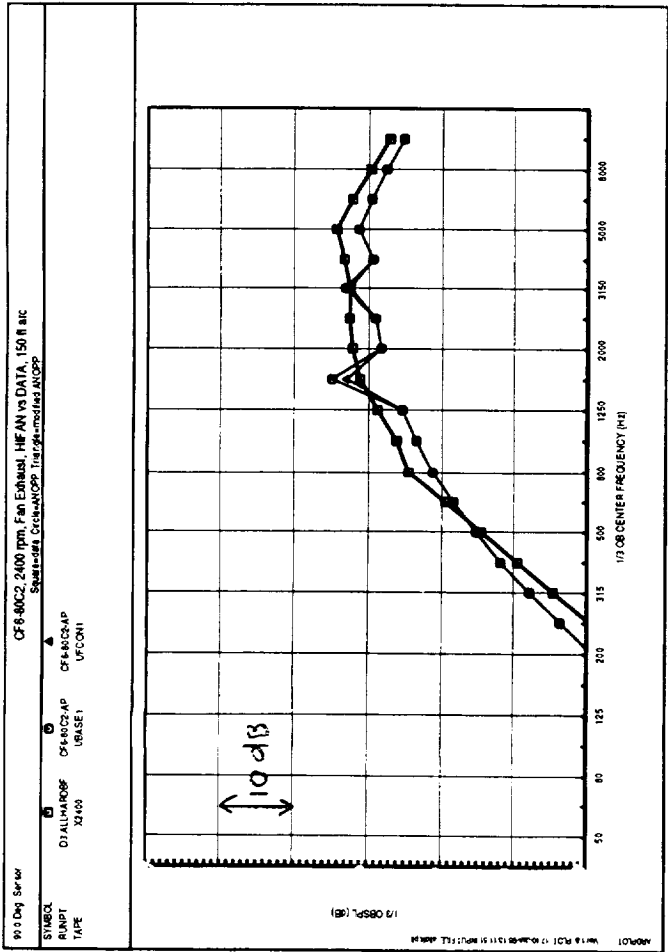


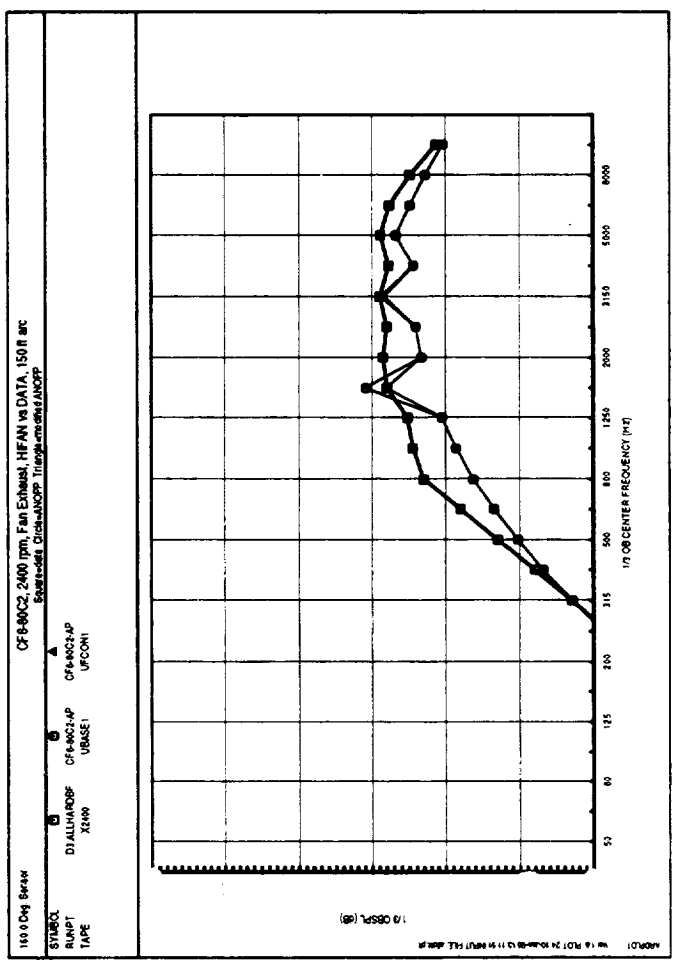
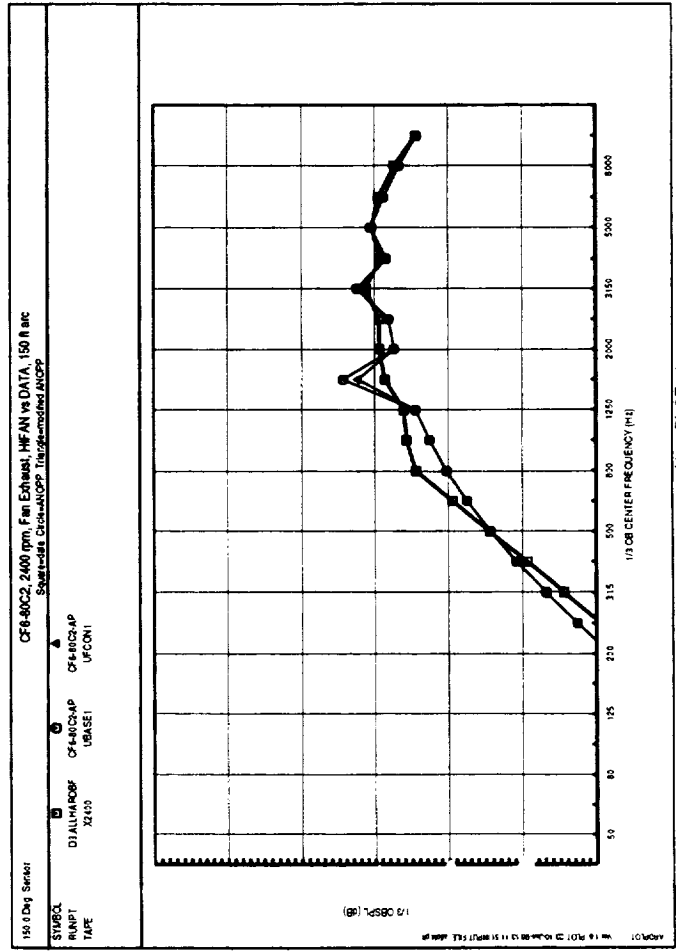
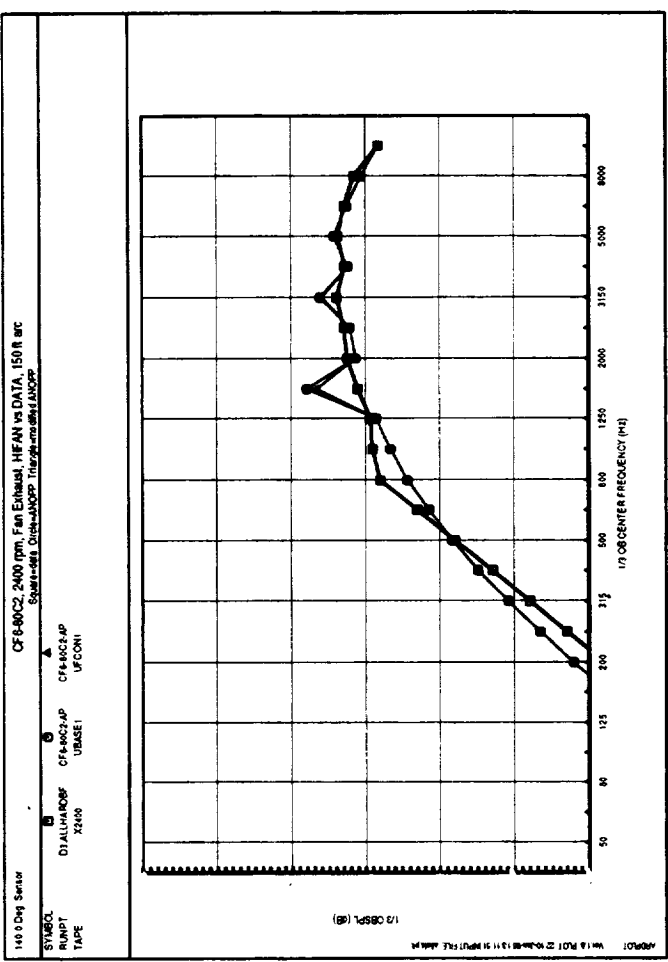
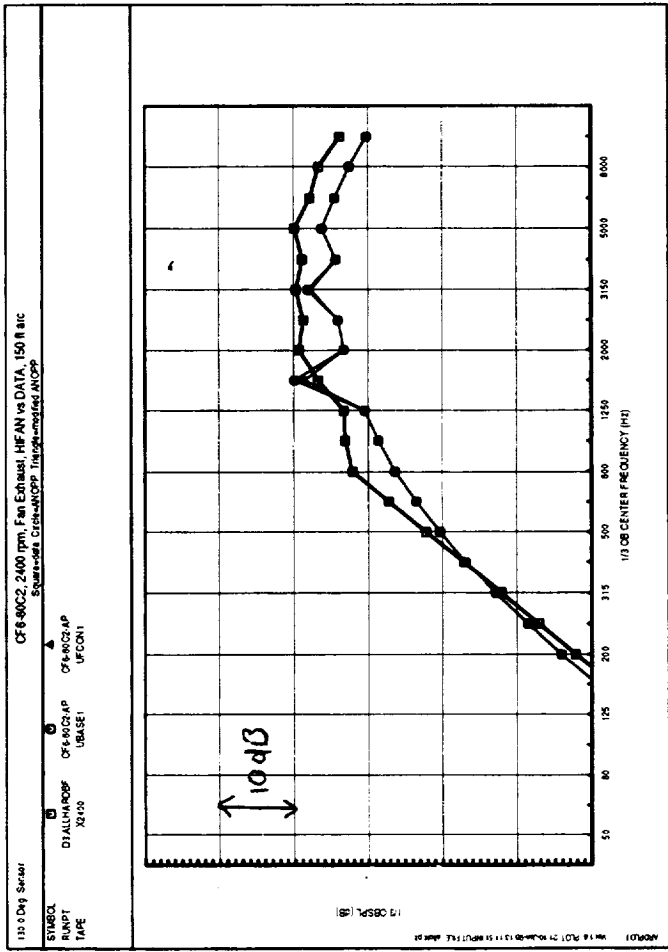
1311 01/10/96 mA10131149 bdf Kontos c0424 X11 PLOT  
 EGS LIB 5.1 12/14/95 EGSREP.XPOST 5.1 12/14/95 on c0424  
 (NO PROG. VER. SPECIFIED)

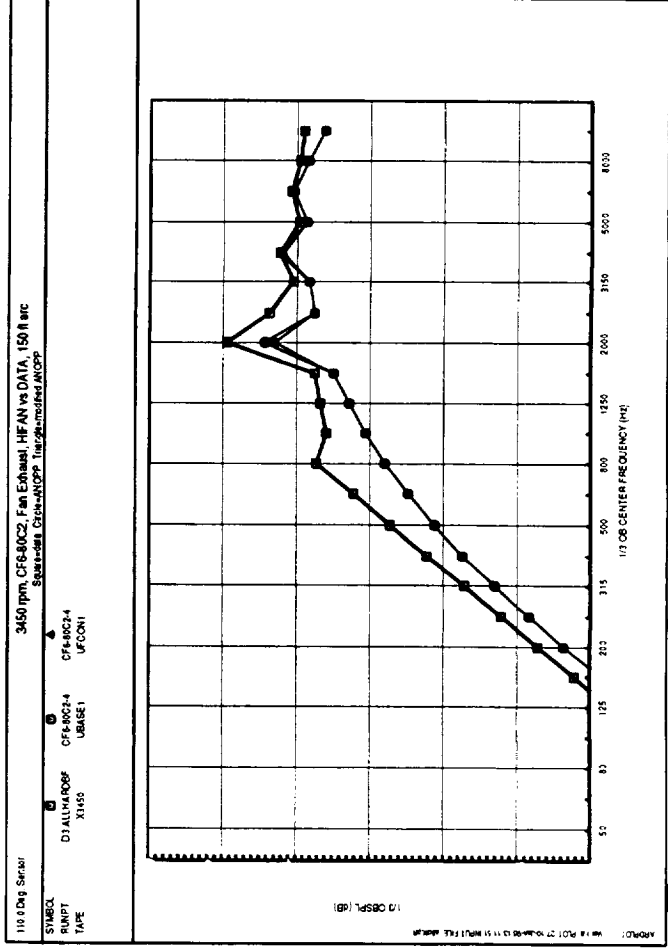
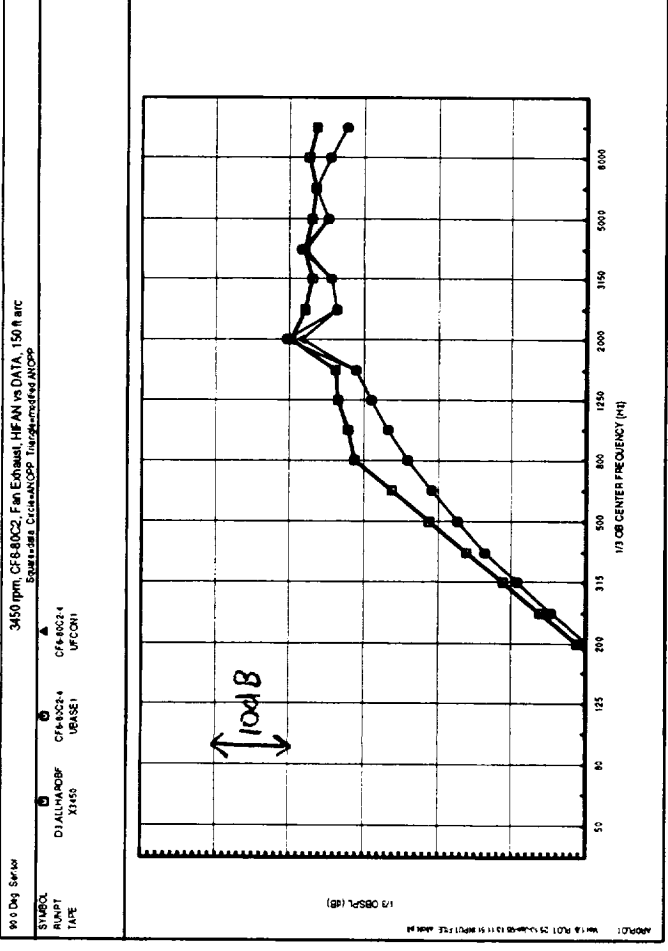
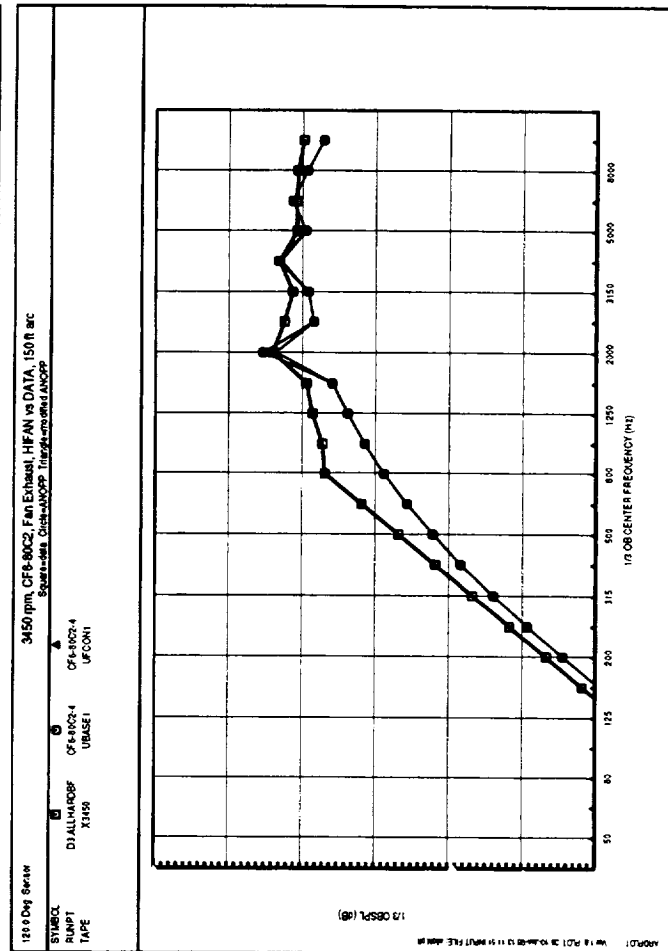
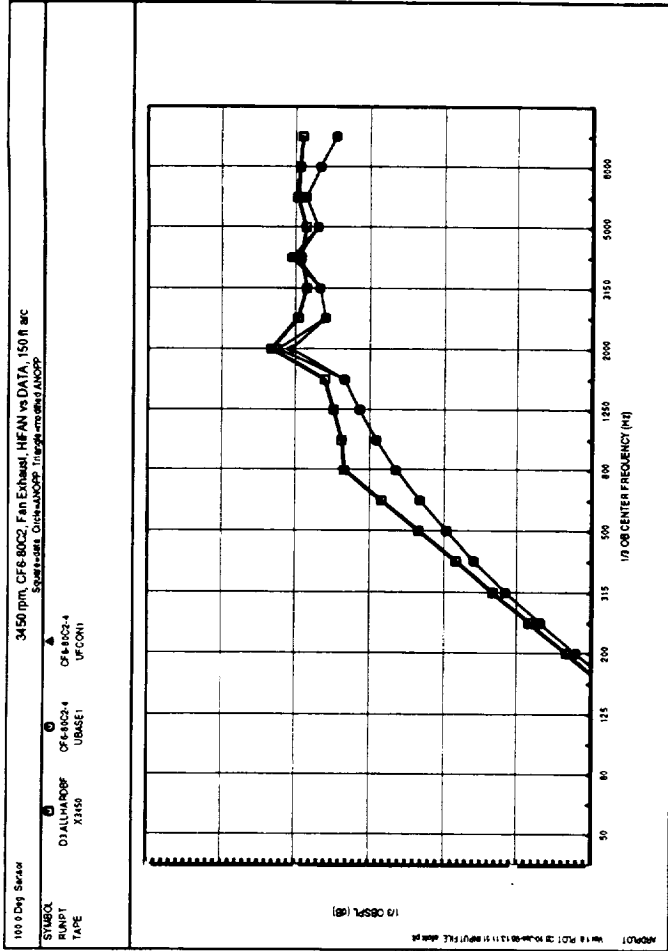


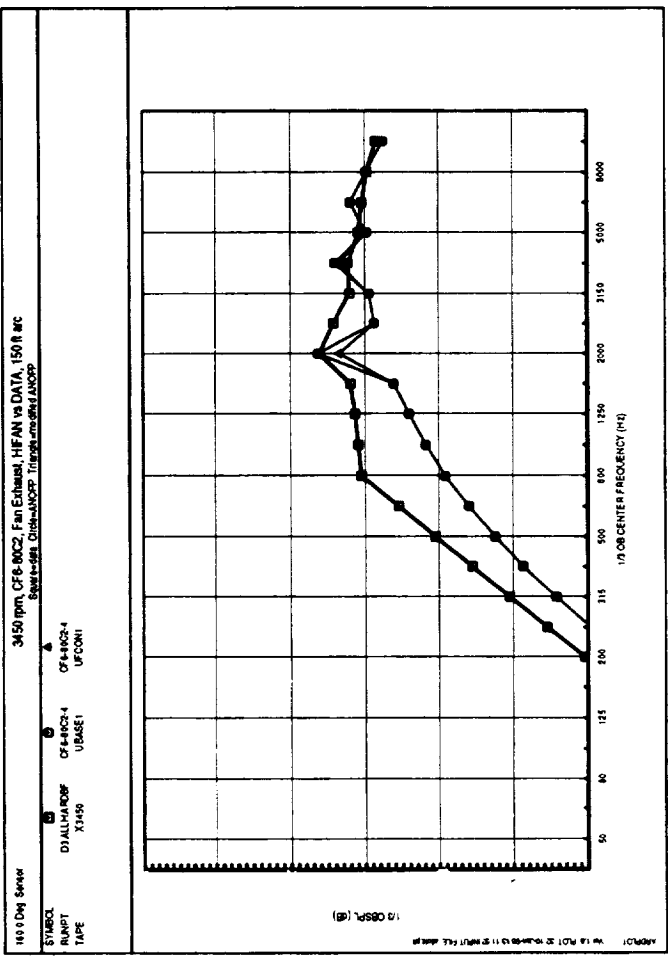
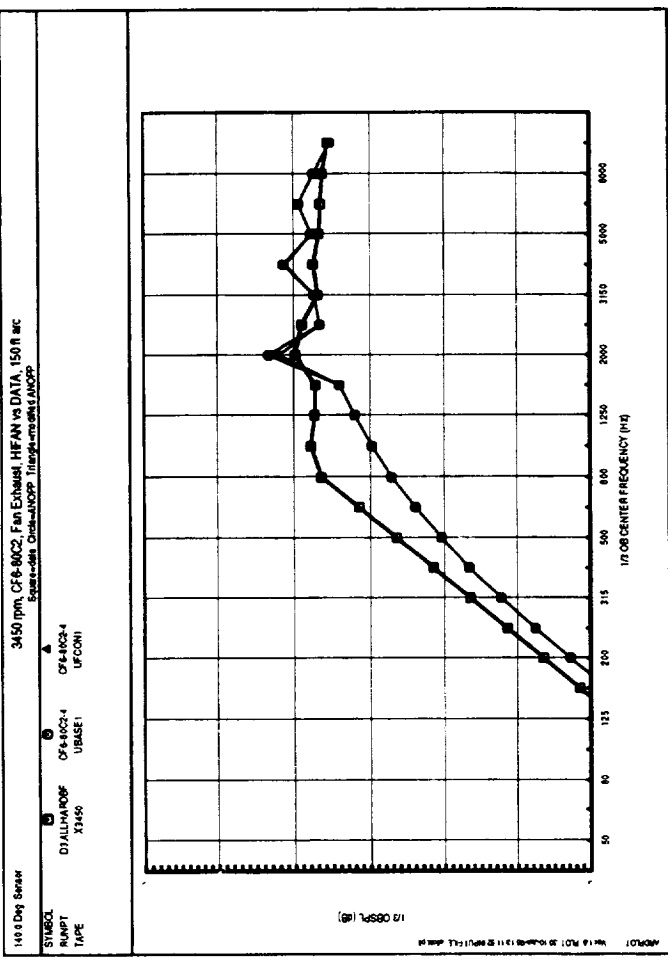
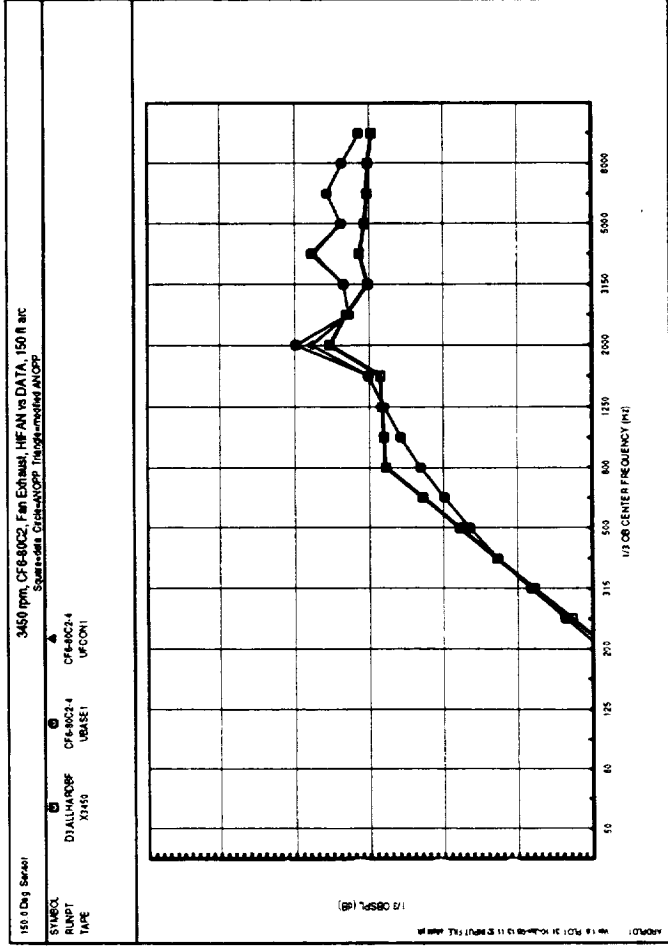
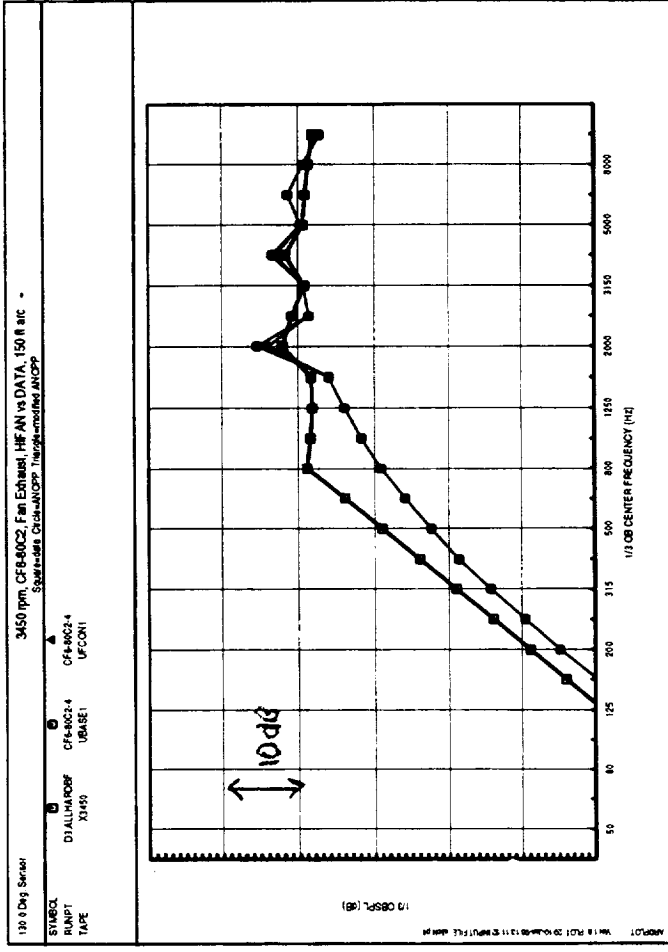


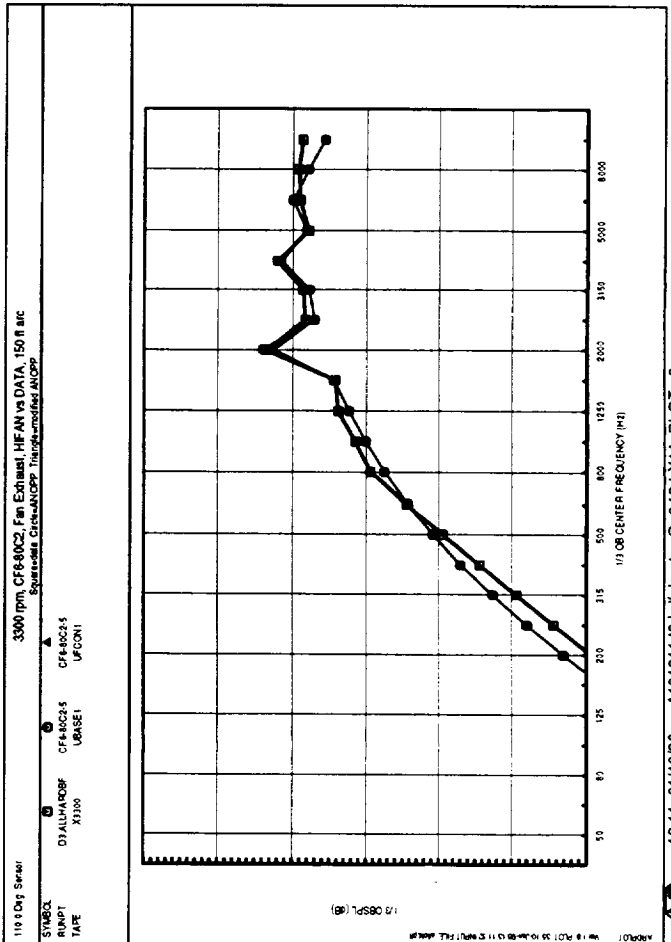
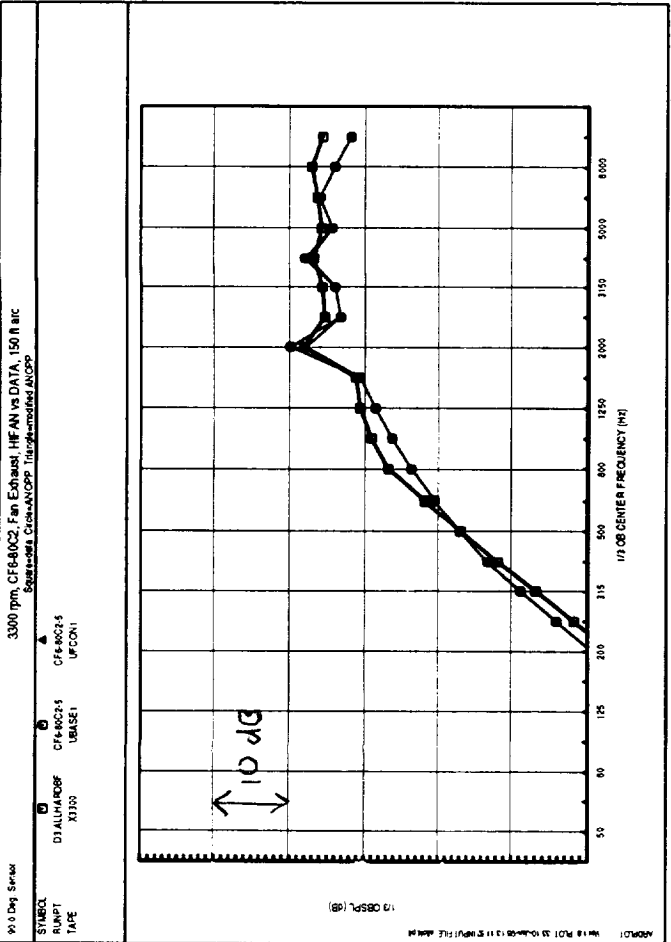
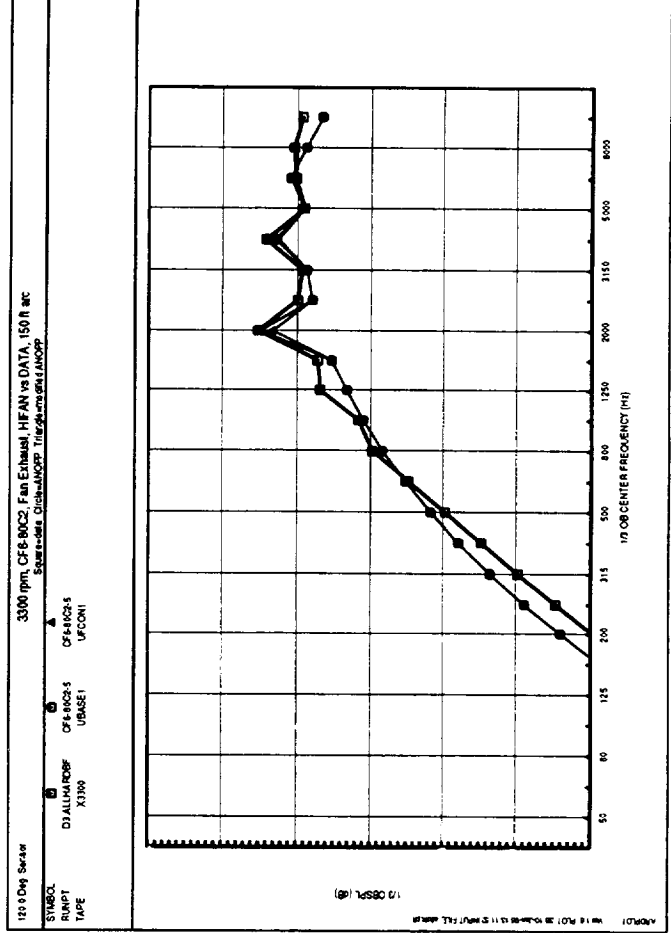
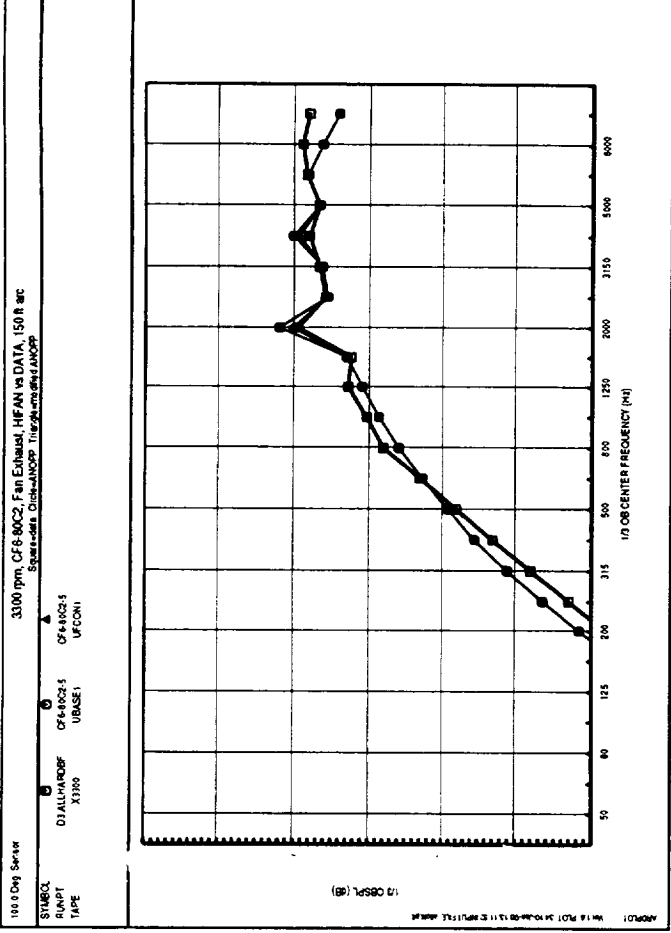


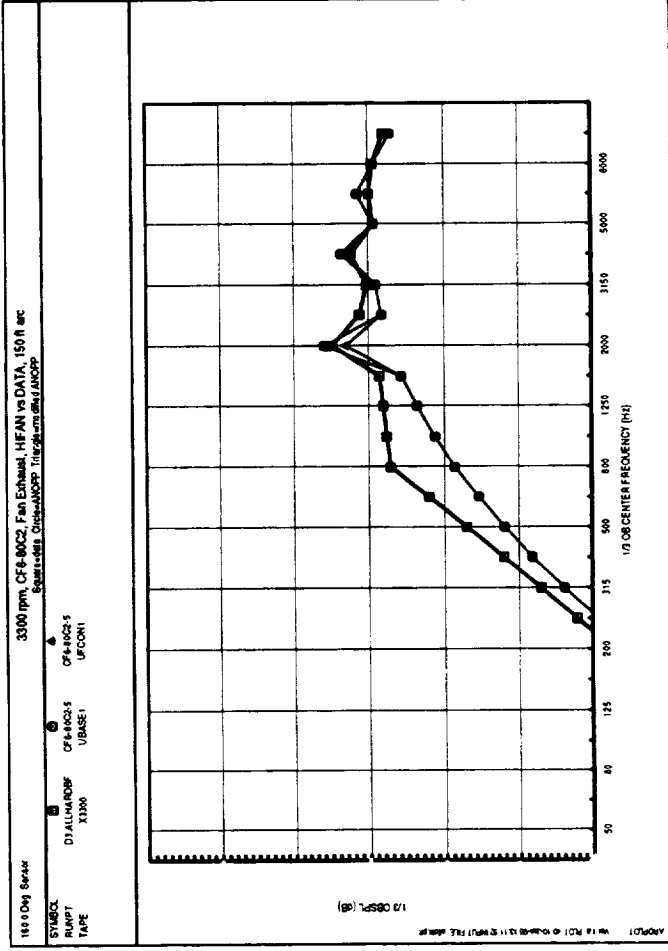
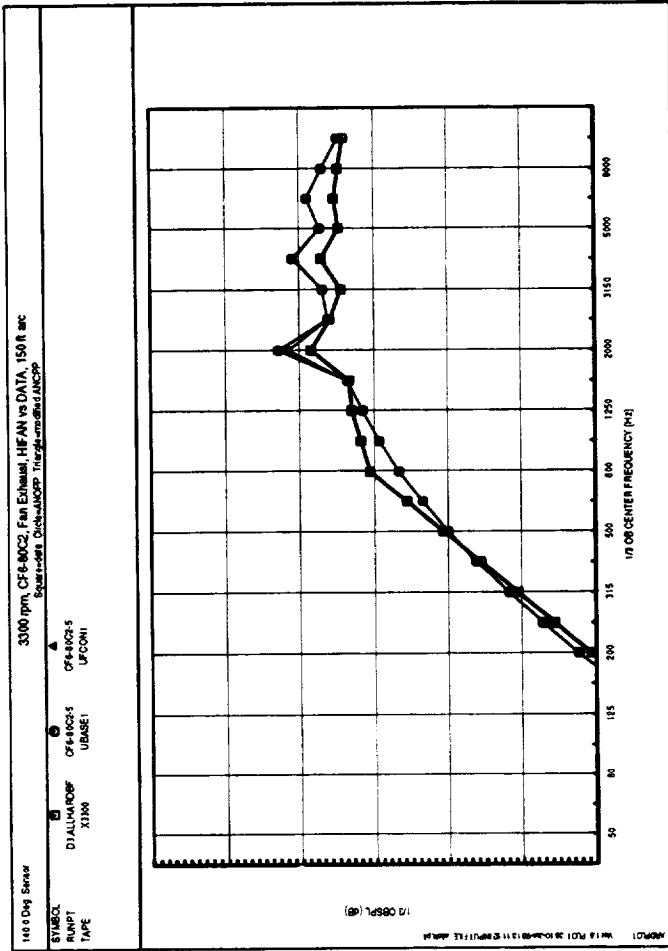
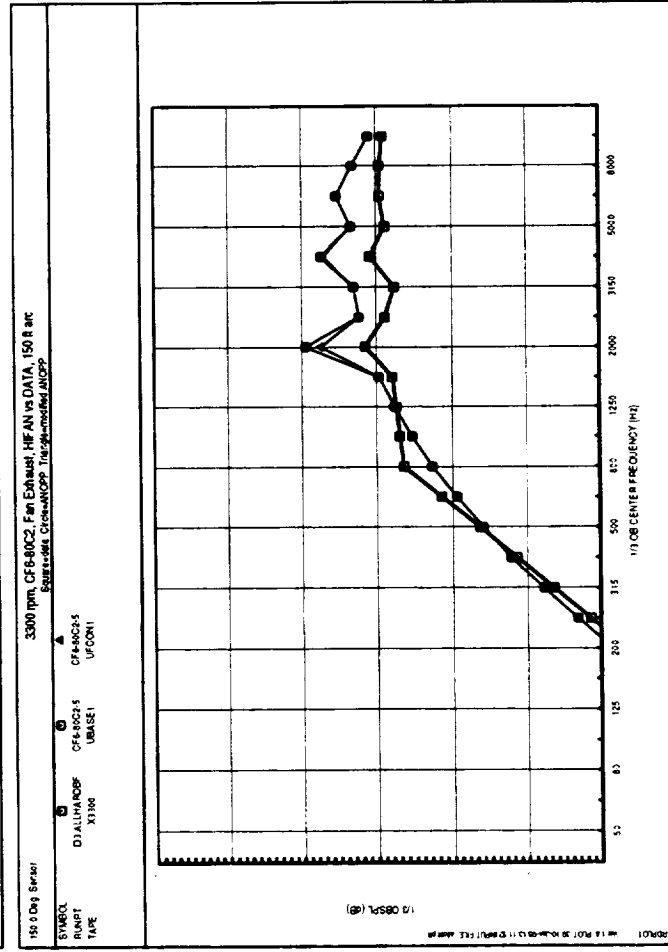
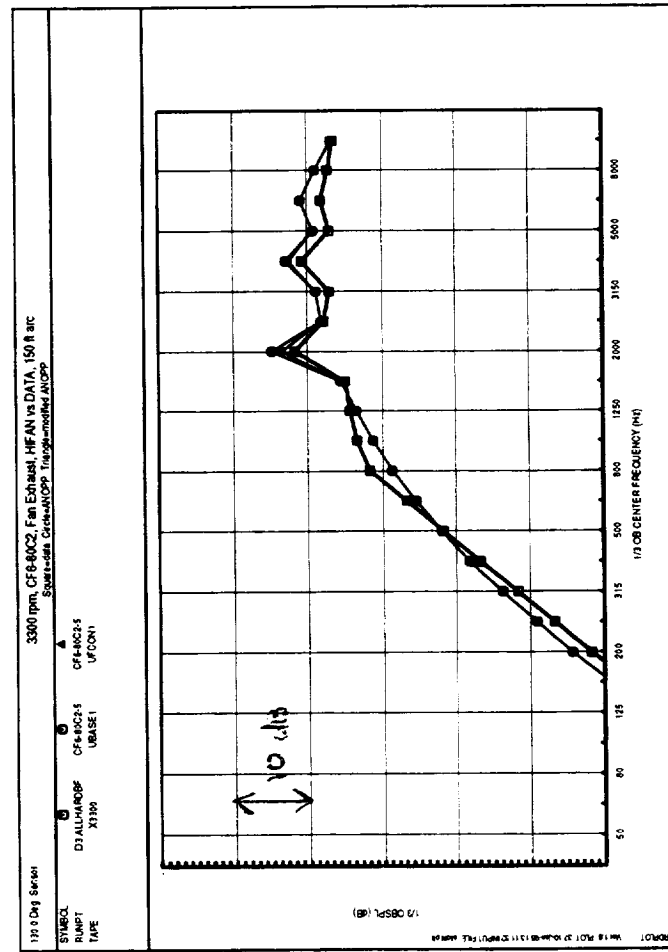


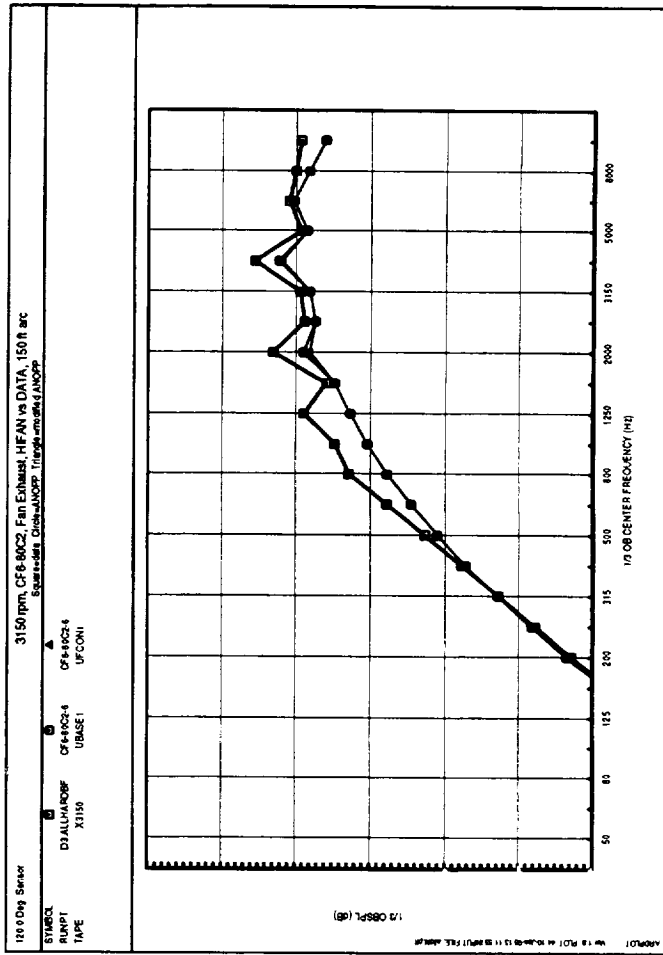
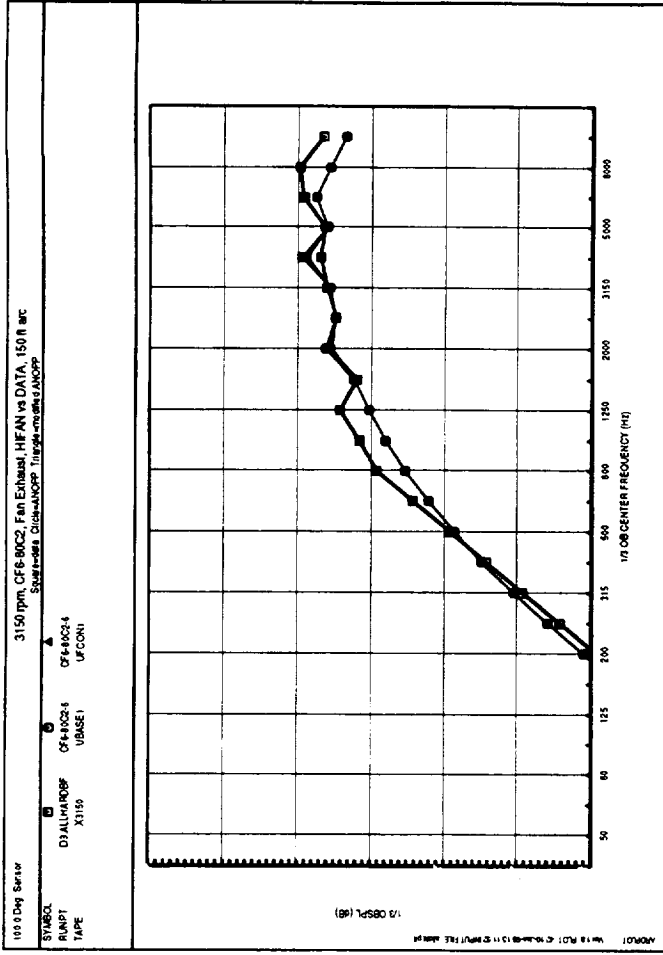
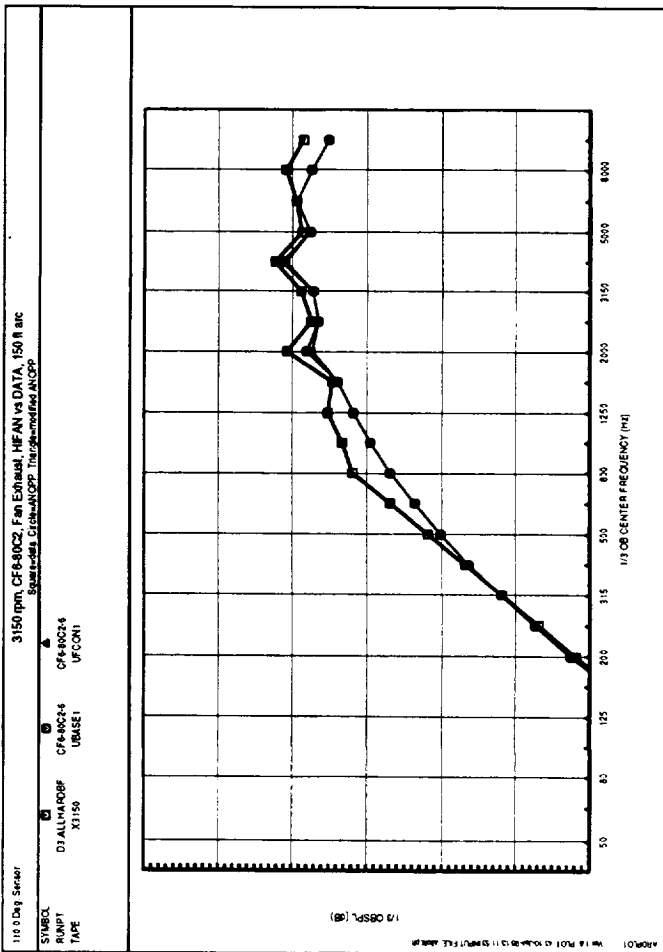
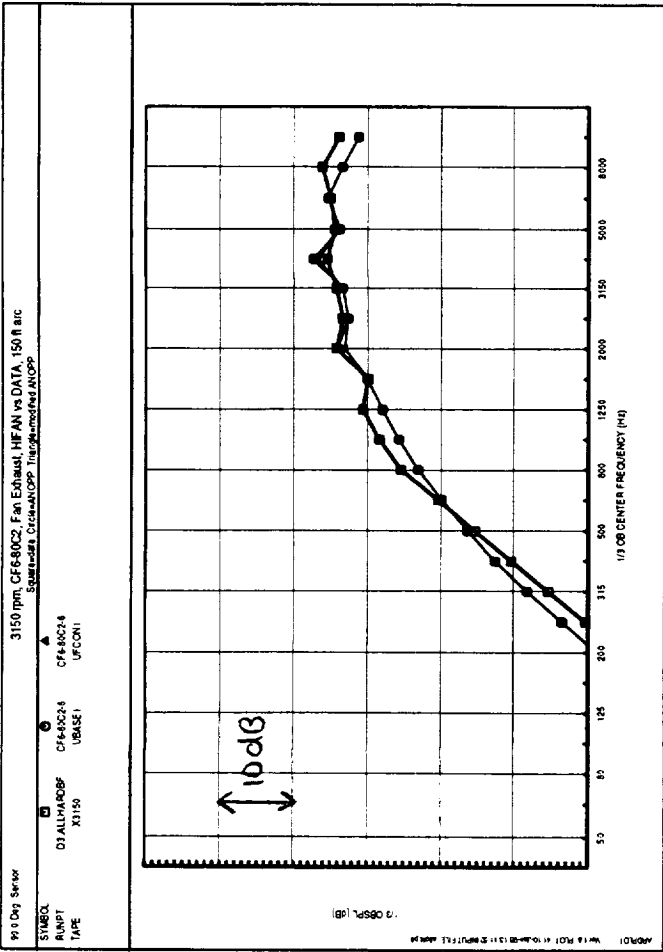


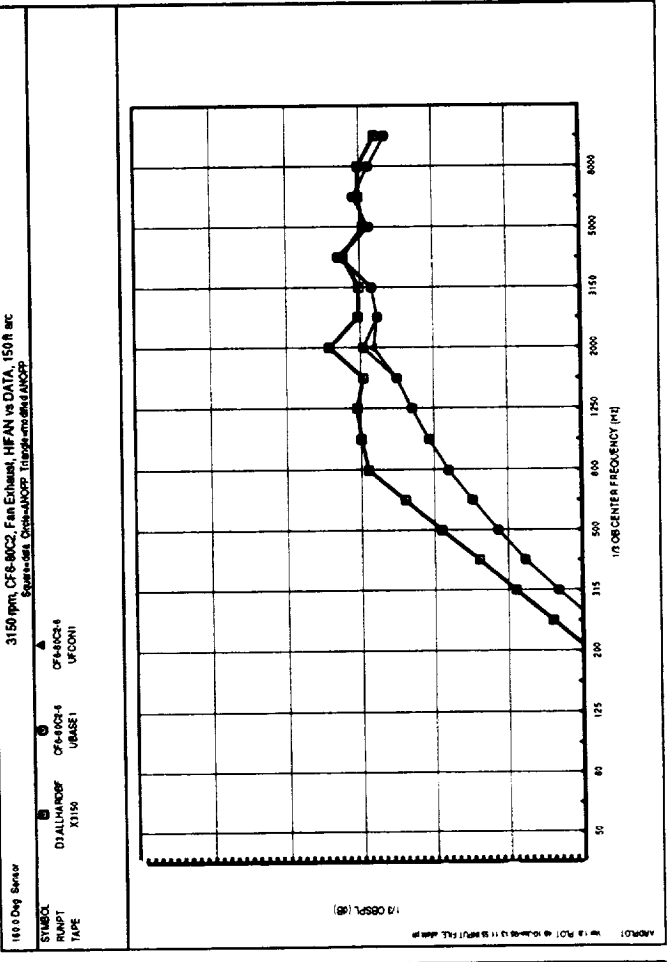
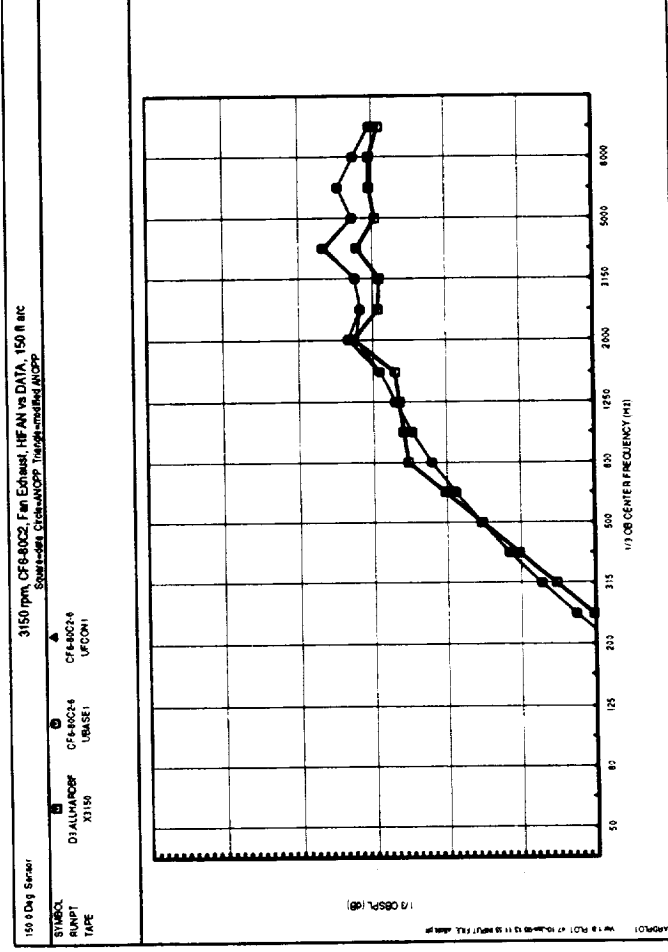
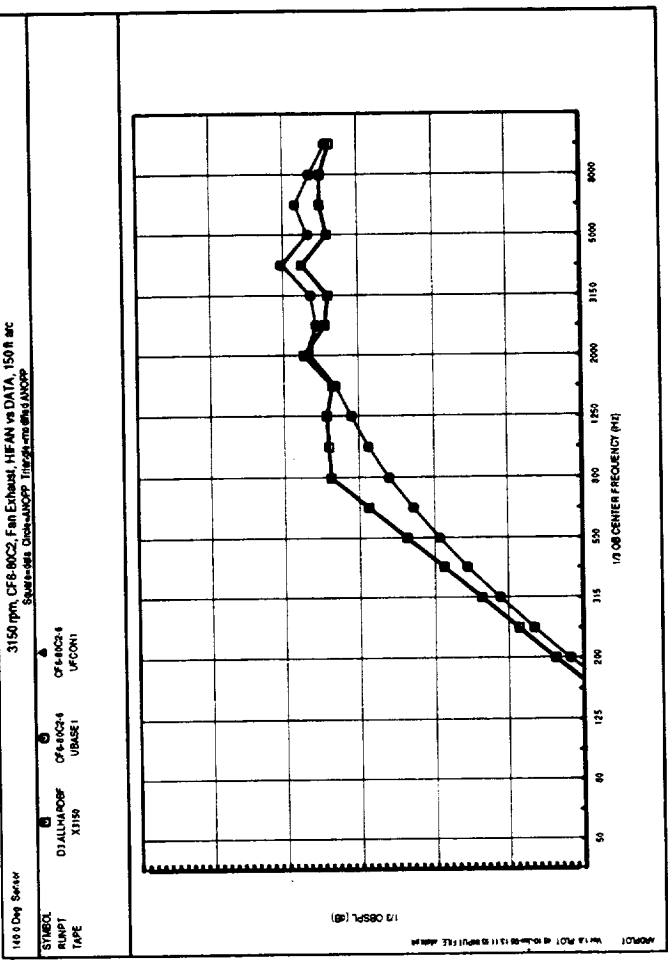
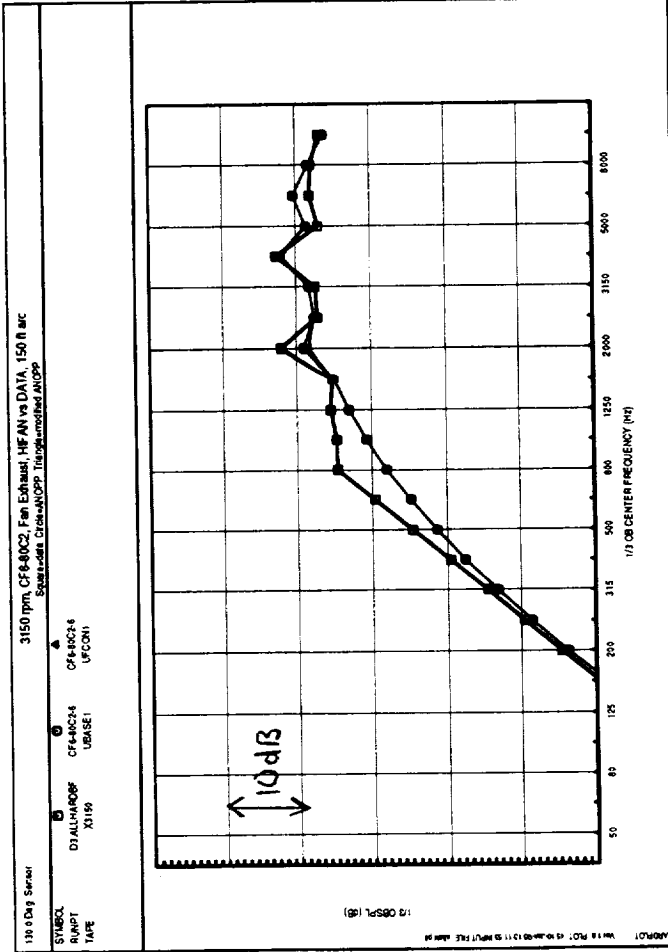




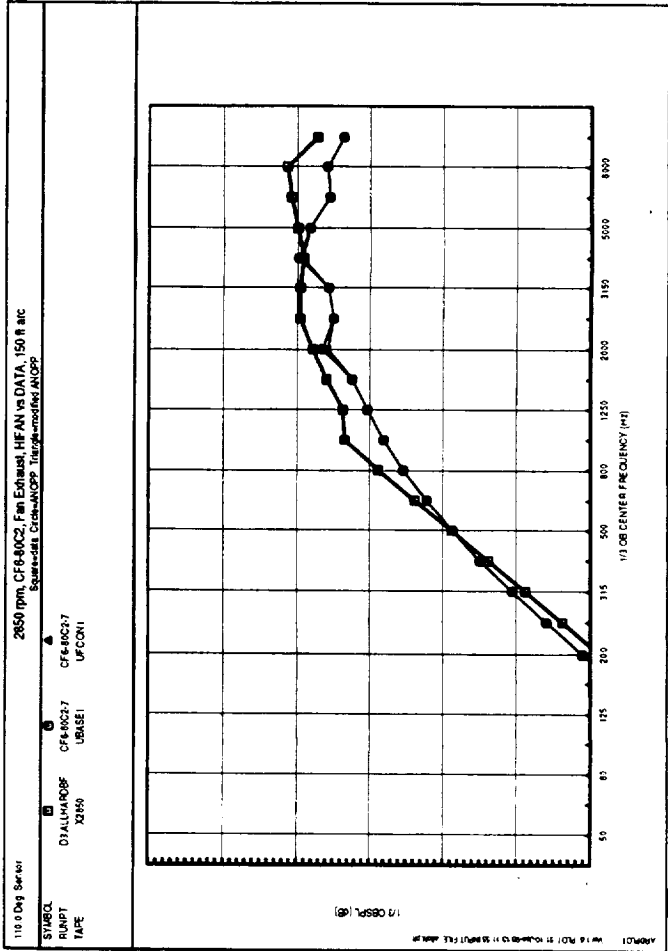
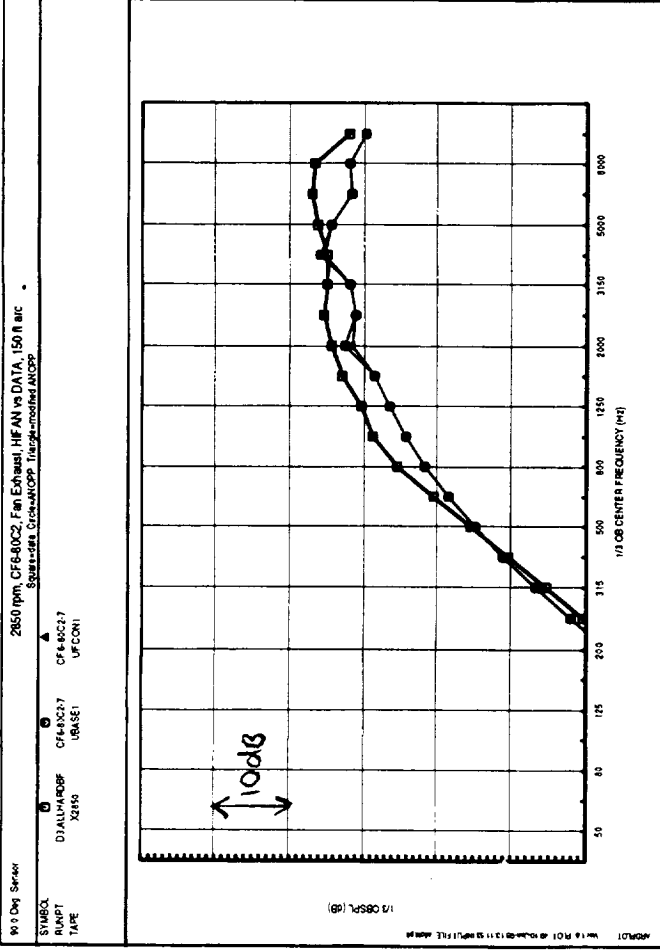
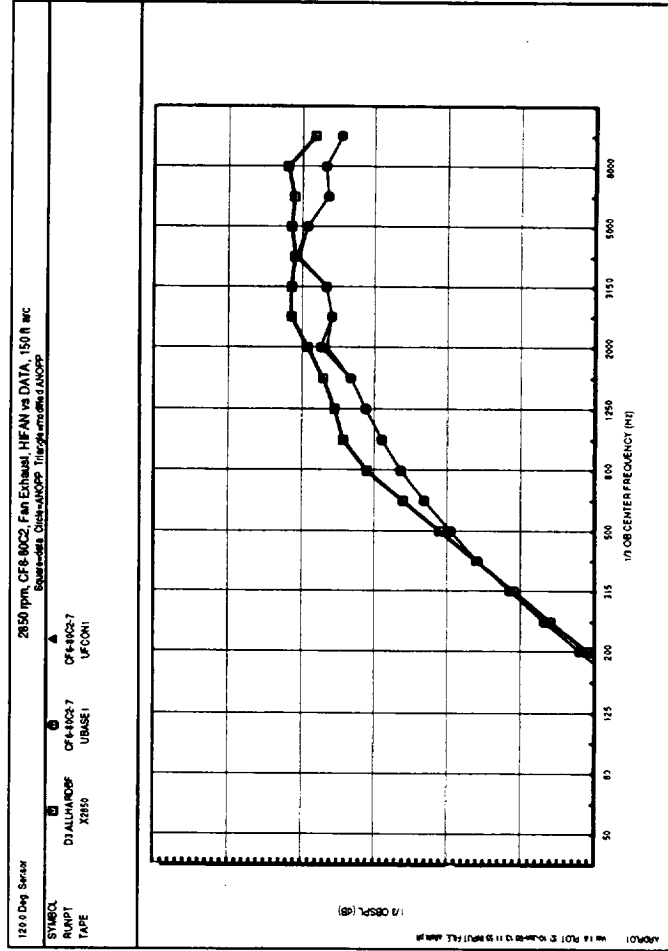
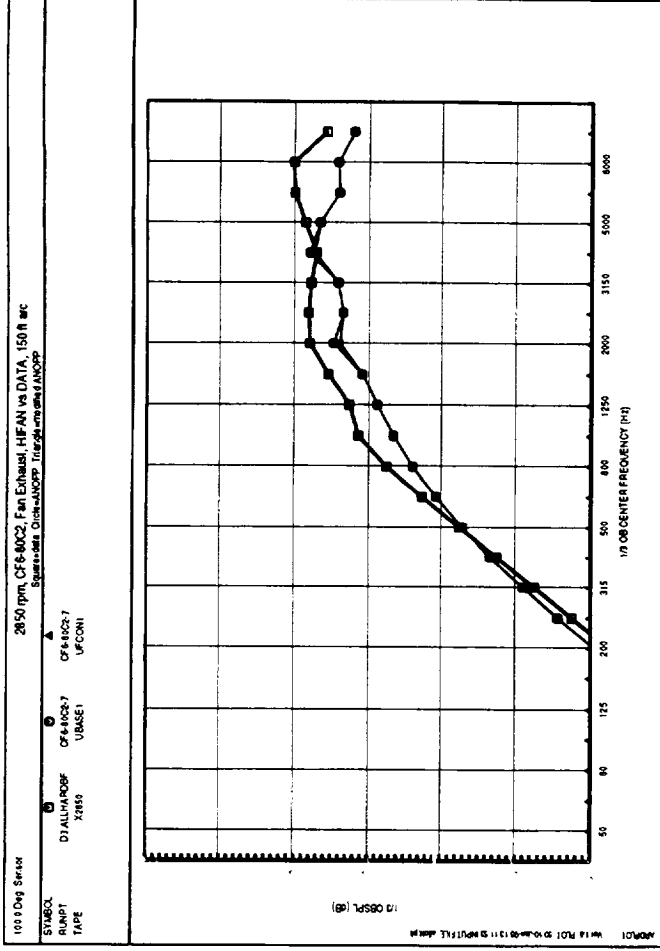


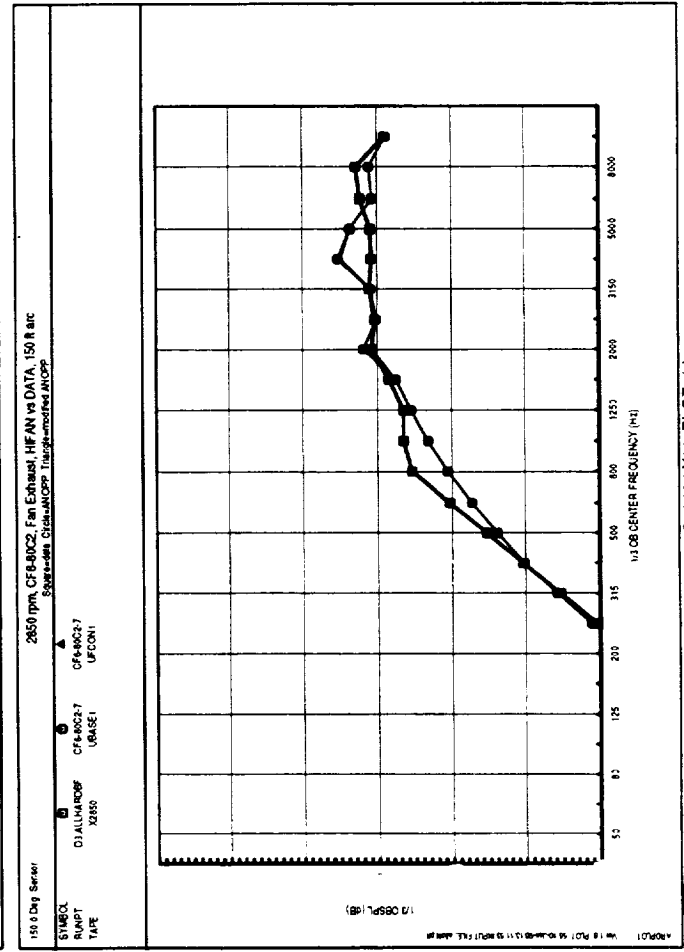
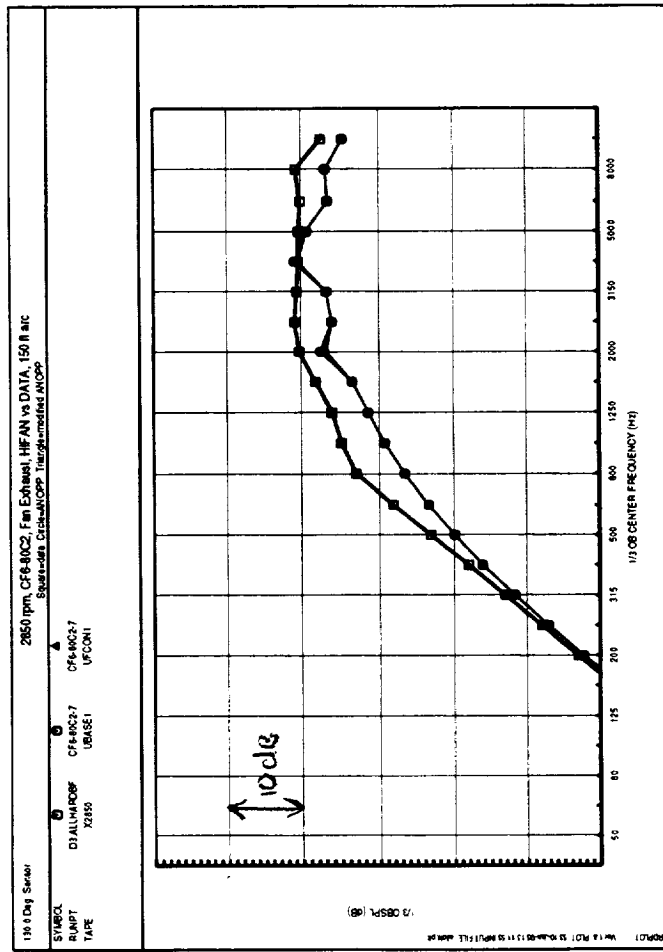
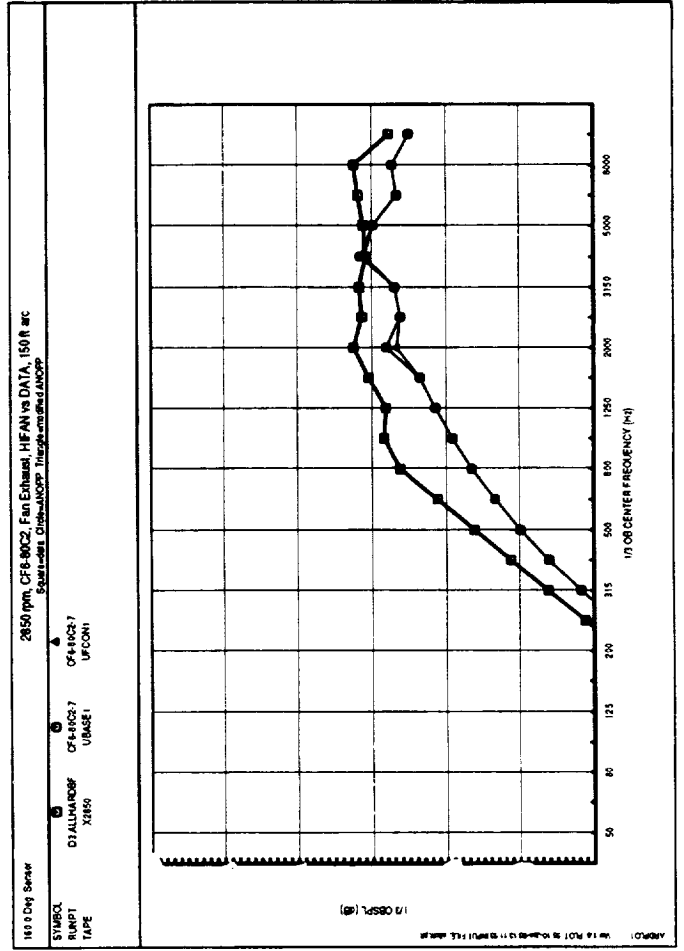
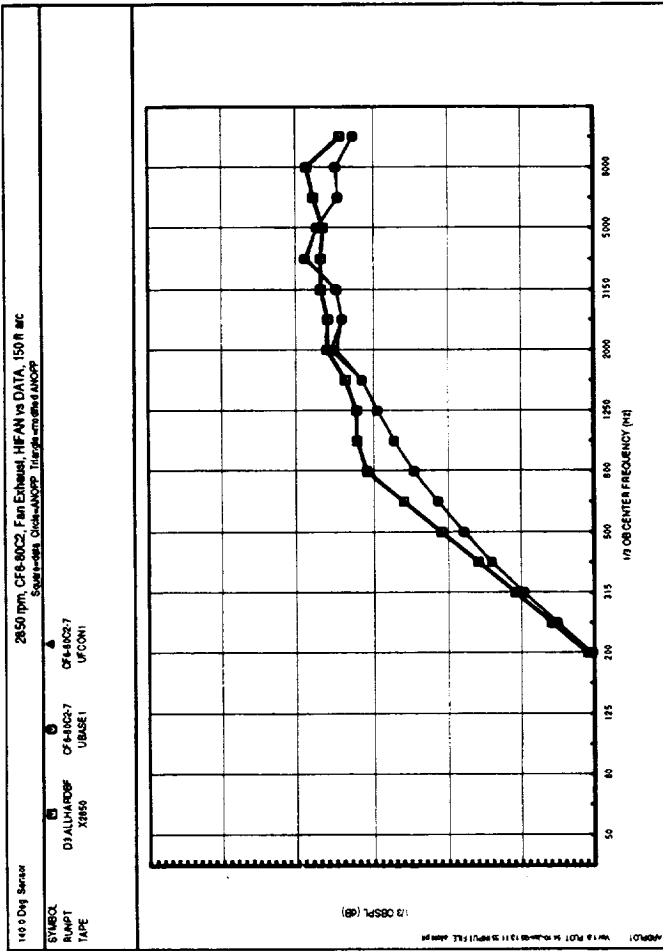


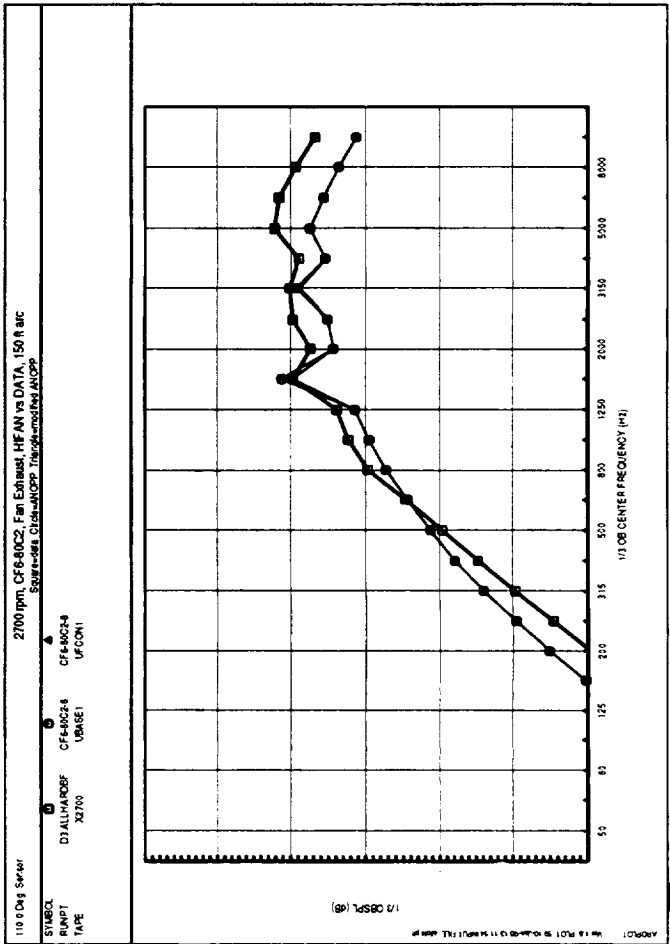
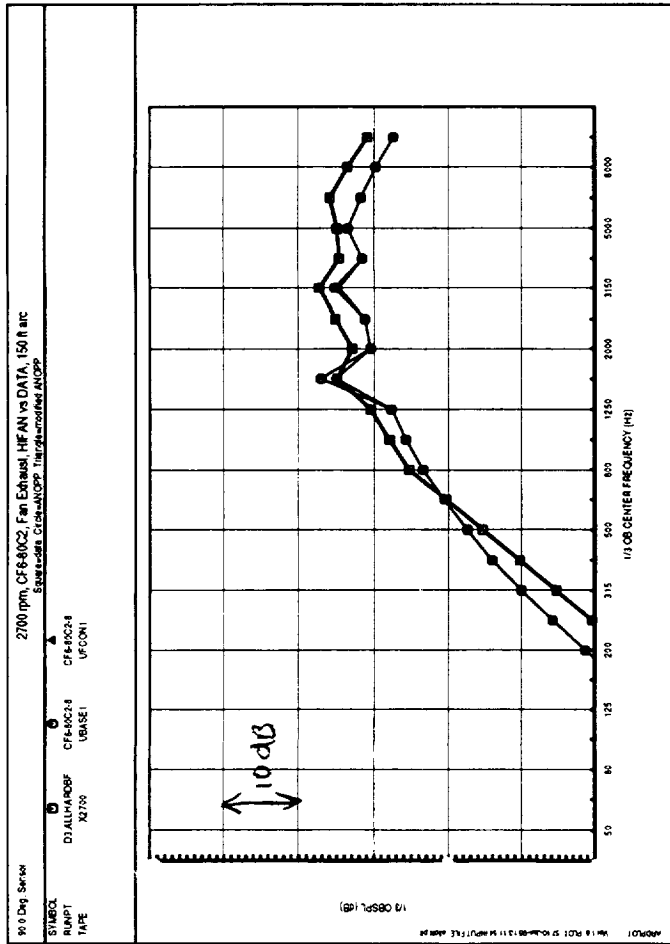
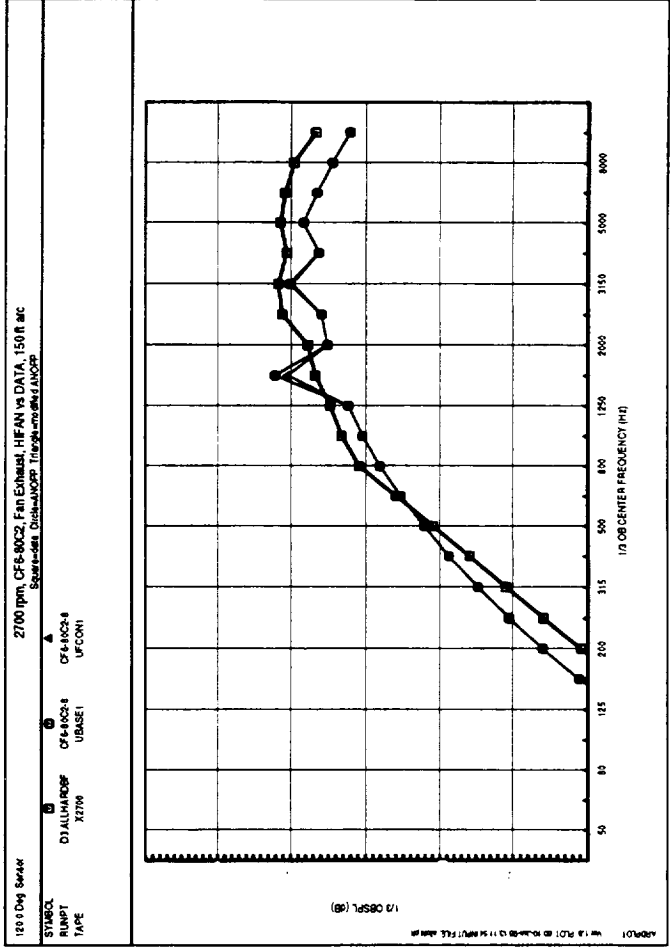
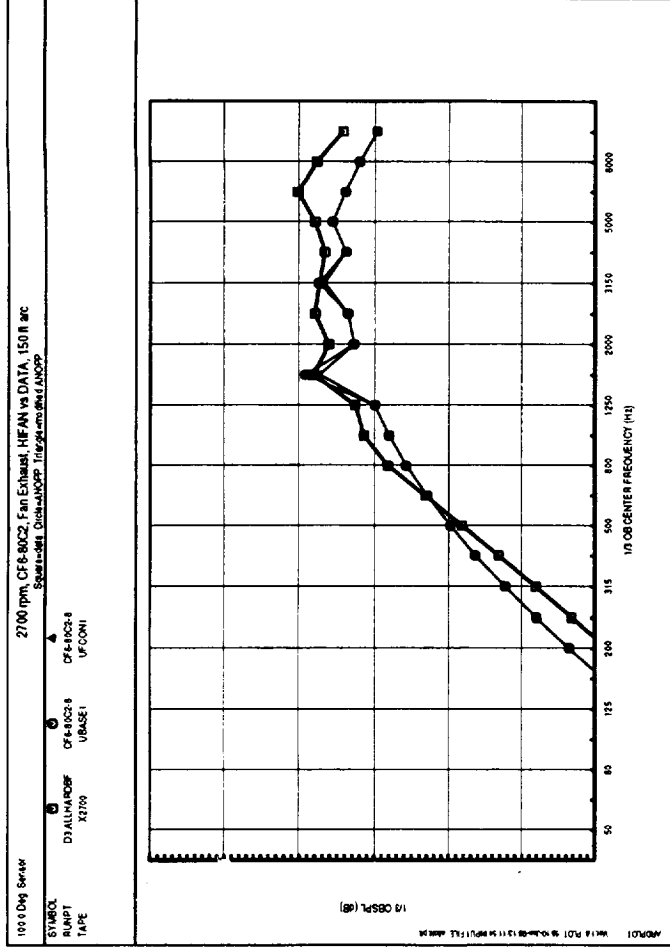


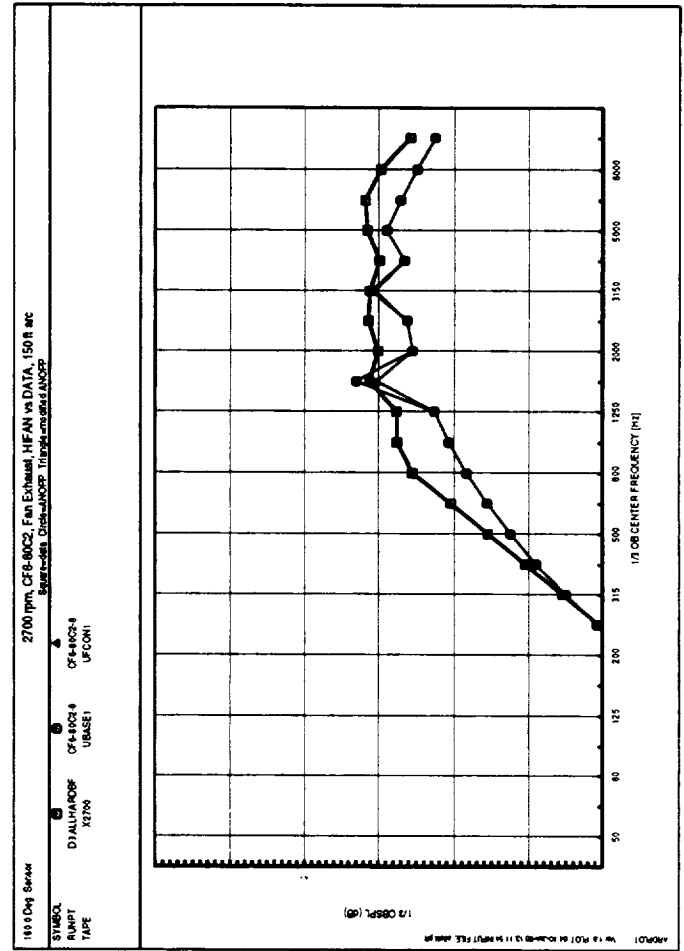
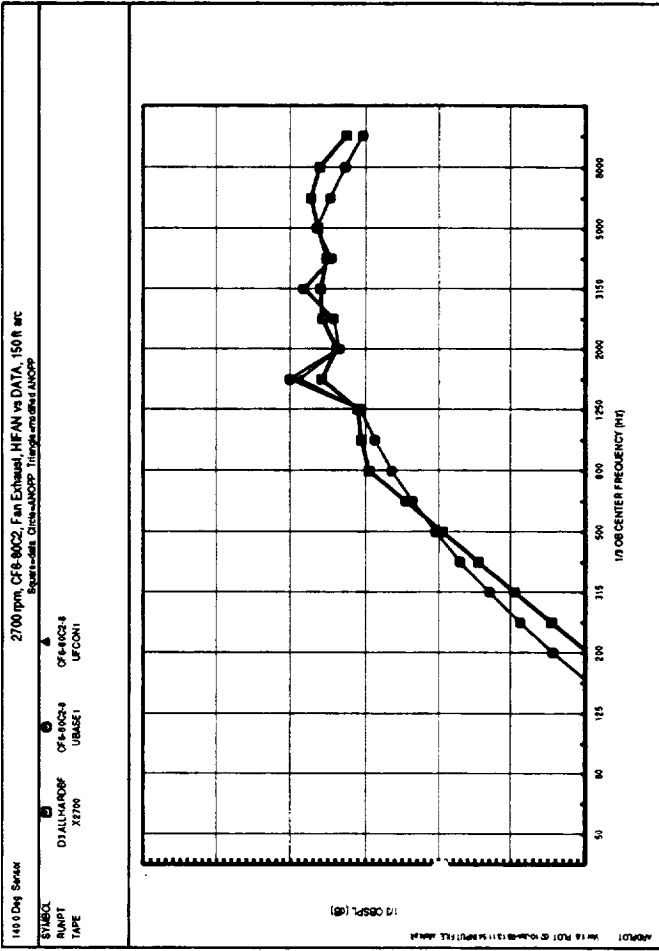
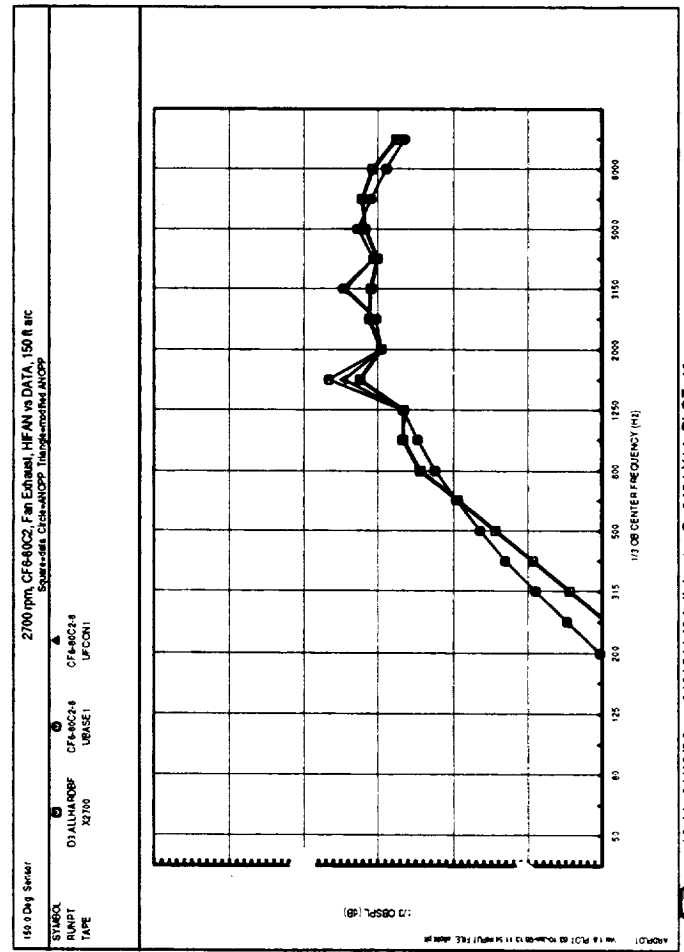
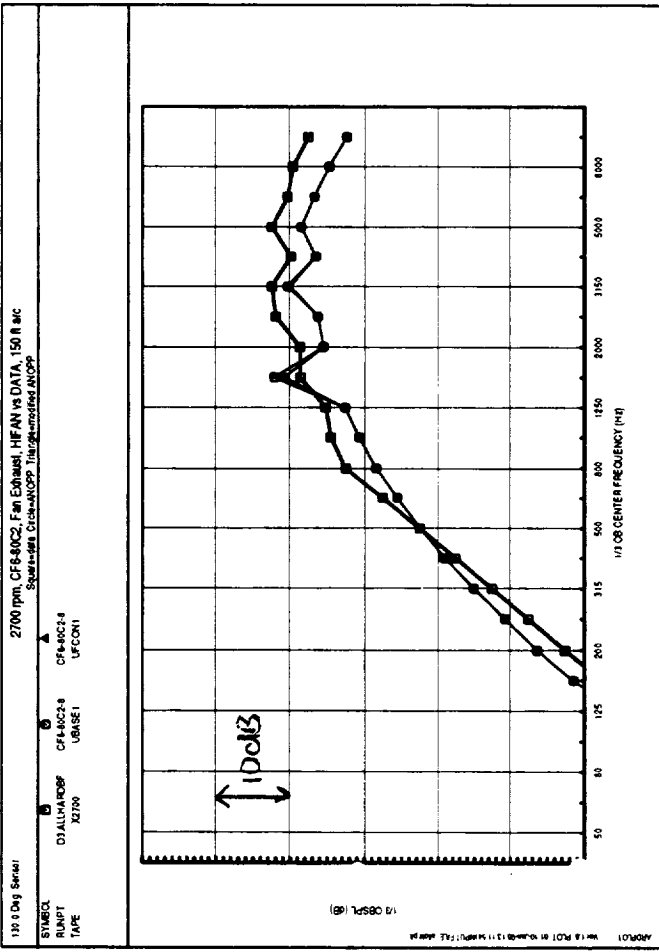


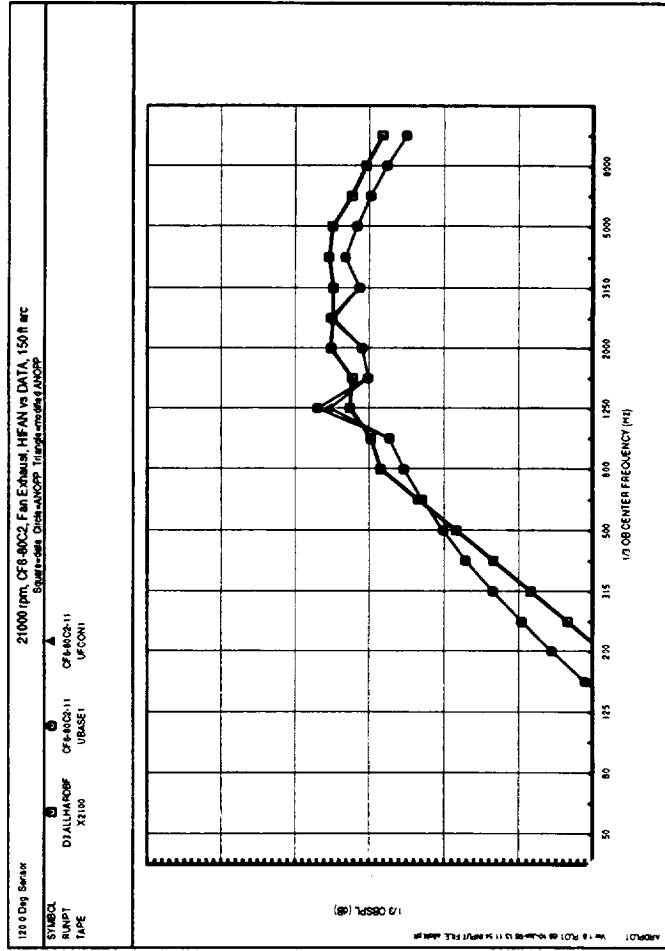
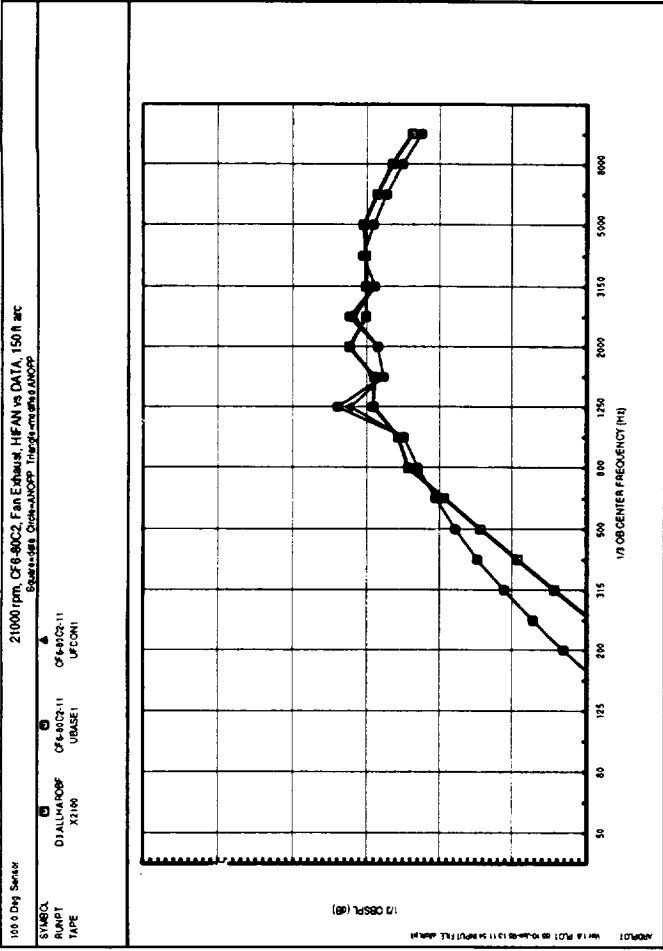
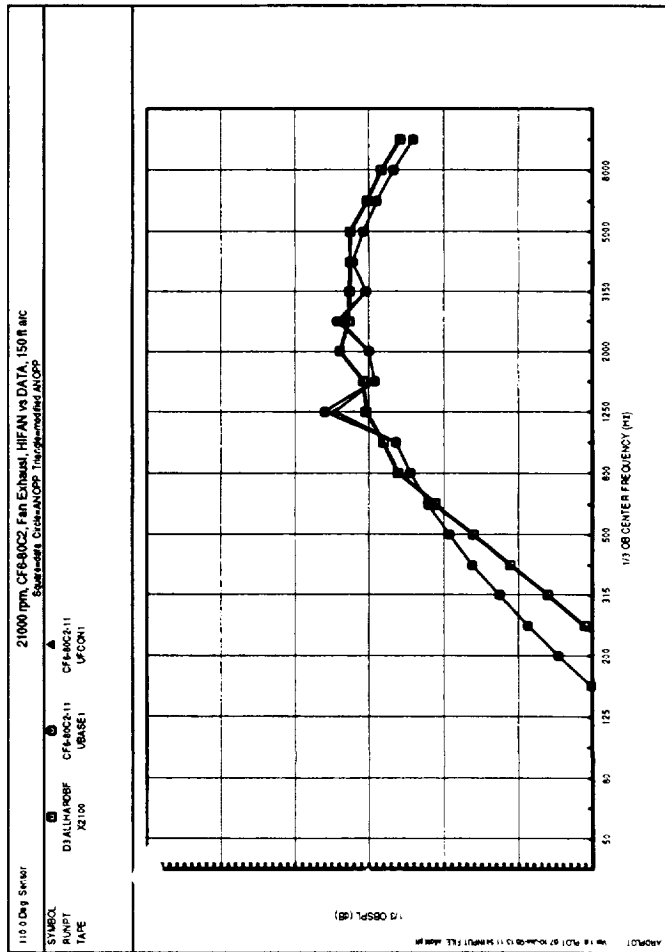
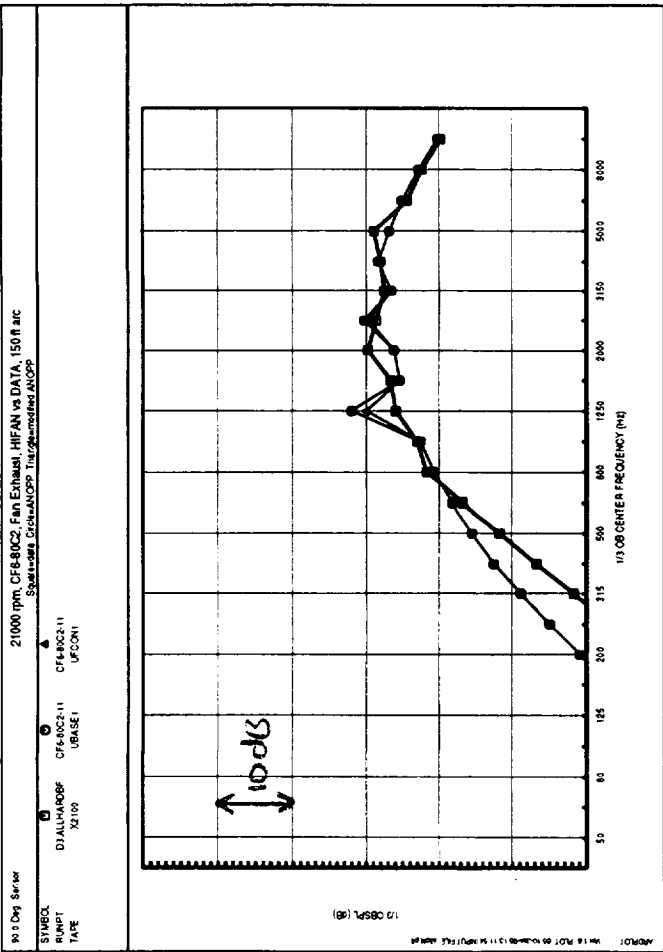


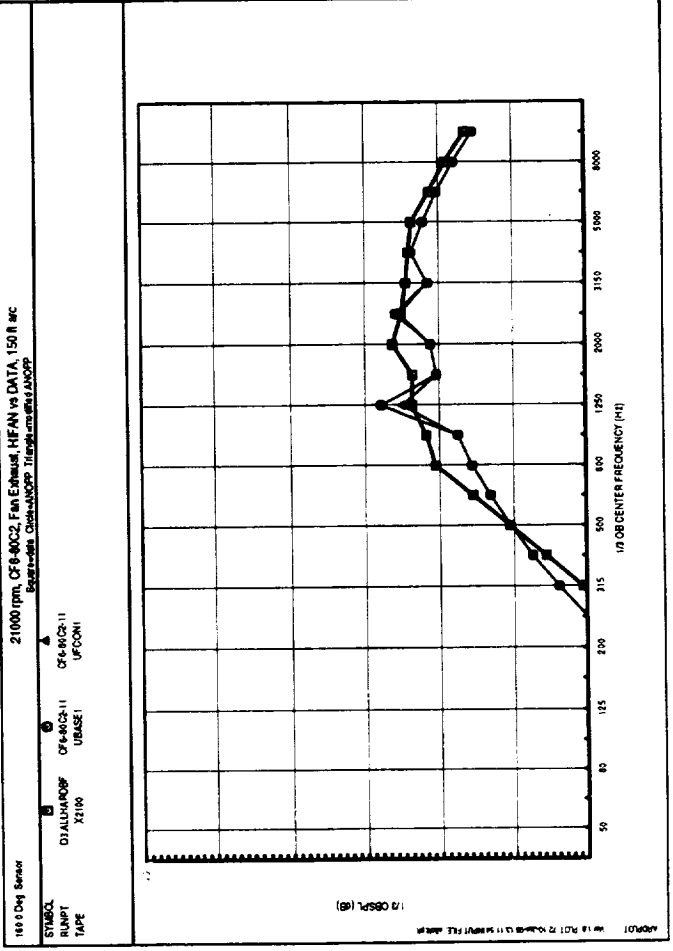
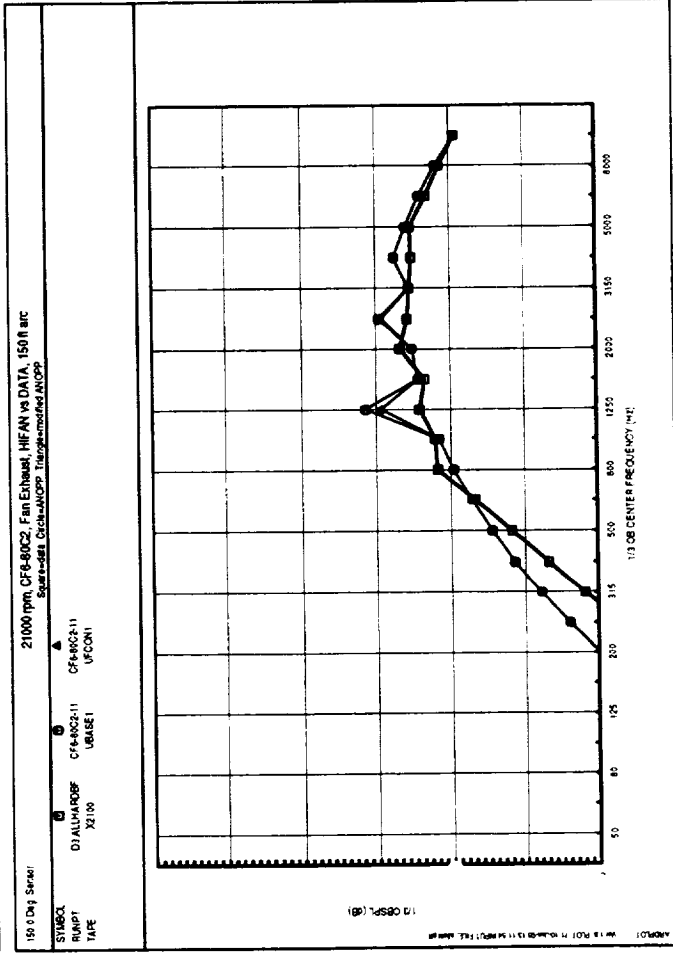
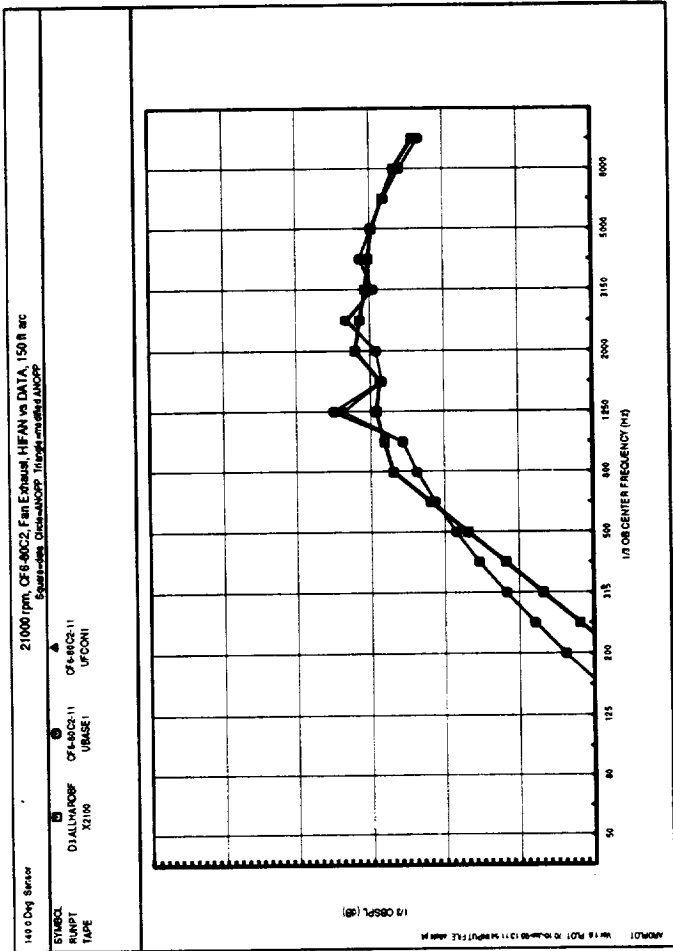
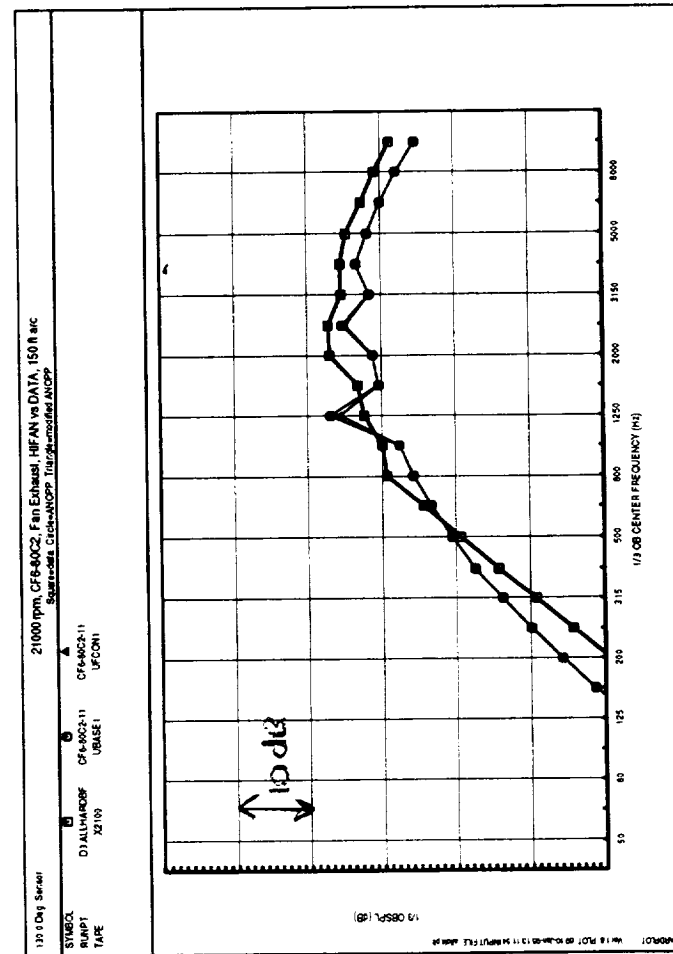


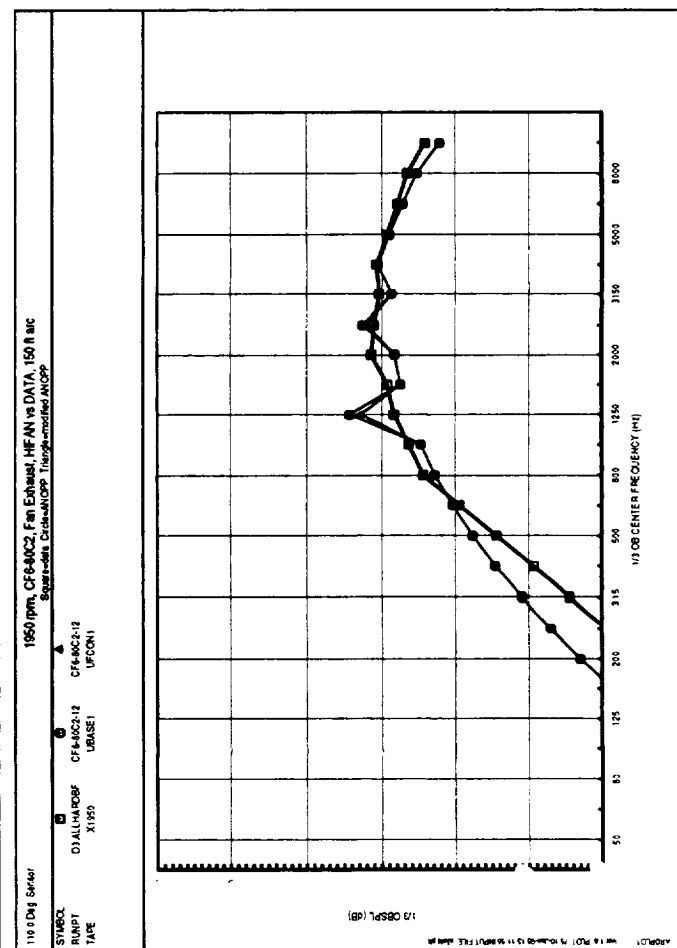
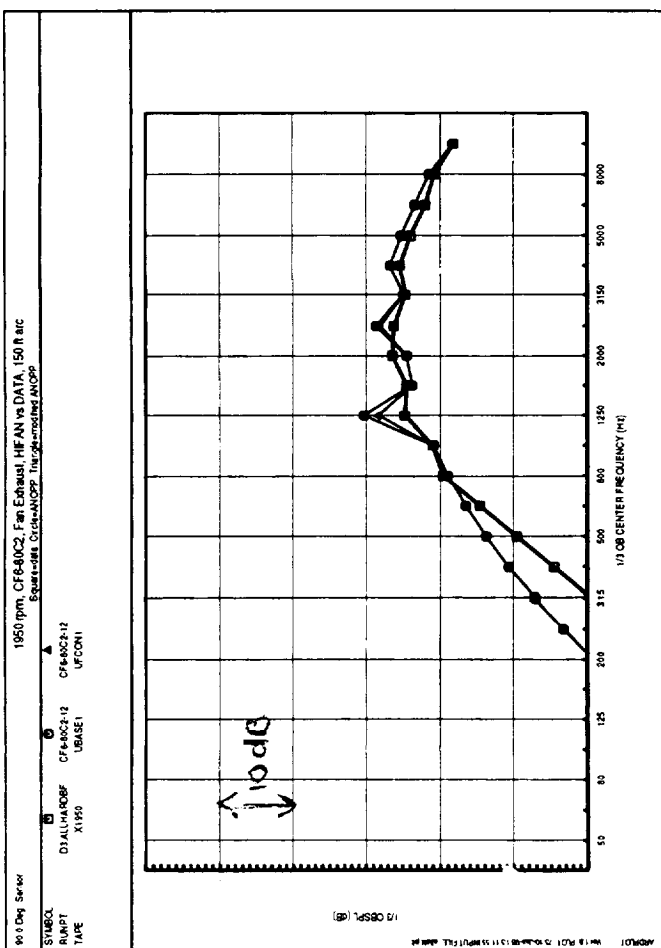
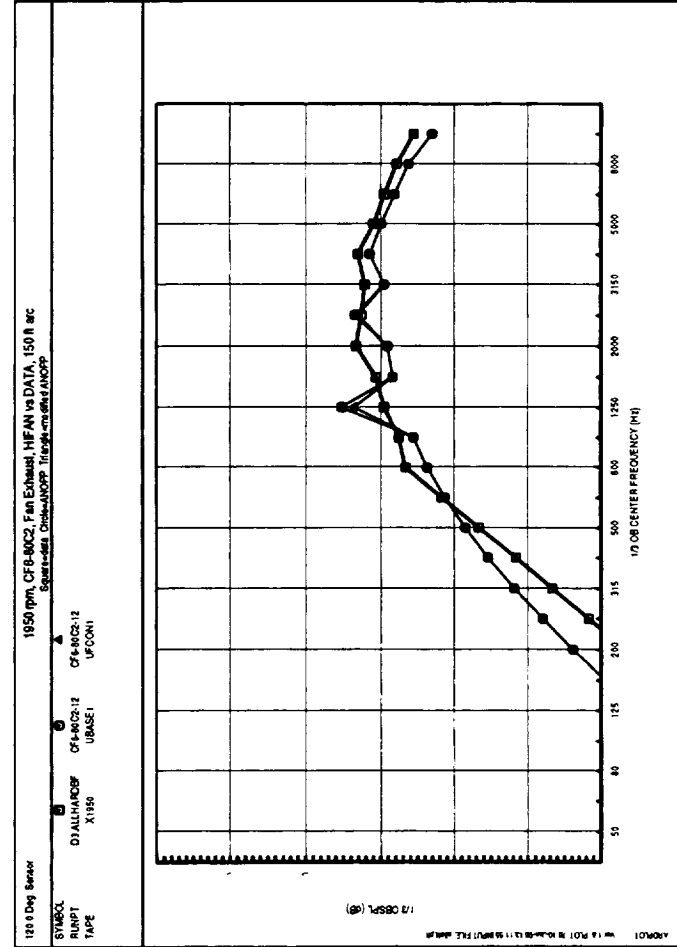
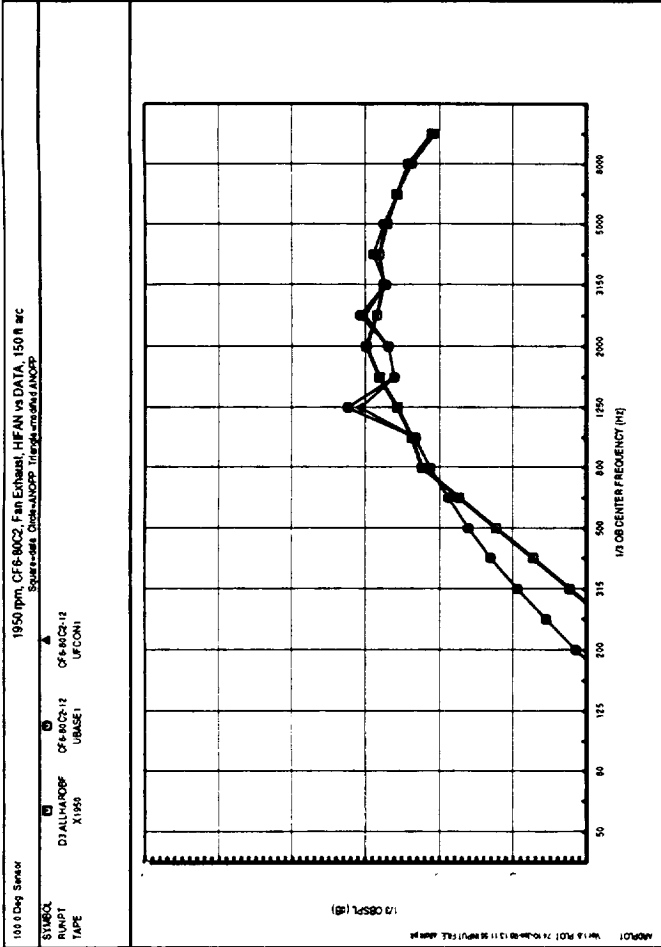


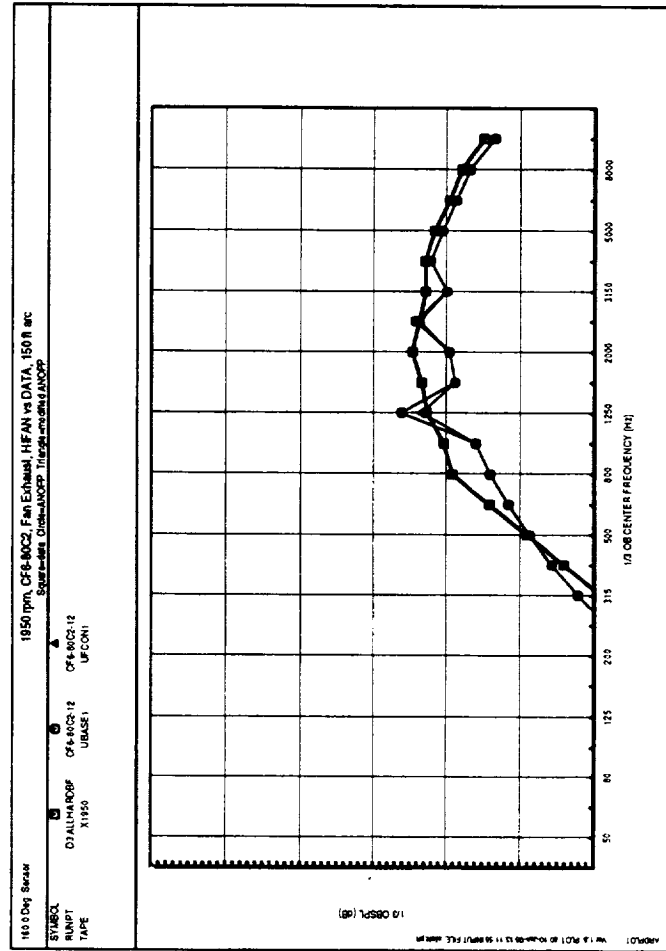
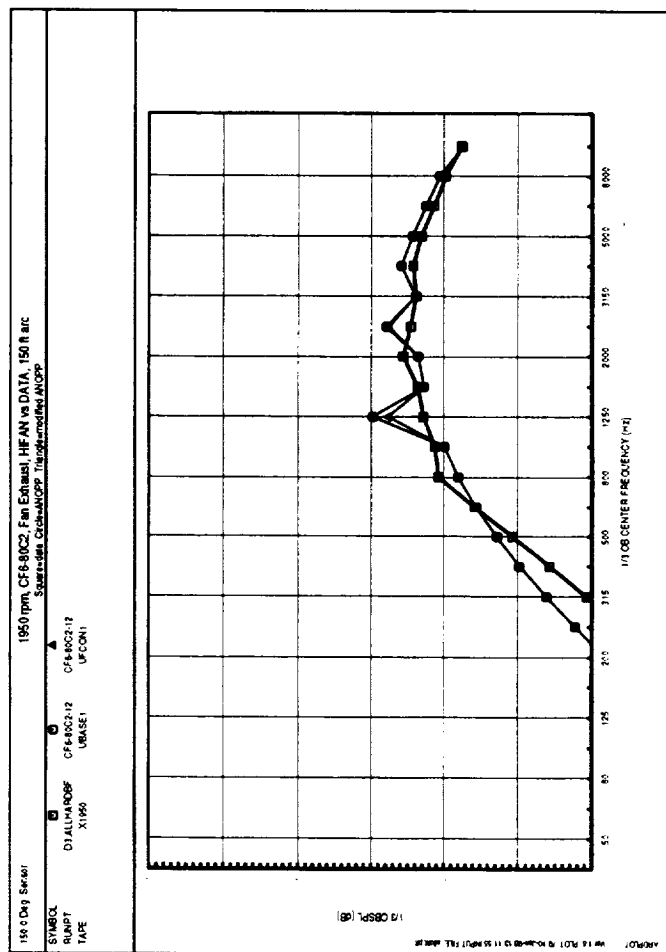
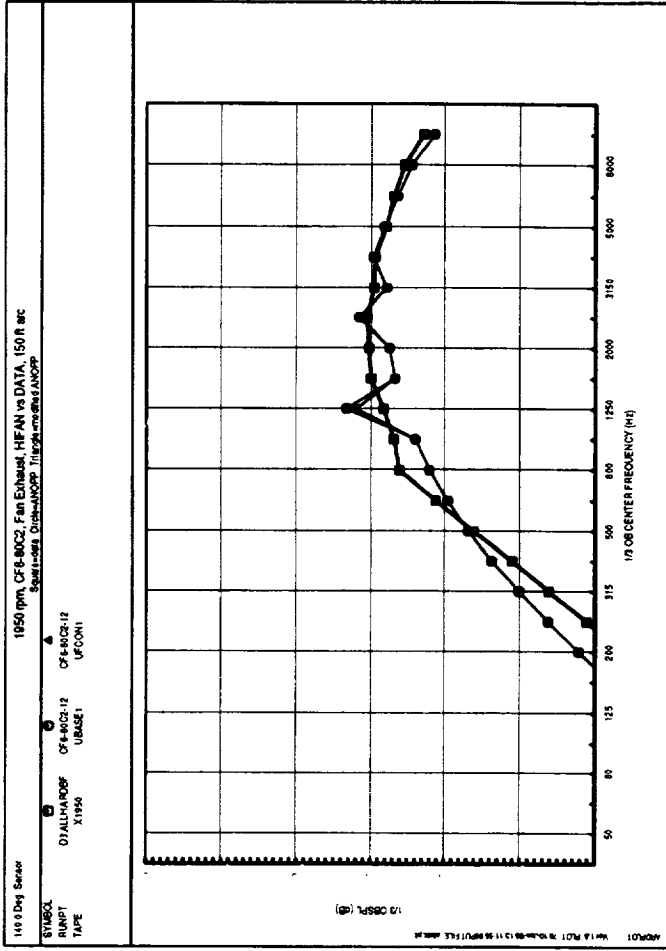
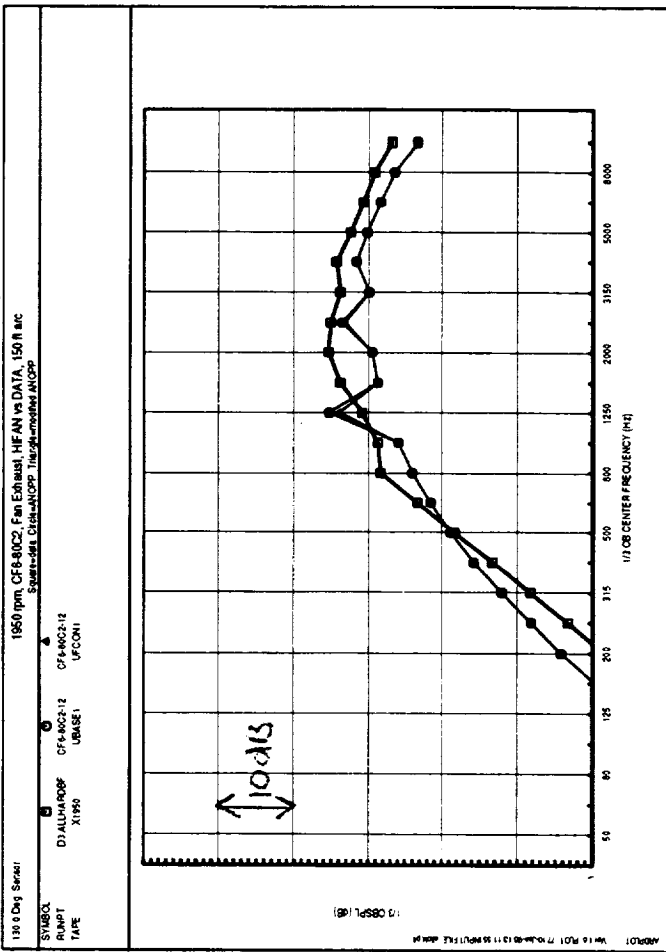




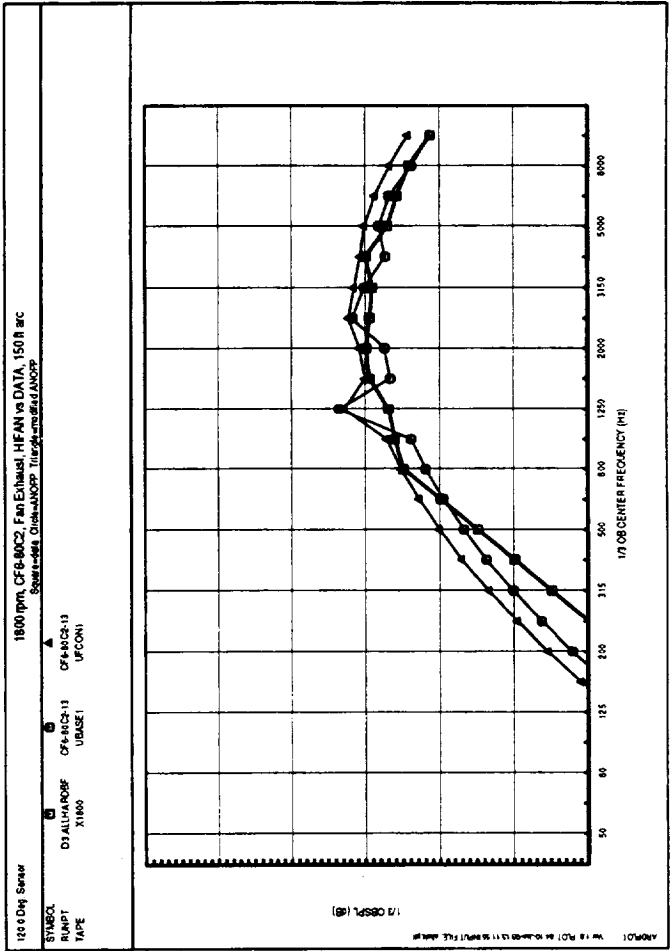
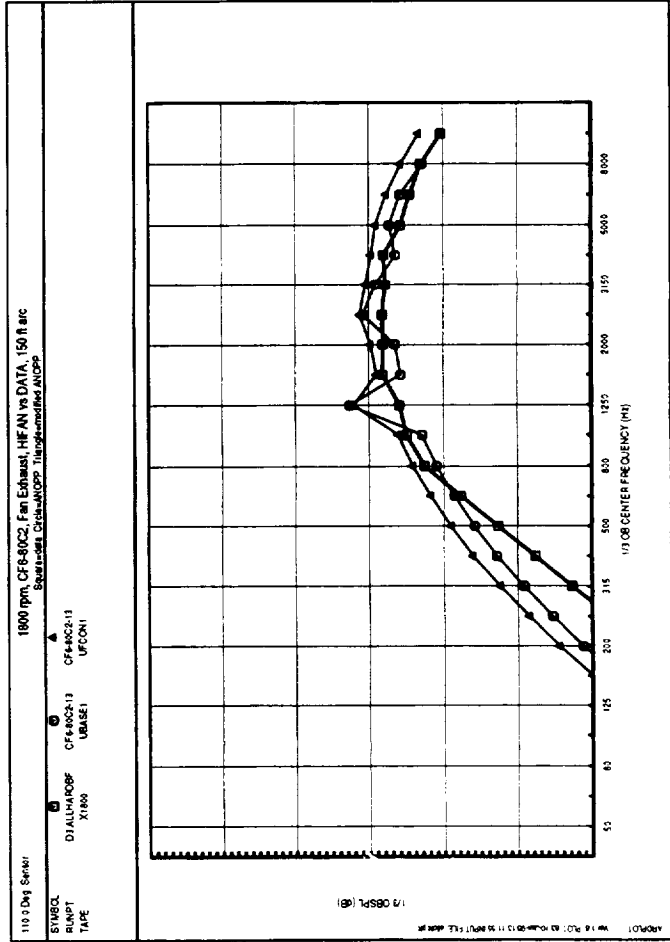
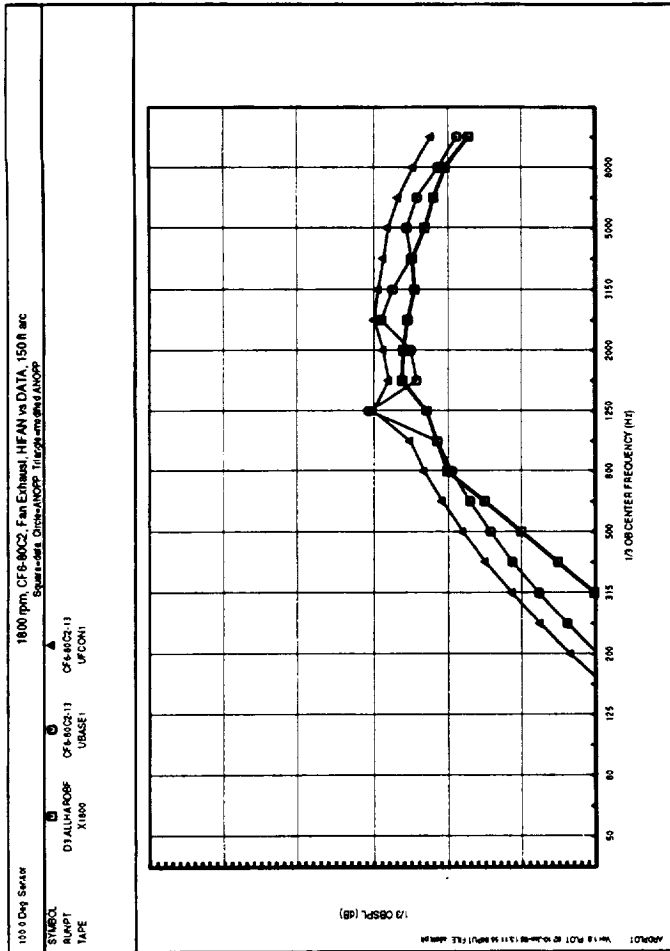
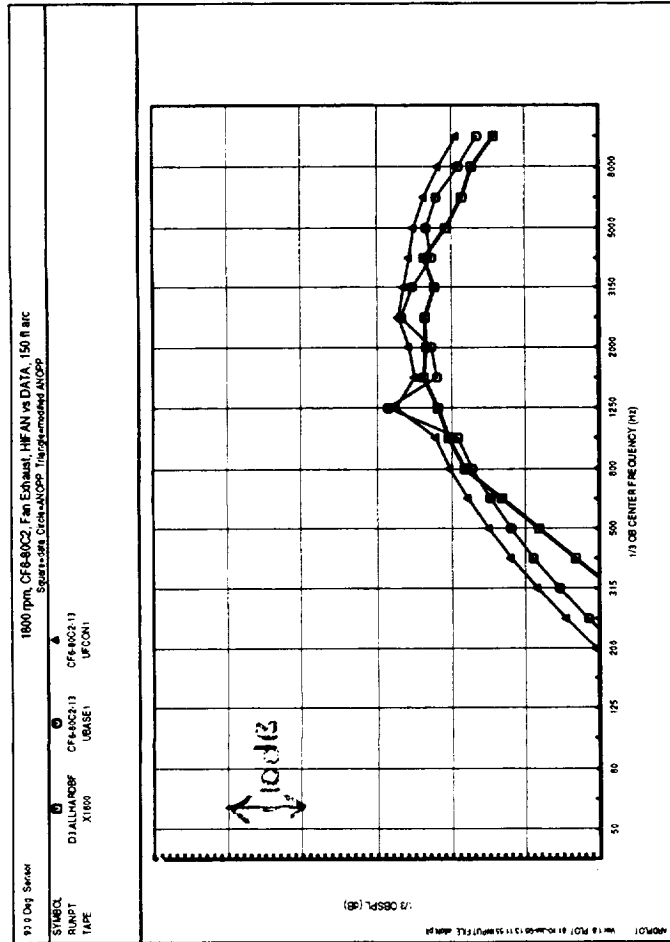


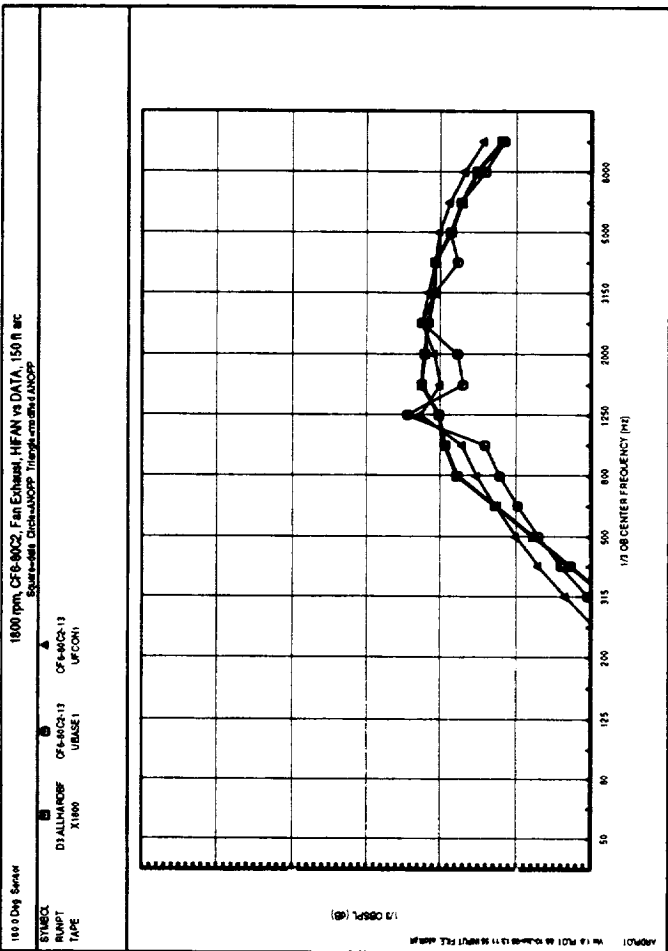
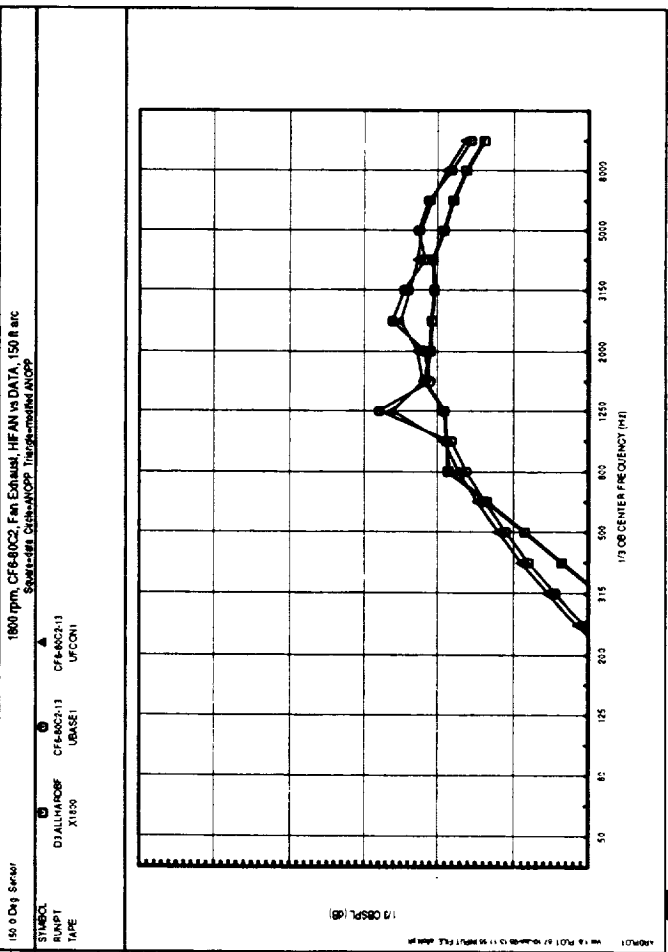
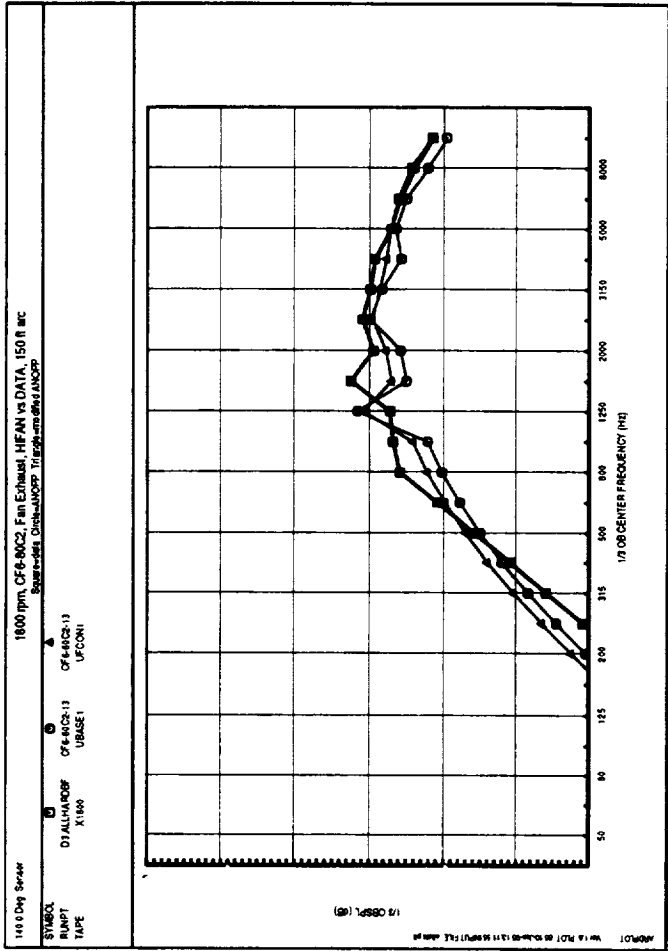
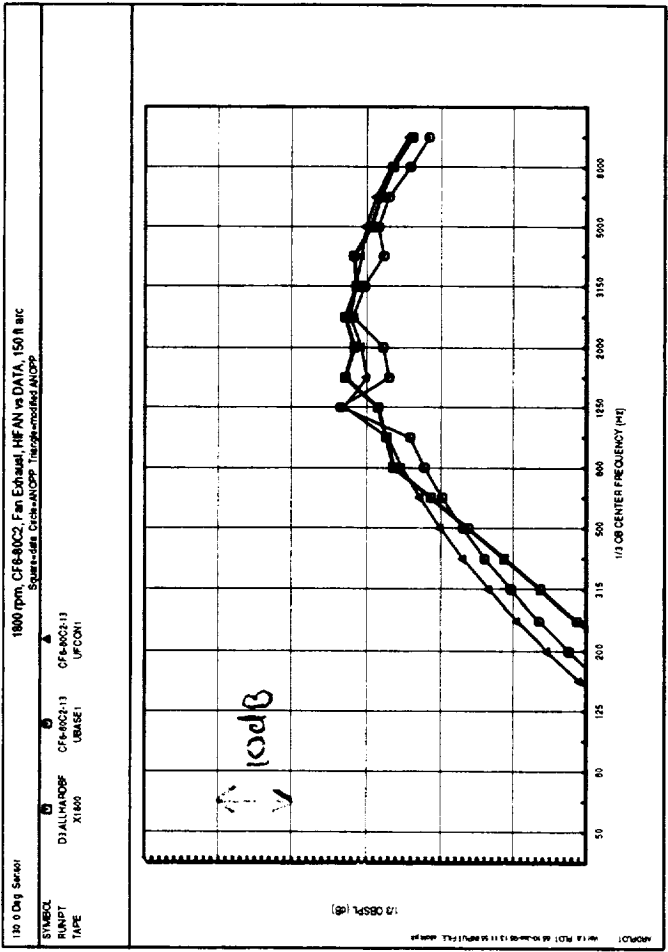


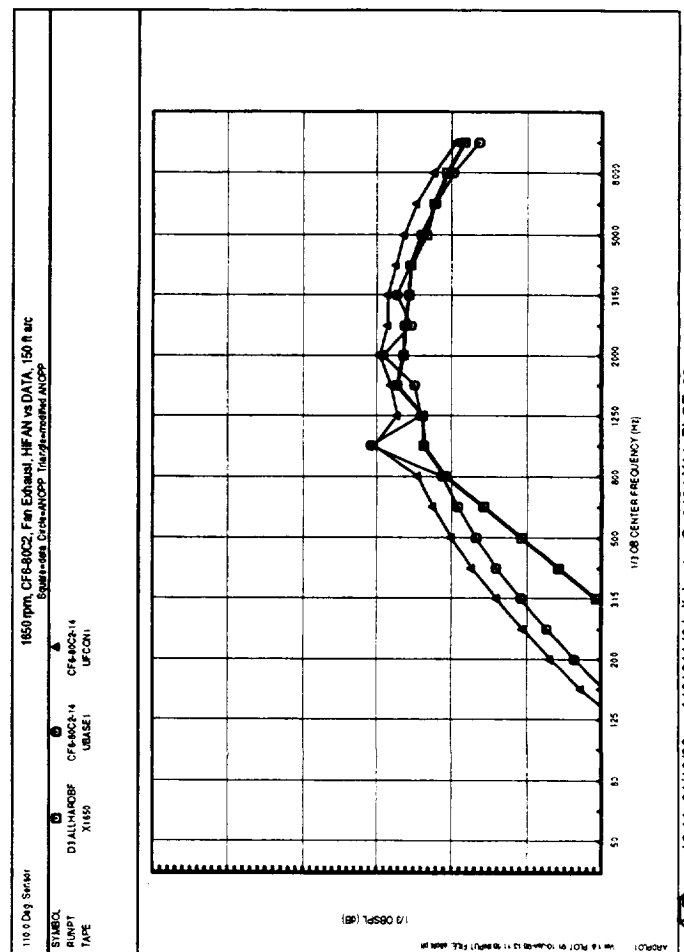
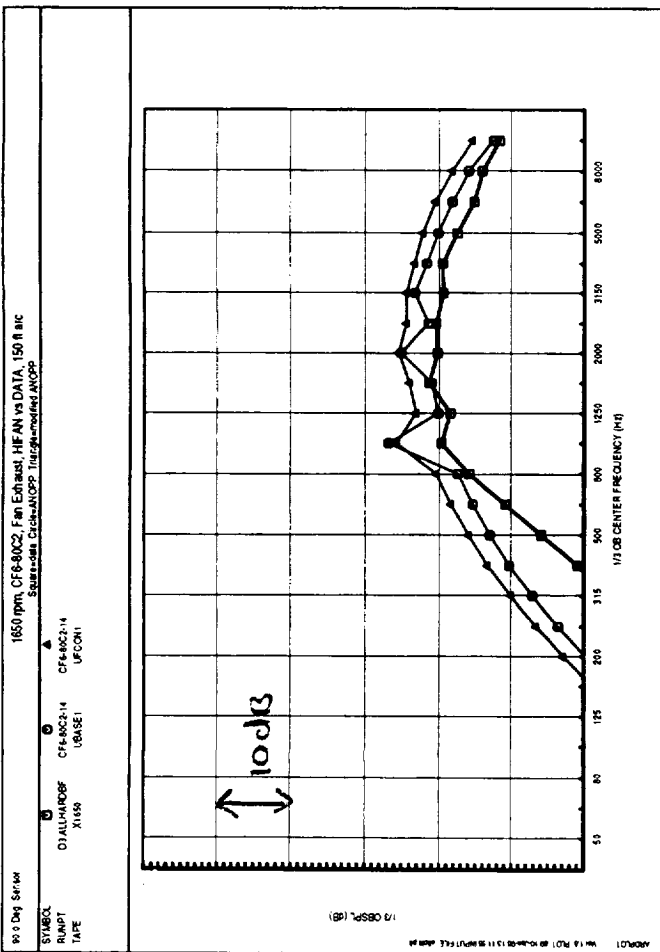
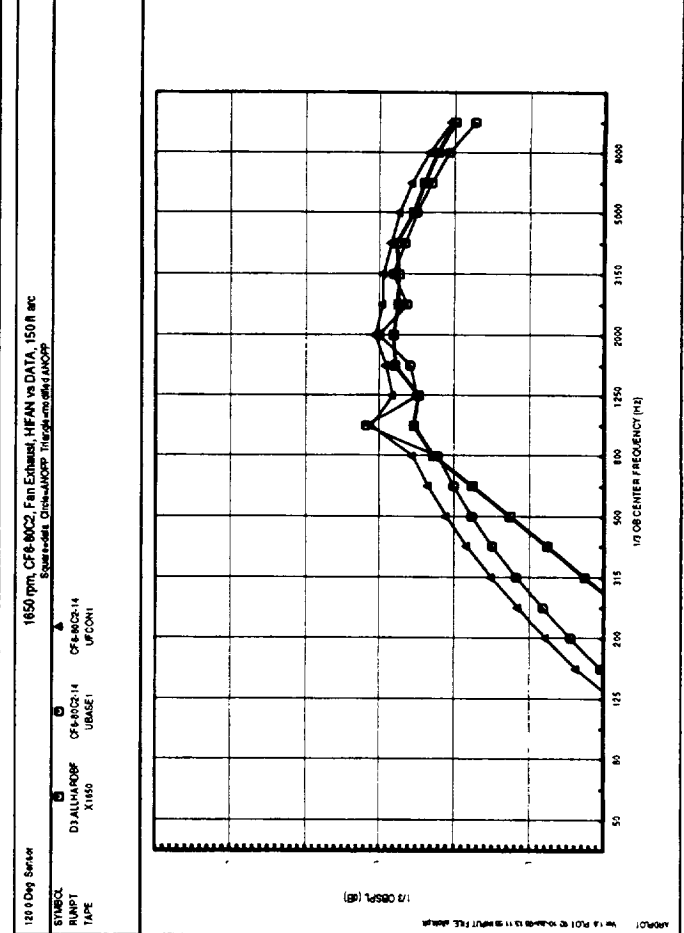
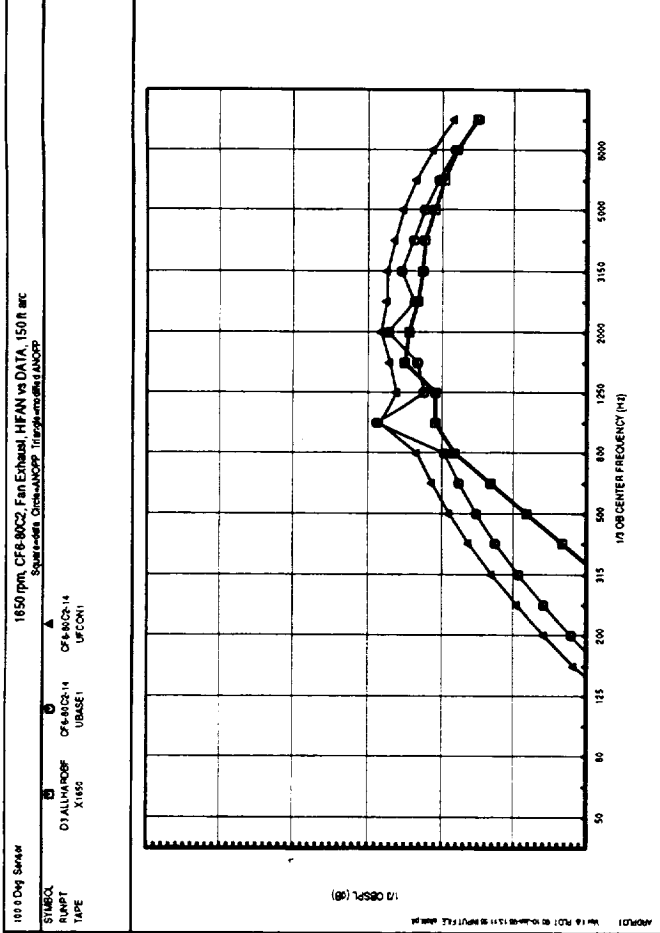






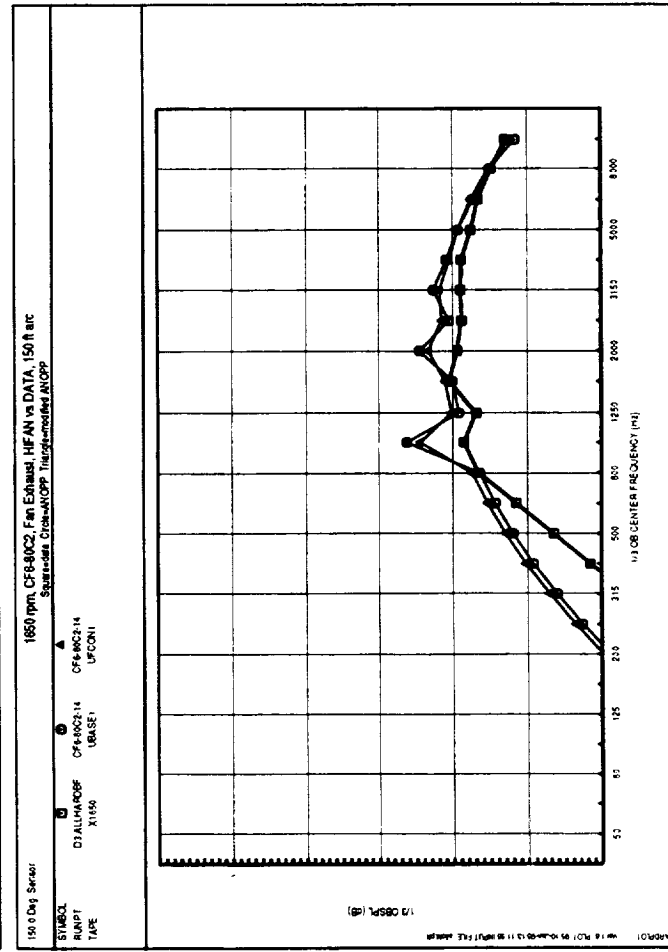
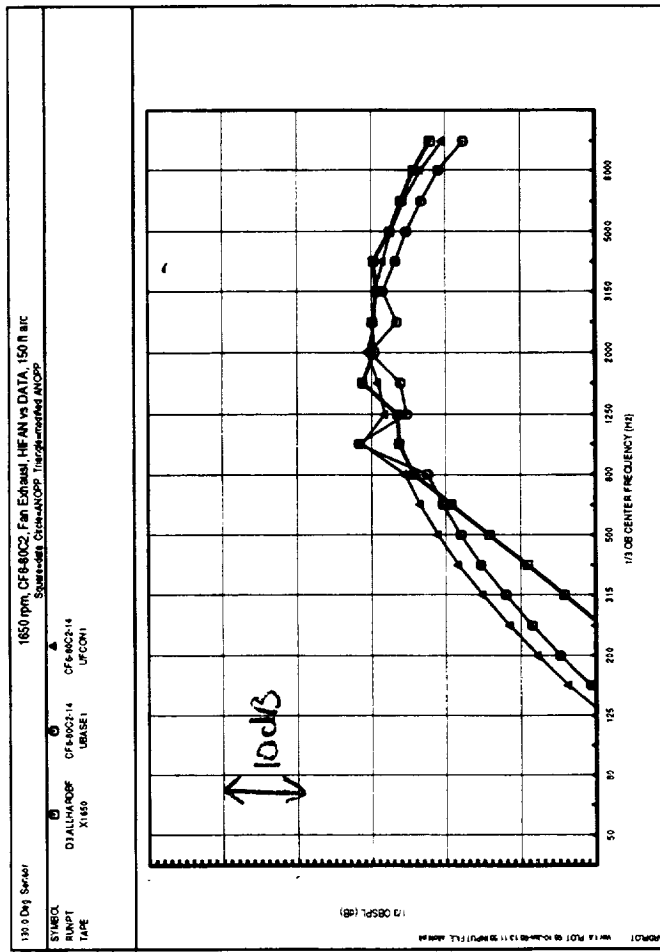
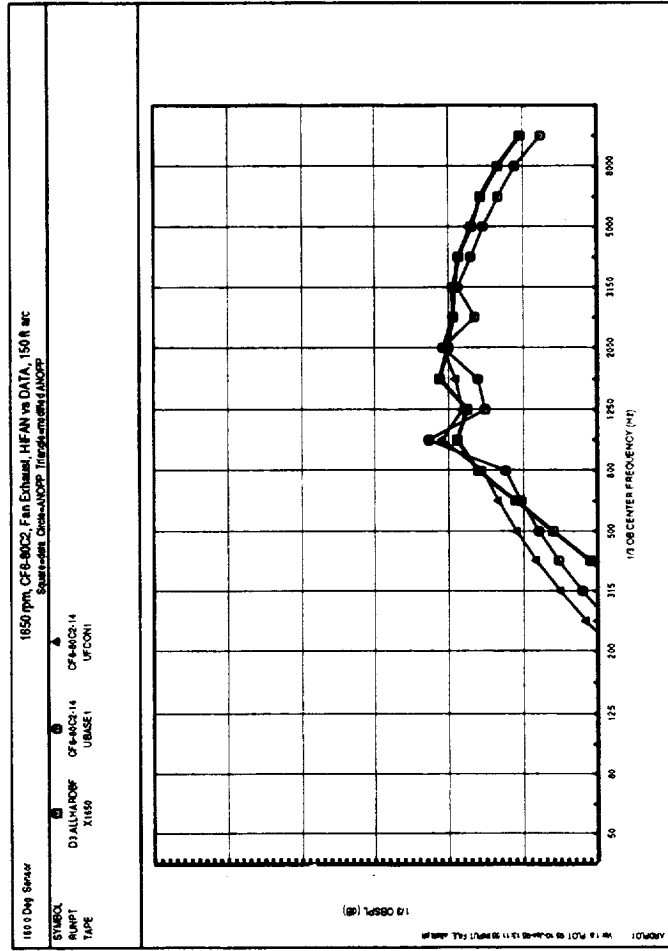
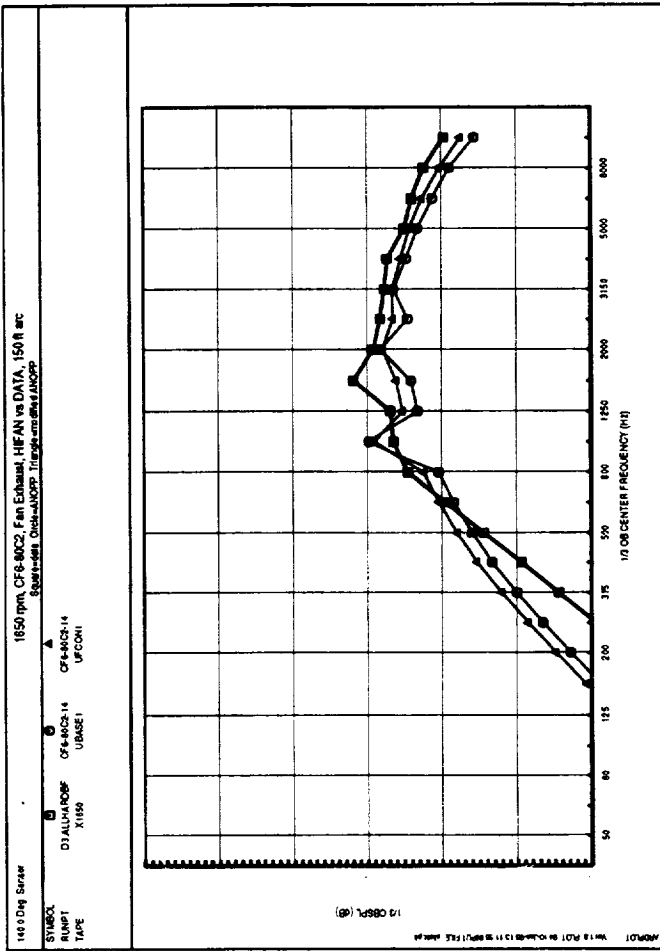






13-11 01/10/96 MA10131149.pdf Kontos@c0424 X11 PLOT 23  
 EGS LIB 5.1 12/4/95 EGSREP.XPOST 5.1 12/14/95 on c0424  
 (NO PROG. VER. SPECIFIED)





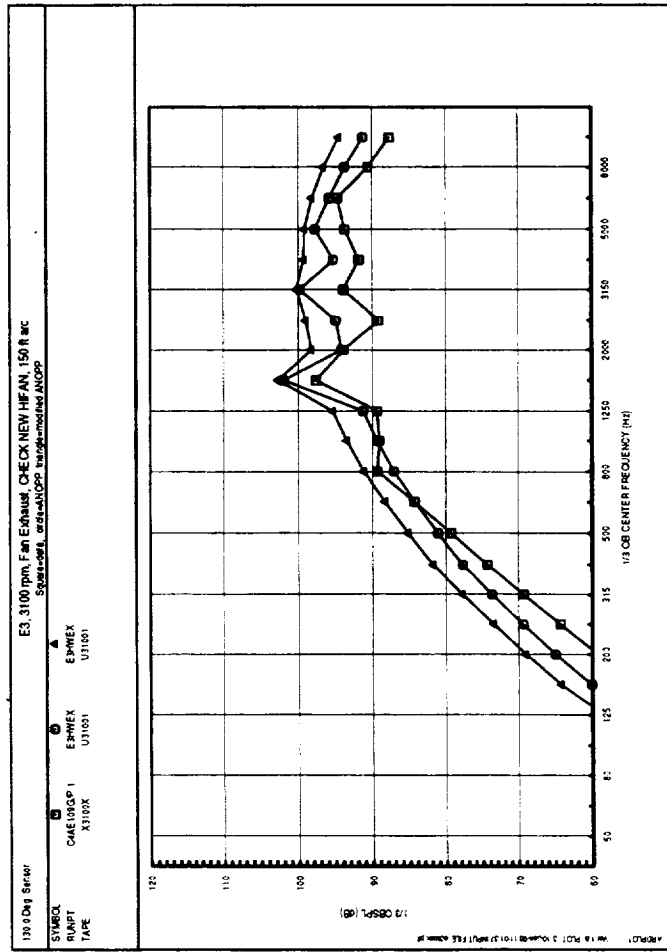
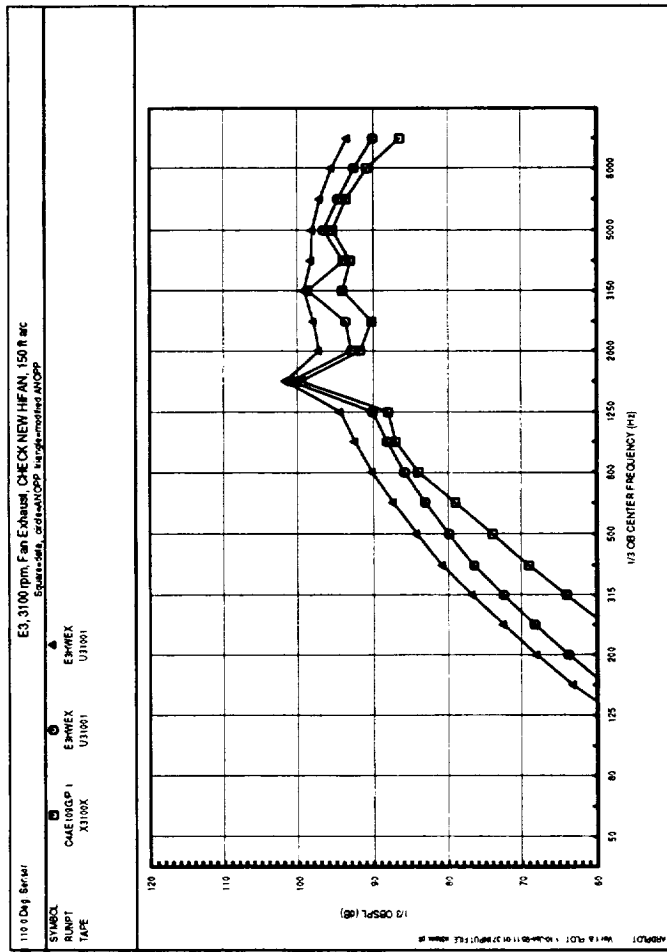
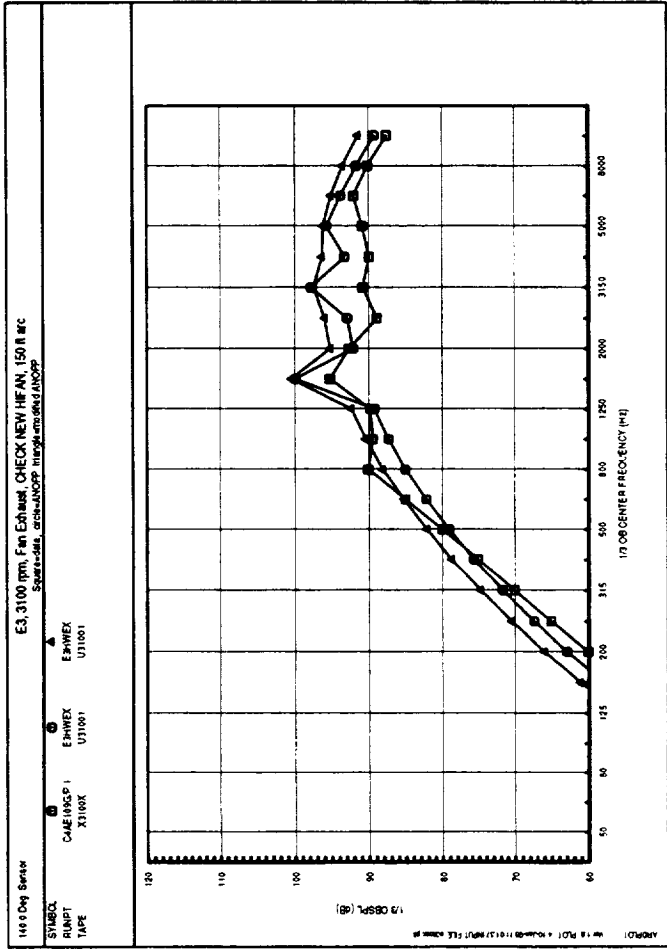
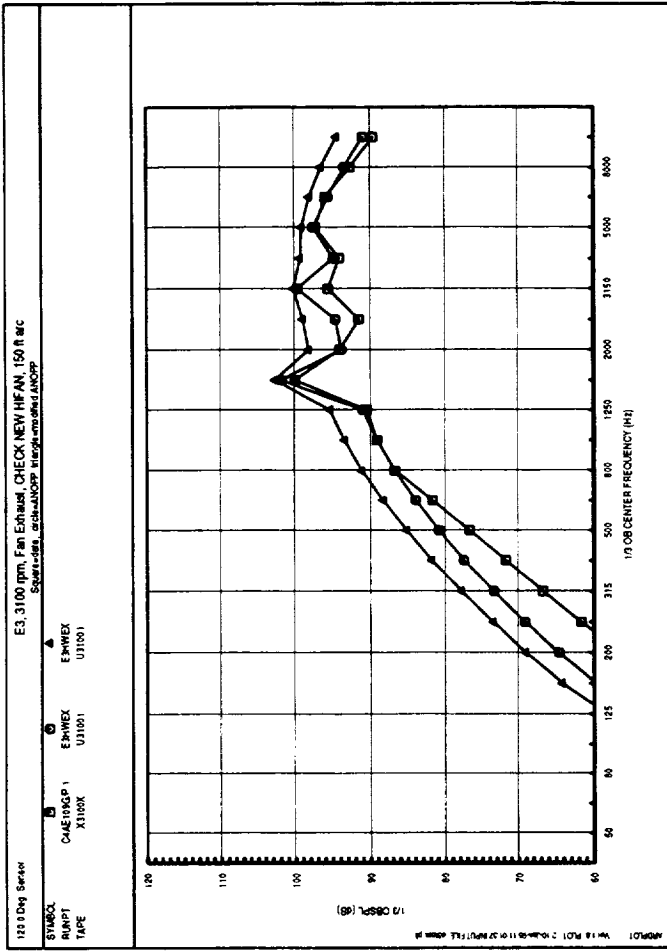
**Appendix F**  
**Fan Exhaust Noise Spectral Comparisons - E<sup>3</sup>**

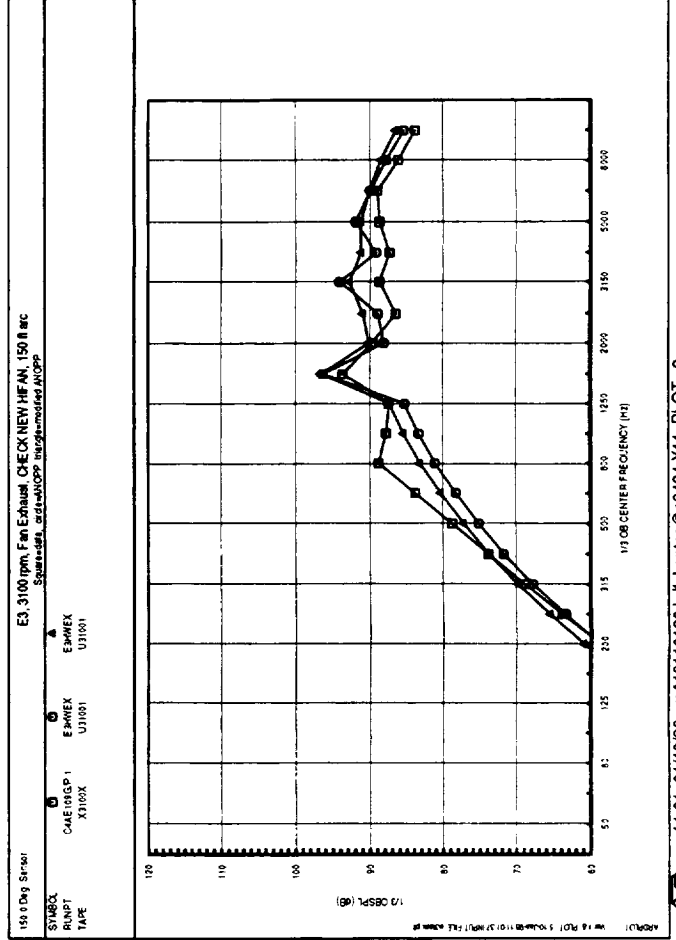
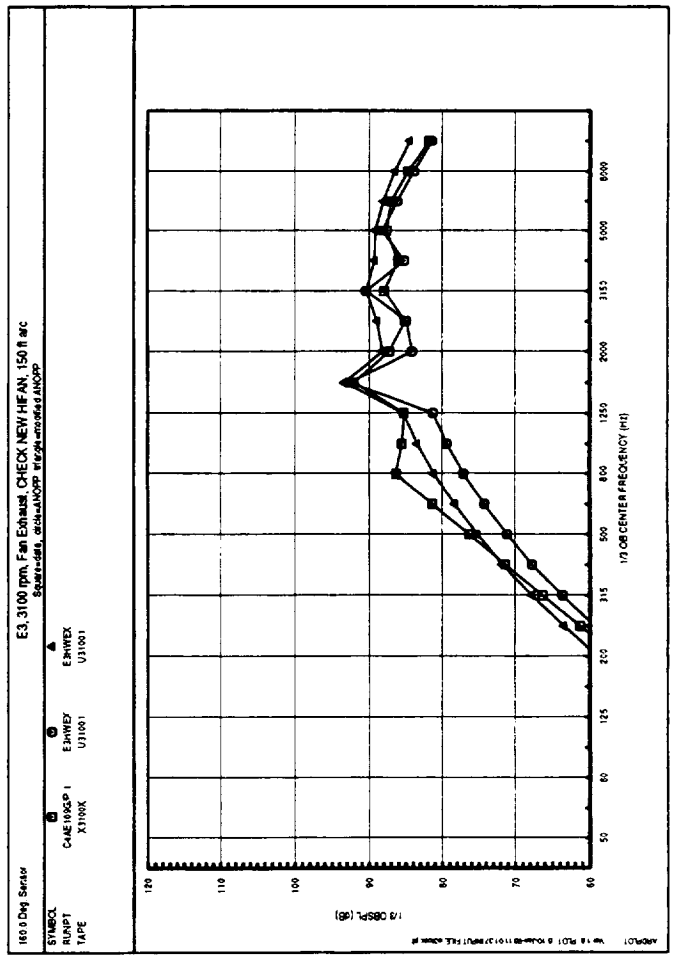
**Appendix F Contents**

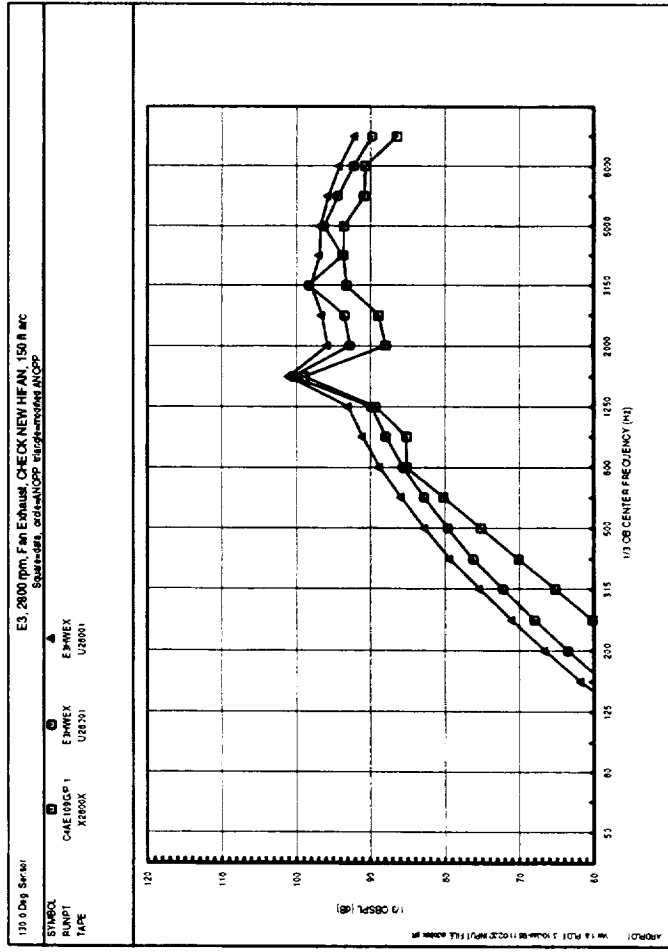
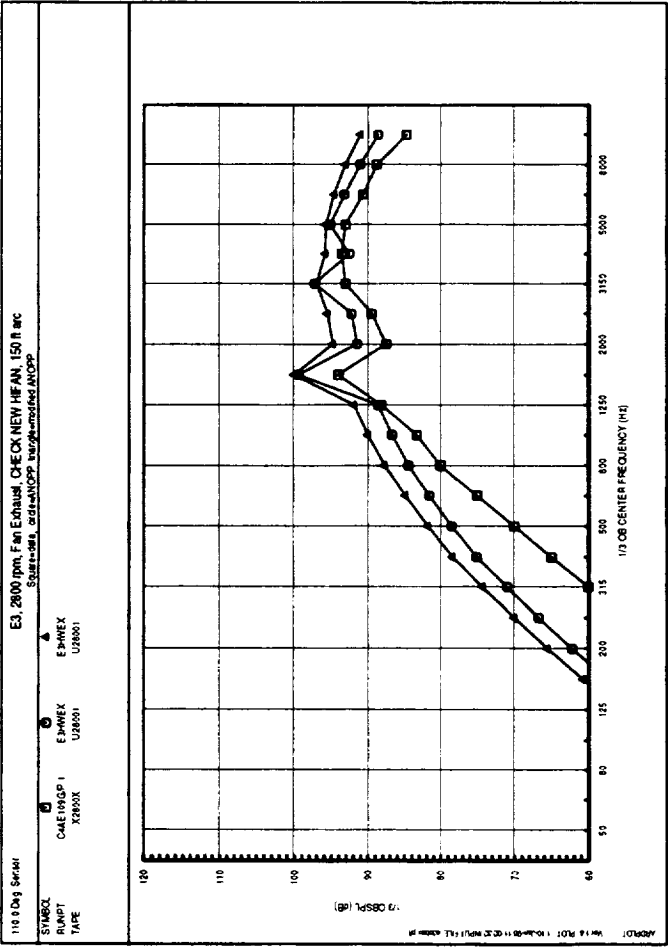
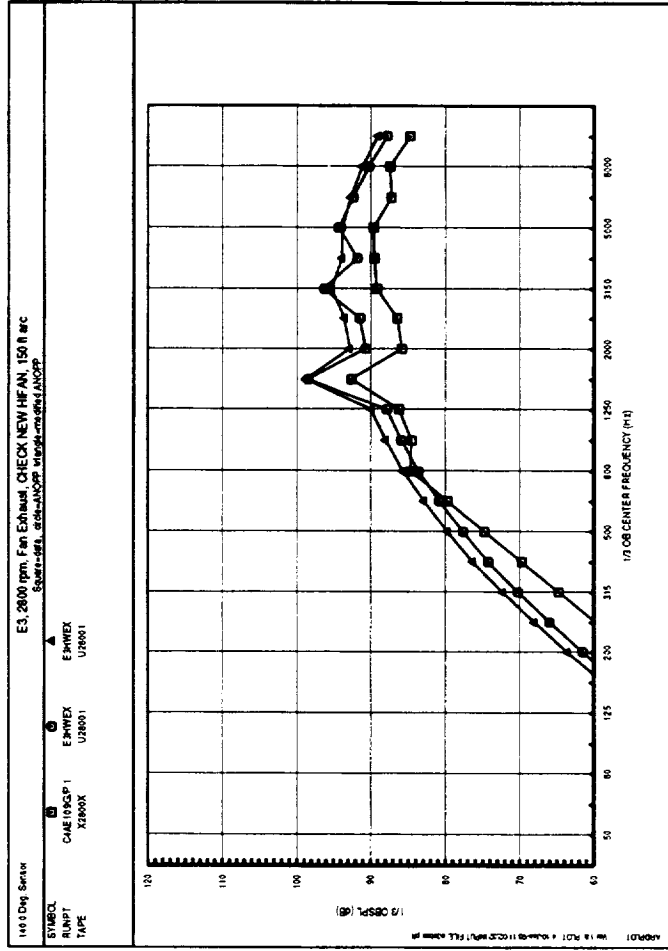
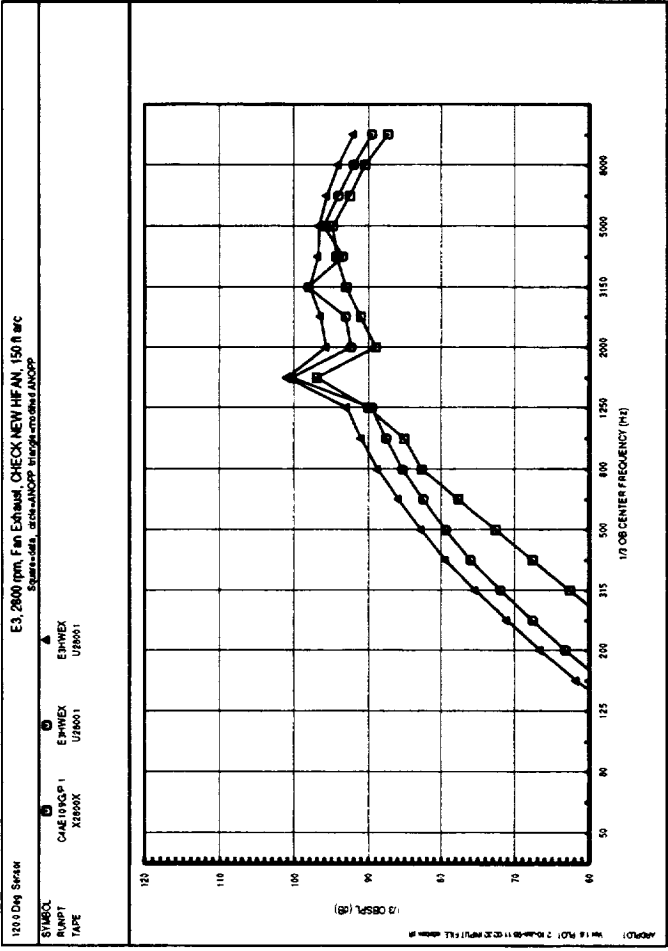
<b>Page</b>	<b>Fan Speed, rpm</b>	<b>Angles, deg</b>
103	3100 (takeoff)	110-140
104	3100 (takeoff)	150-160
105	2800 (cutback)	110-140
106	2800 (cutback)	150-160
107	1820 (approach)	110-140
108	1820 (approach)	150-160

**Key to Plots:**

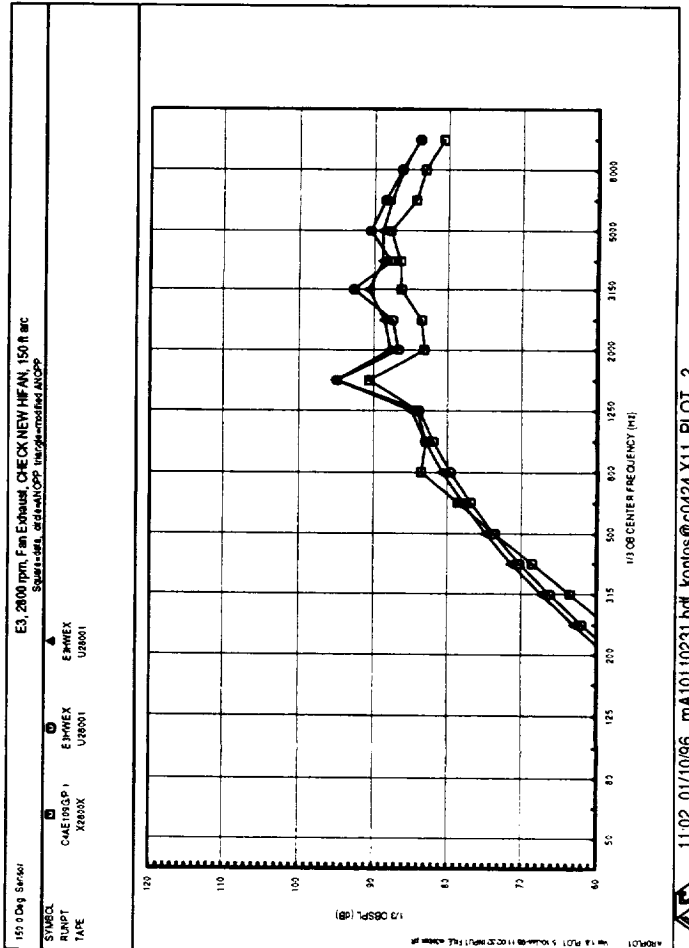
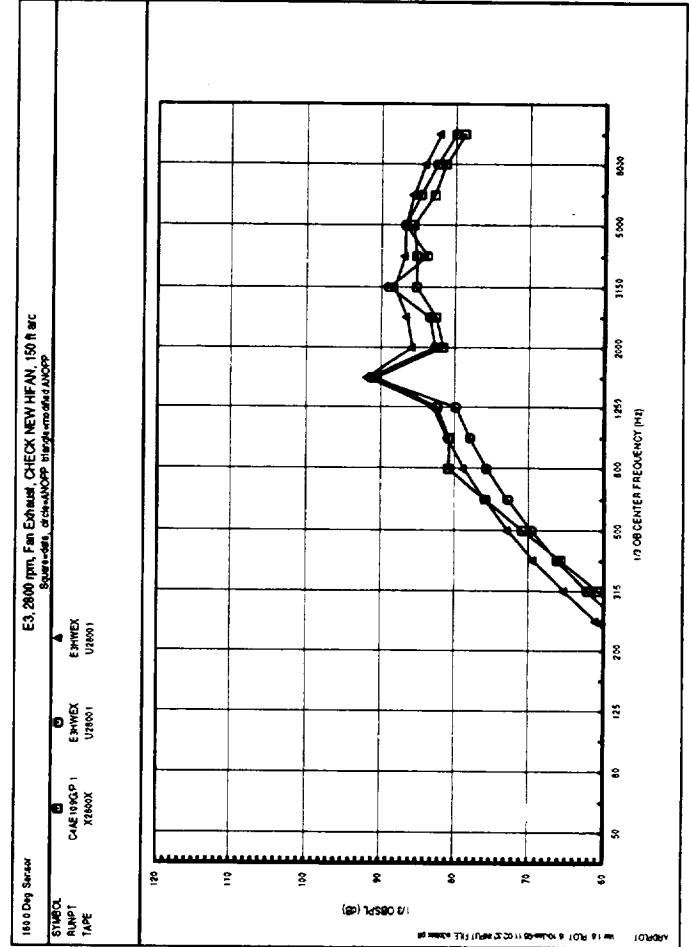
- squares = total measured engine data
- circles = Heidmann method prediction
- triangles = modified Heidmann method prediction (see Section 4)



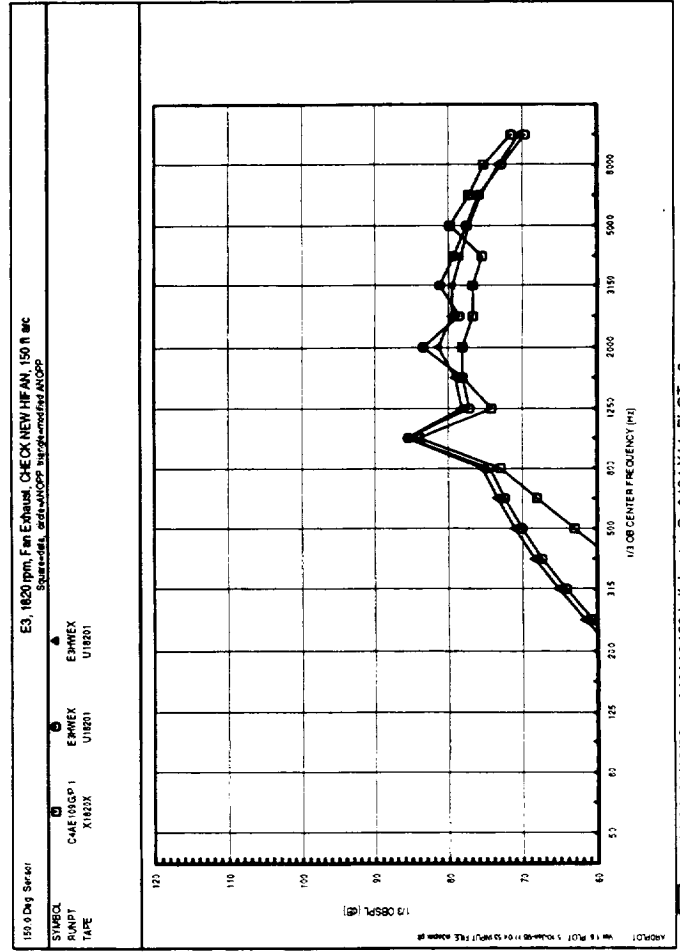
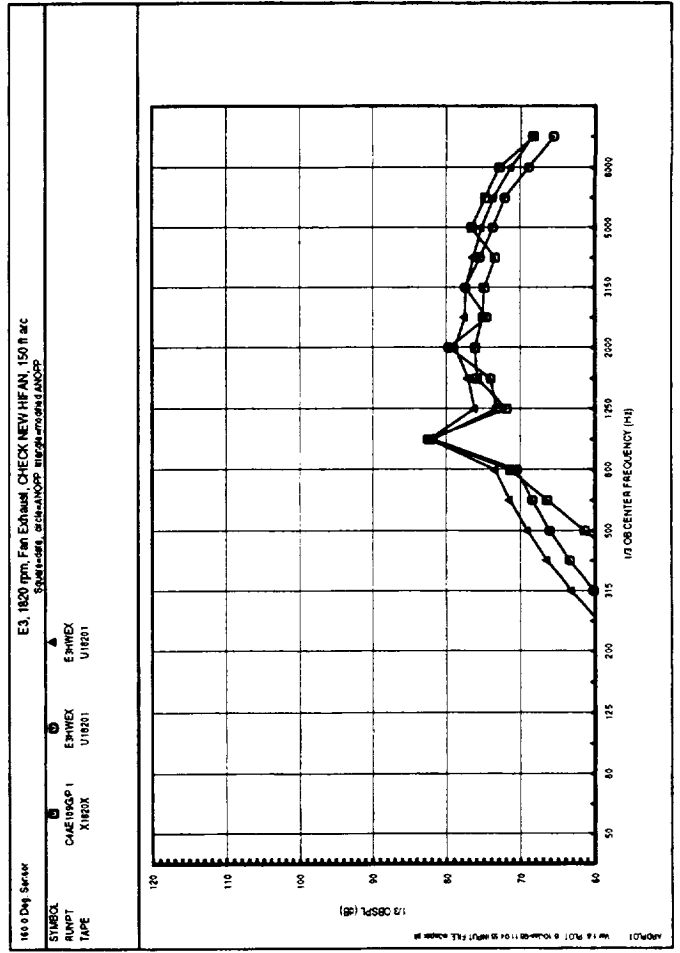












11.04.01/10/95 MA10110452.bcf kontos@c0424.X11.PLOT\_2  
 EGS LIB 5.1.12/14/95 EGSREP.XPOST 5.1.12/14/95 on c0424)  
 (NO PROG. VER. SPECIFIED)



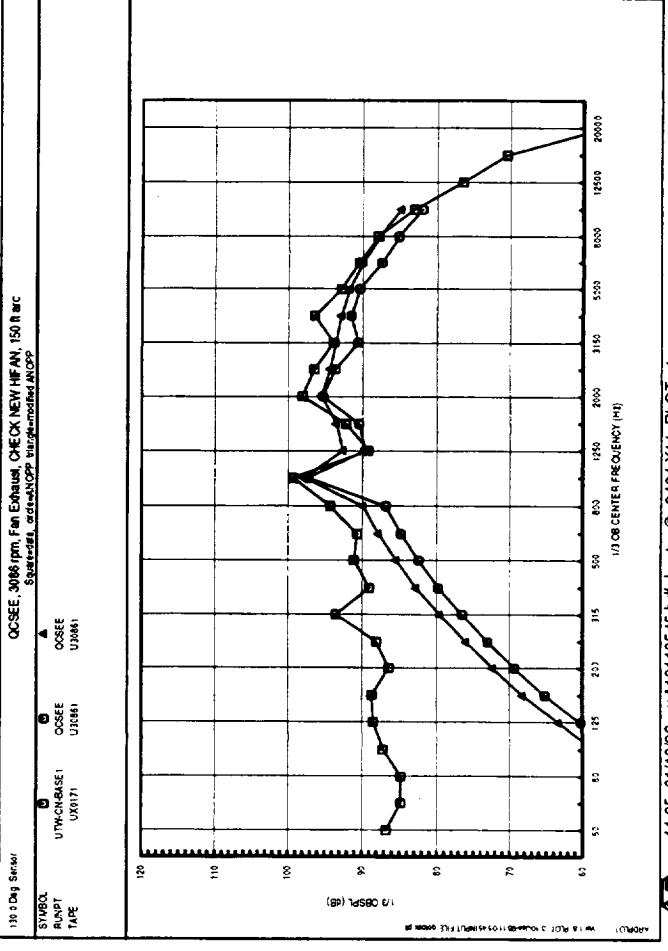
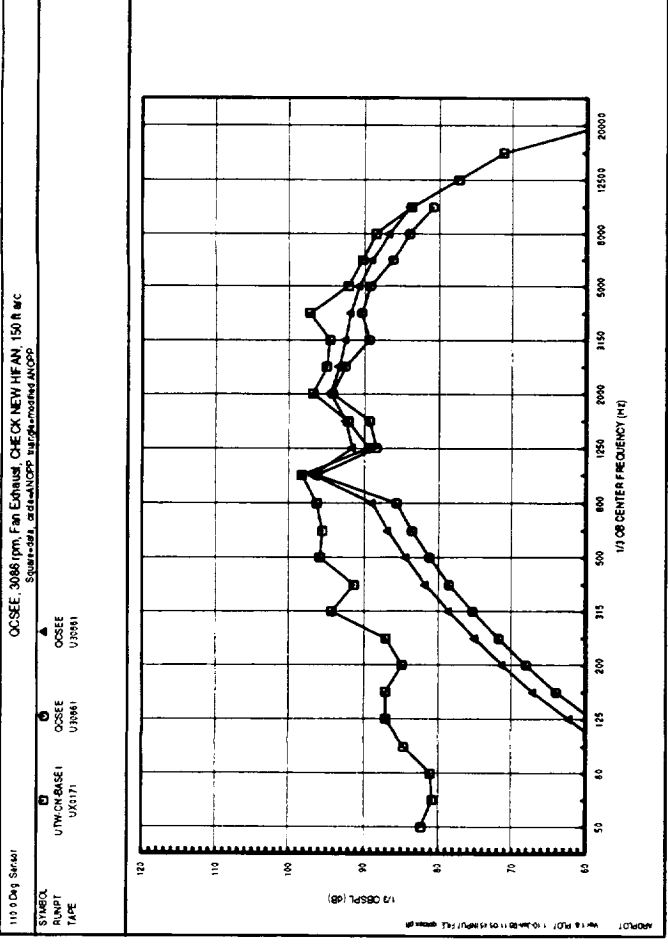
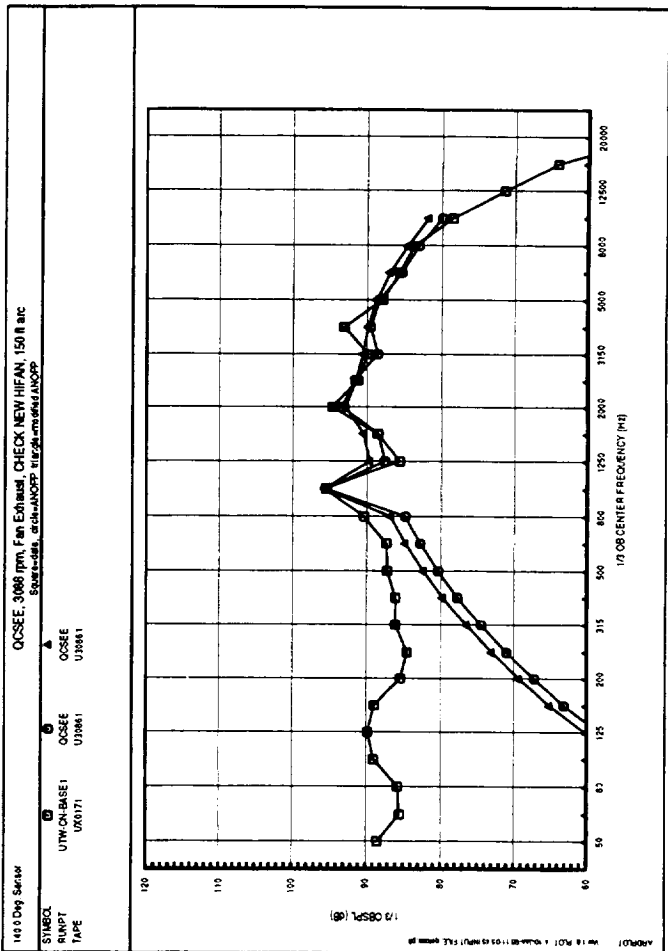
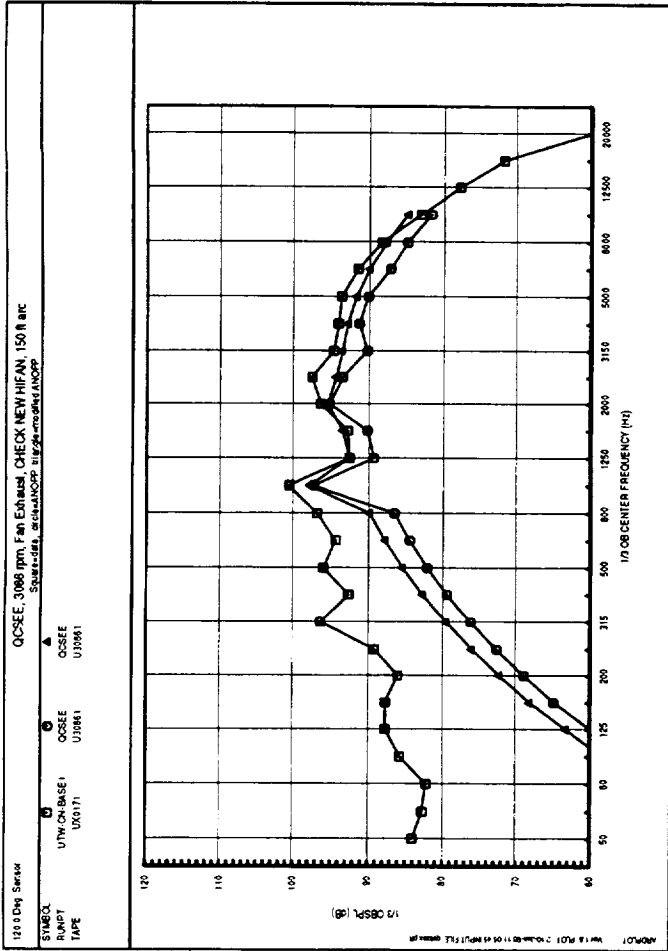
**Appendix G**  
**Fan Exhaust Noise Spectral Comparisons - QCSEE**

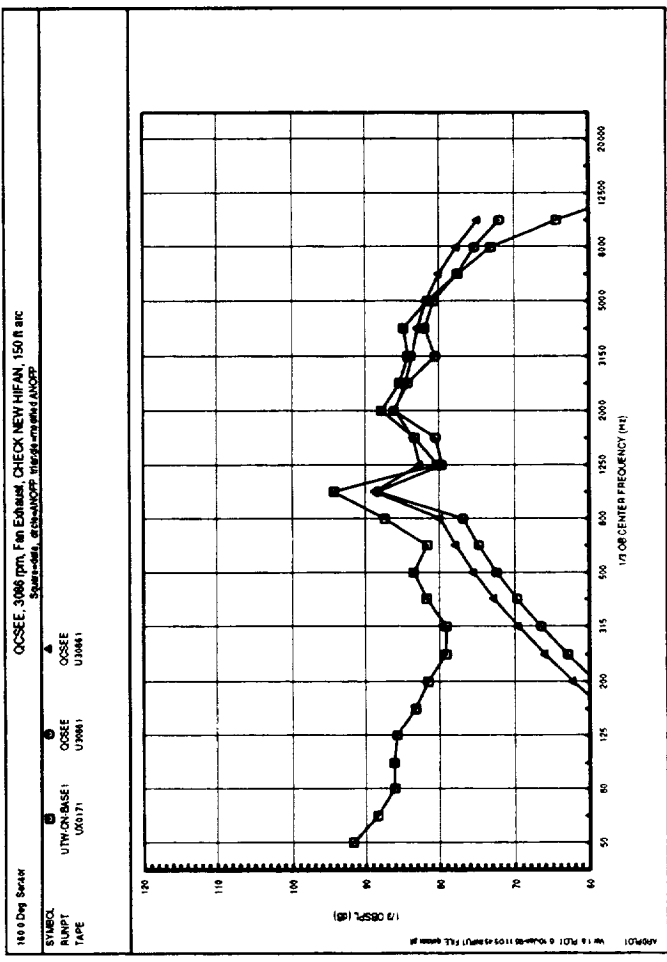
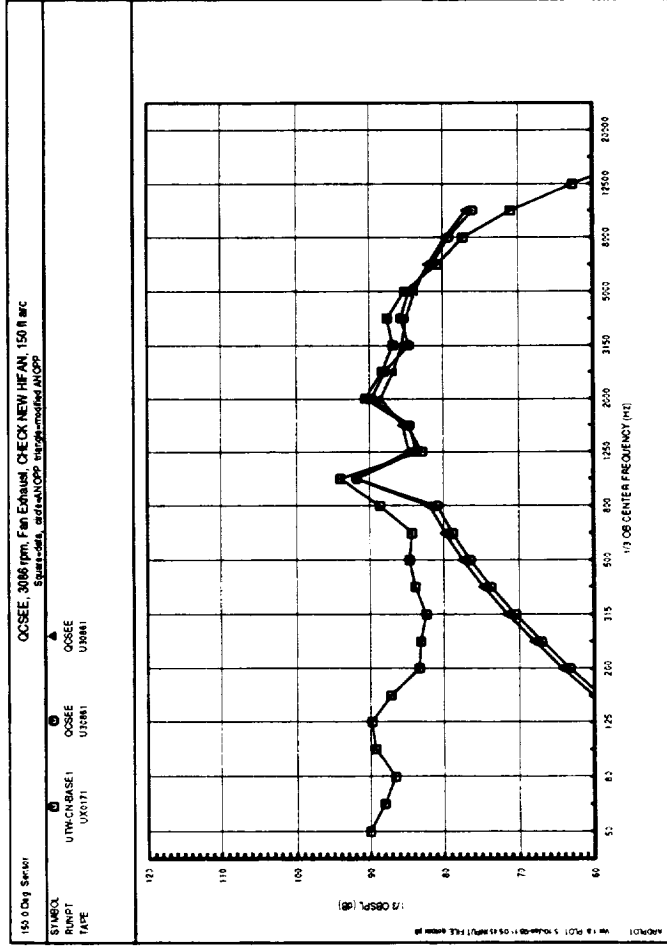
**Appendix G Contents**

<b>Page</b>	<b>Fan Speed, rpm</b>	<b>Angles, deg</b>
110	3086 (takeoff)	110-140
111	3086 (takeoff)	150-160
112	2923 (cutback)	110-140
113	2923 (cutback)	150-160
114	2759 (approach)	110-140
115	2759 (approach)	150-160

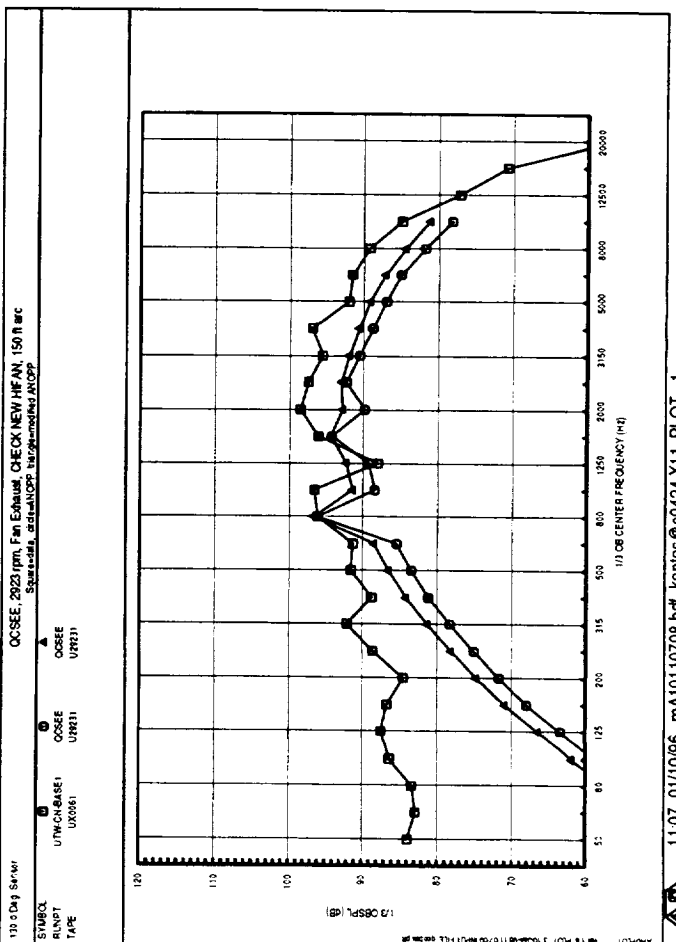
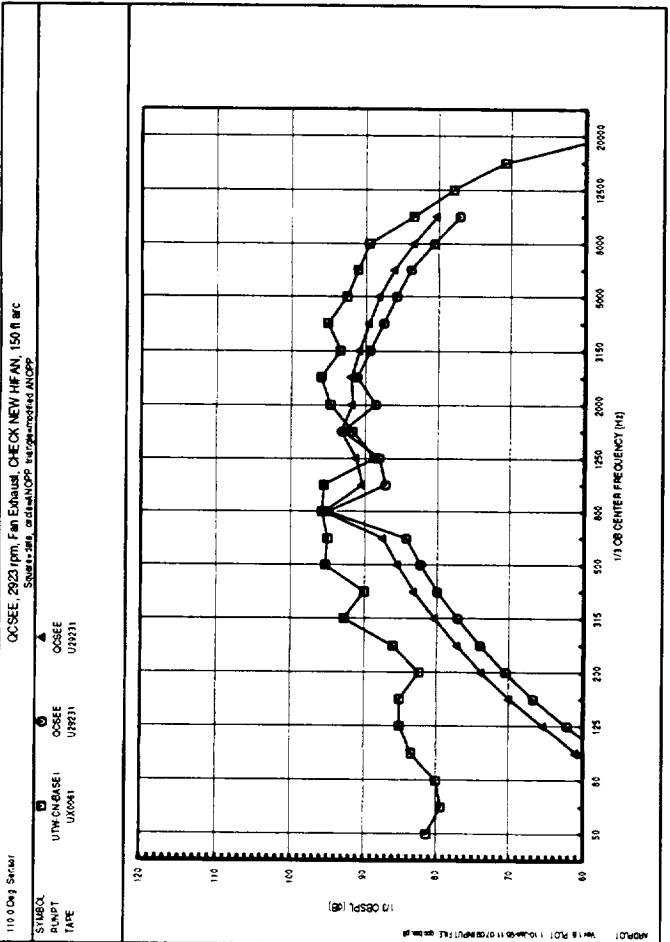
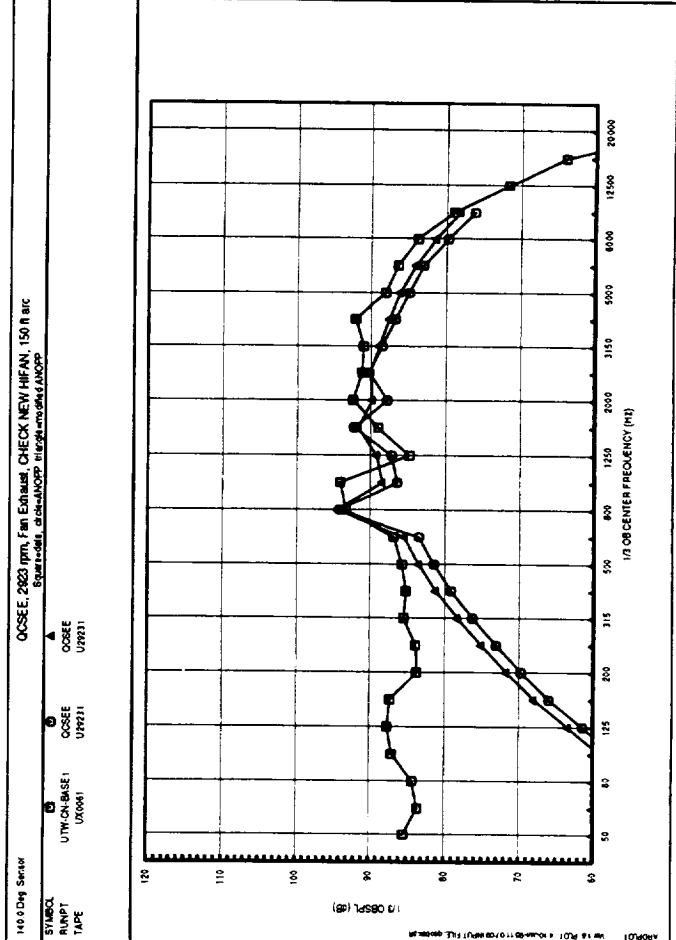
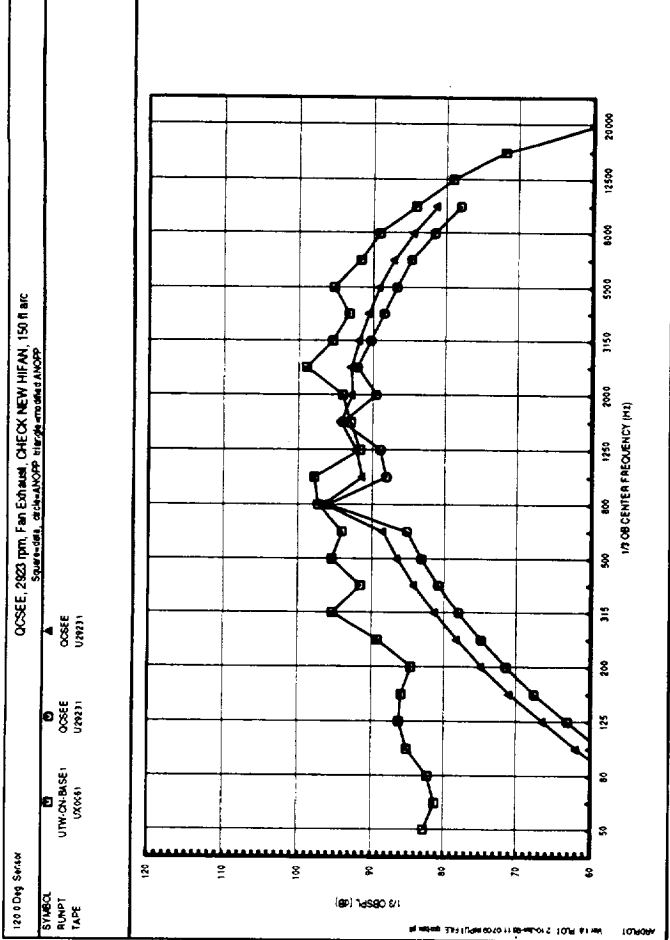
**Key to Plots:**

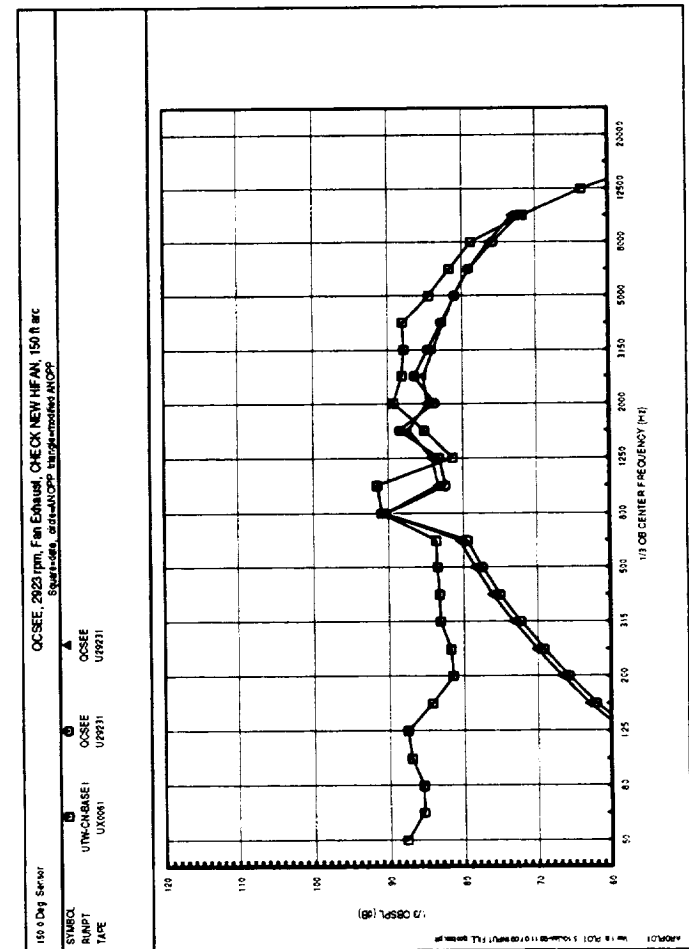
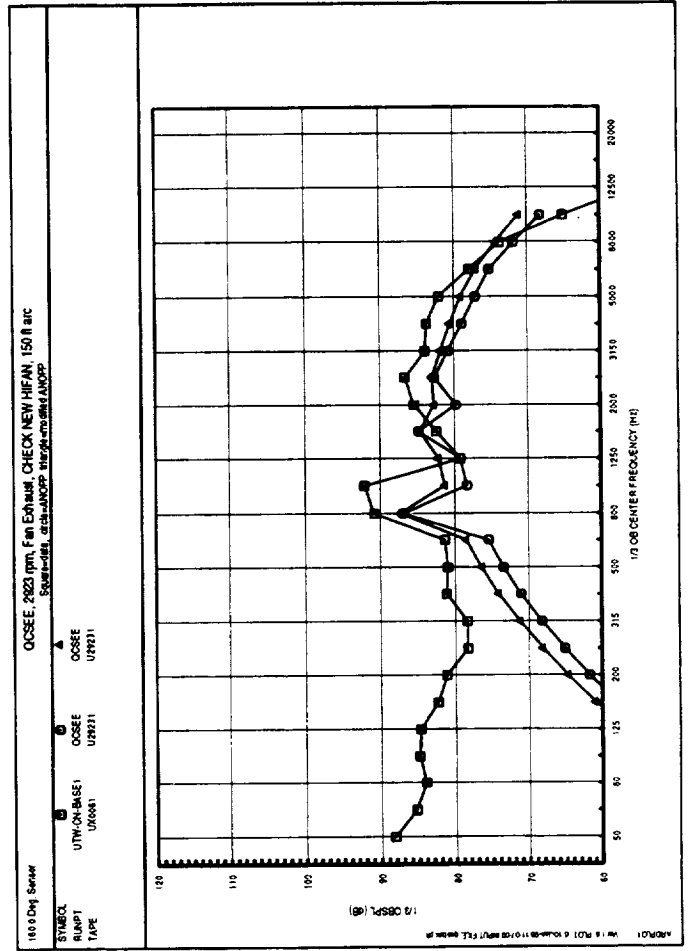
squares = total measured engine data  
circles = Heidmann method prediction  
triangles = modified Heidmann method prediction (see Section 4)



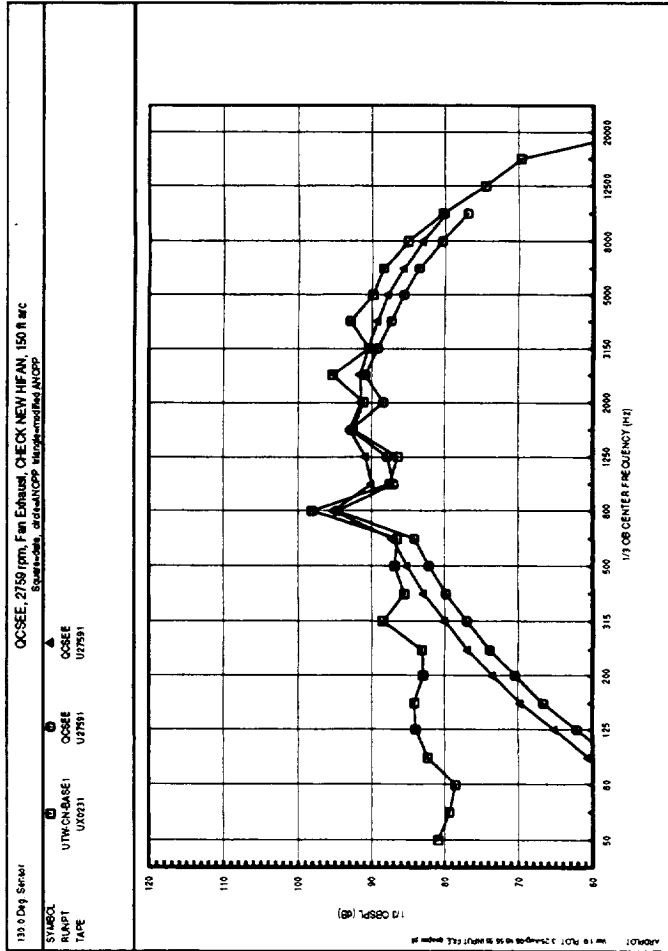
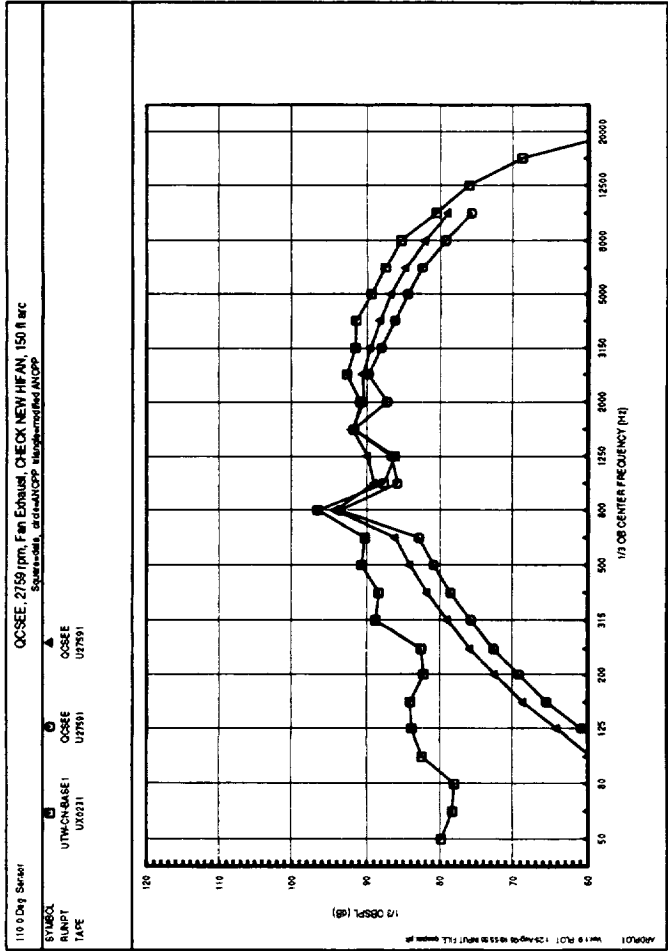
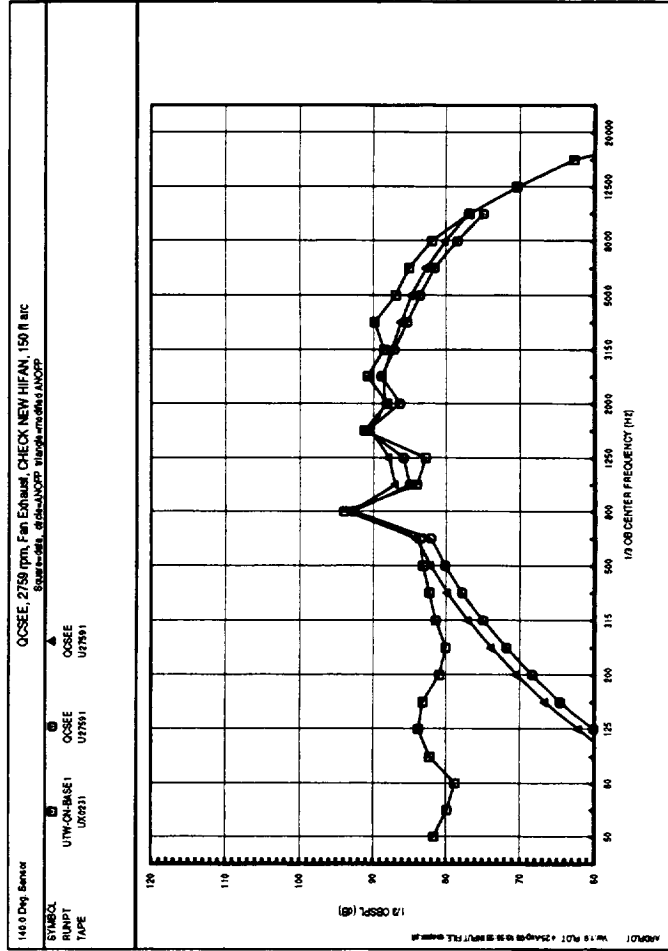
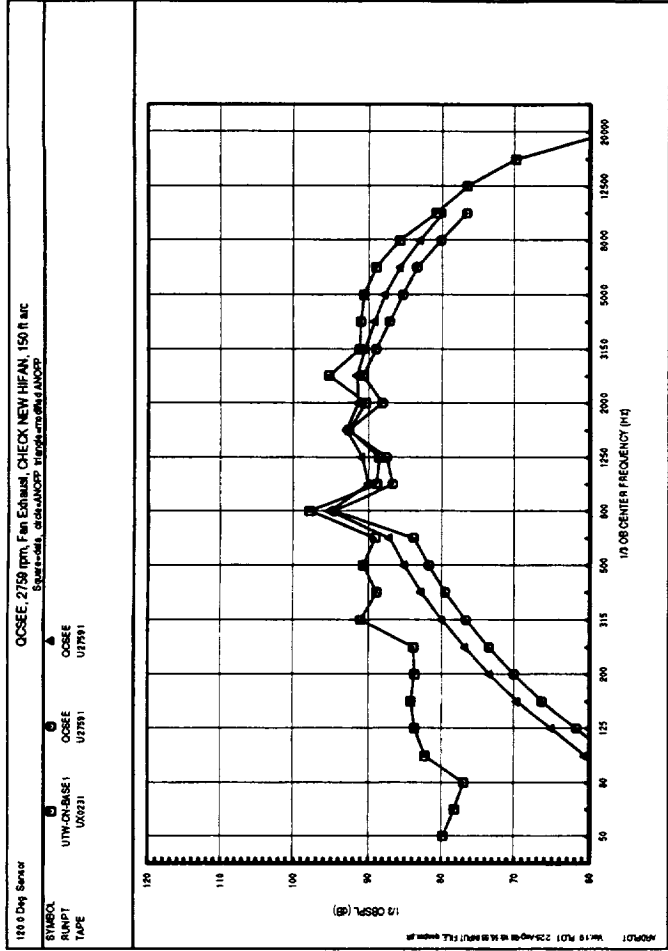


111









160 9 Day Sensor

OCSEE, 2750 rpm, Fan Exhaust, CHECK NEW HIFAN, 150 ft arc

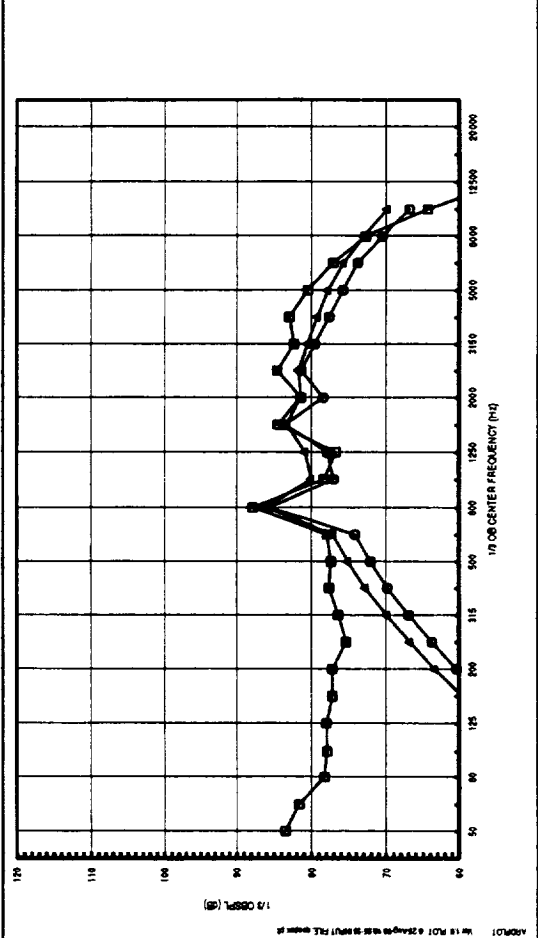
STARCOL  
RUNPT  
TAPE

UTW-CH-RISE1  
U76231

OCSEE  
U7791

UTW-CH-RISE1  
U7791

OCSEE  
U7791



160 9 Day Sensor

OCSEE, 2750 rpm, Fan Exhaust, CHECK NEW HIFAN, 150 ft arc

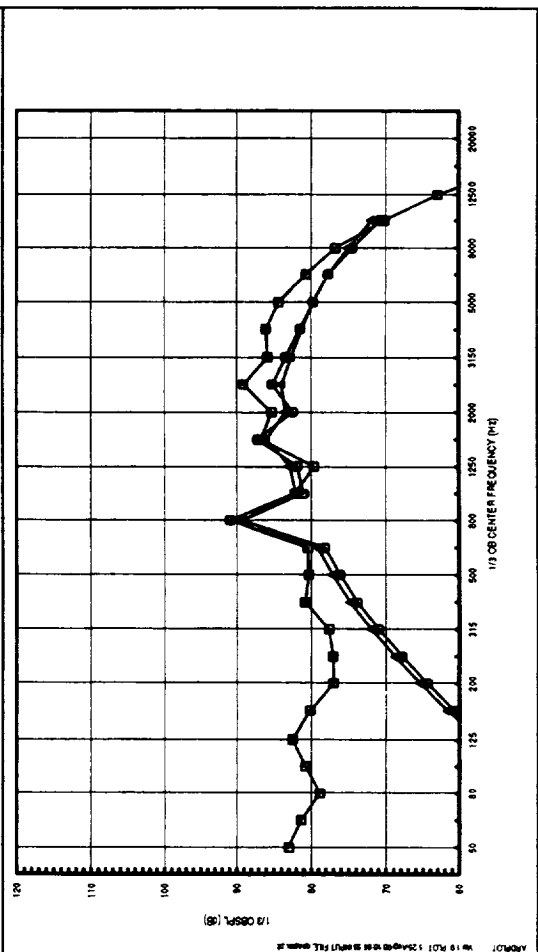
STARCOL  
RUNPT  
TAPE

UTW-CH-RISE1  
U76231

OCSEE  
U7791

UTW-CH-RISE1  
U7791

OCSEE  
U7791



**Appendix H**  
**Jet Noise Spectral Comparison, 150 degrees**

**Appendix H Contents**

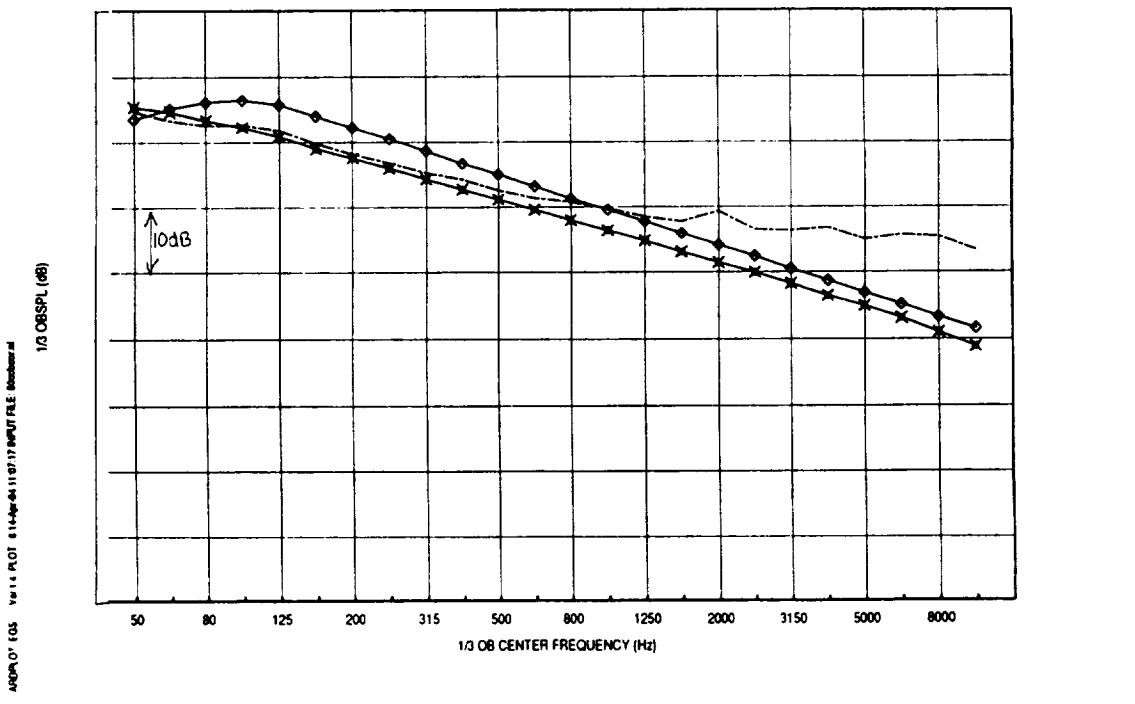
<b>Page</b>	<b>Engine</b>	<b>Condition</b>
117	CF6-80C2	cutback
117	CF6-80C2	approach
118	E <sup>3</sup>	cutback
118	E <sup>3</sup>	approach
119	QCSEE	cutback
119	QCSEE	approach

**Key to Plots:**

dashed line = total measured engine data  
 X = GE jet noise  
 diamonds = ANOPP jet noise (STNJET) prediction

150.0 Deg. Sensor

### ANOPP versus JTFXFN PREDICTION CFR JET, 150 FT ARC, CLIMB CONDITION

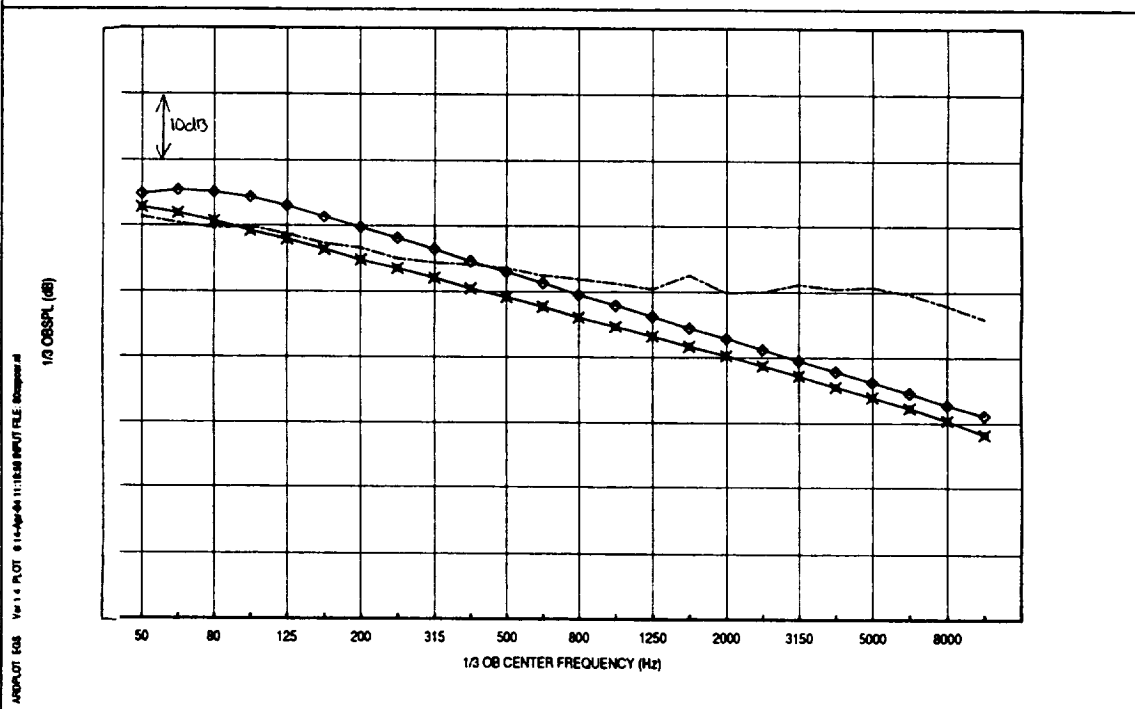


ANOPPLOT EGS Ver 1.4 PLOT 8 14-Apr-84 11:07:33 INPUT FILE: ANOPPLOT.M

11 07 04/14/84 MD14110683 bnf c0262 X11 PLOT 3  
EGS 1.0 4 SJ 04/08/84 (EGSREP XCPST 4 SJ 04/08/84 on c0424)  
(NO PROG VER SPECIFIED)

150.0 Deg. Sensor

### ANOPP versus JTFXFN PREDICTION CFR JET, 150 FT ARC, APPROACH CONDITION

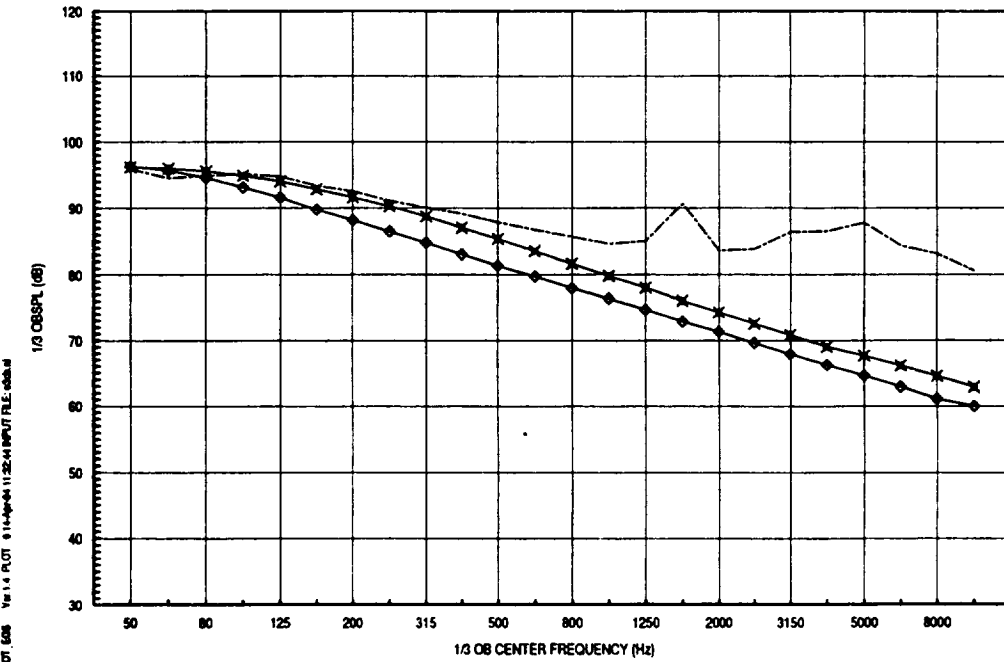


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(NO PROG VER SPECIFIED)

150.0 Deg. Sensor

ANOPP versus JTFXFN PREDICTION  
E3 JET, 150 FT ARC, CUTBACK CONDITION

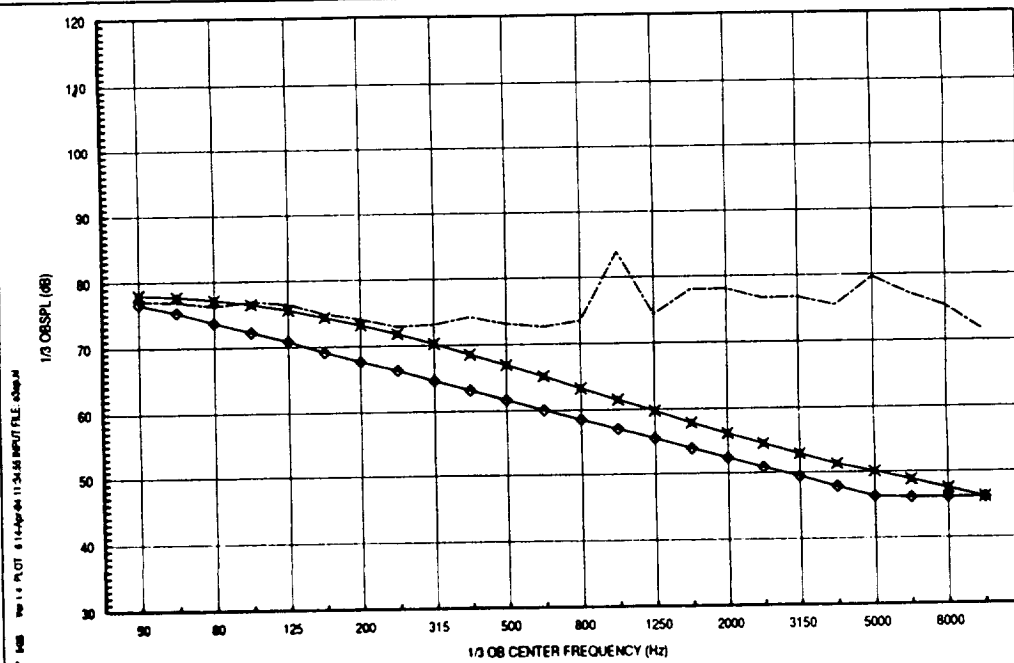


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11 32 04/14/94 m01411323 301 c0824 Y11 PLOT 4  
EGS 1.0 & SJ 04/08/94 (EGSREP XCPST 4 SJ 04/08/94 on c0424)  
NO PROG VER SPECIFIED

150.0 Deg. Sensor

ANOPP versus JTFXFN PREDICTION  
E3 JET, 150 FT ARC, APPROACH CONDITION

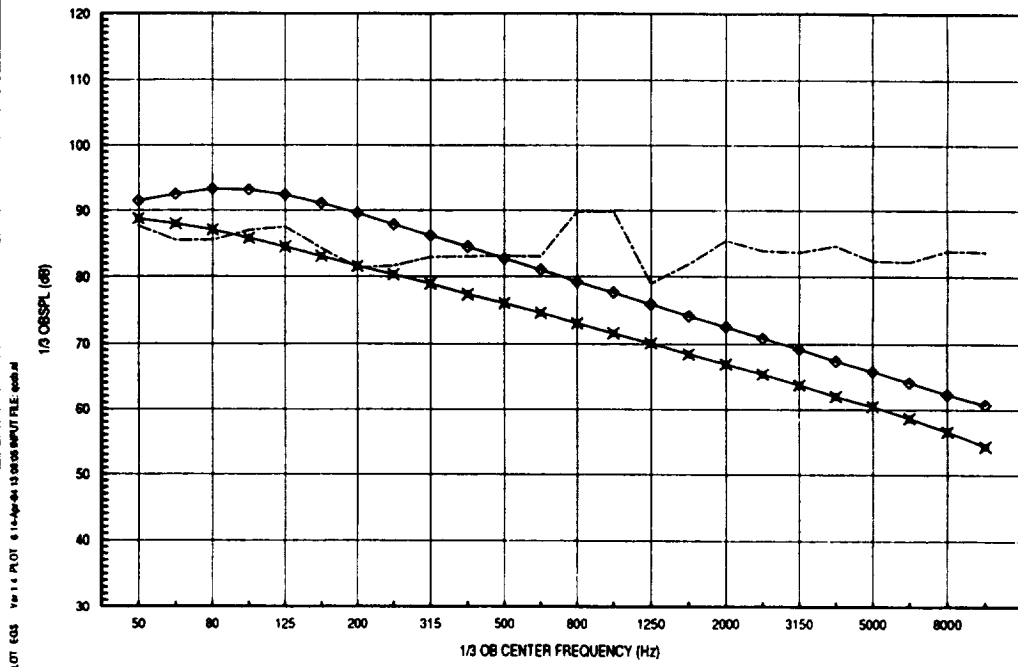


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NO PROG VER SPECIFIED

150.0 Deg. Sensor

ANOPP versus JTFXFN PREDICTION  
QCSEE JET, 150 FT ARC, CUTBACK CONDITION

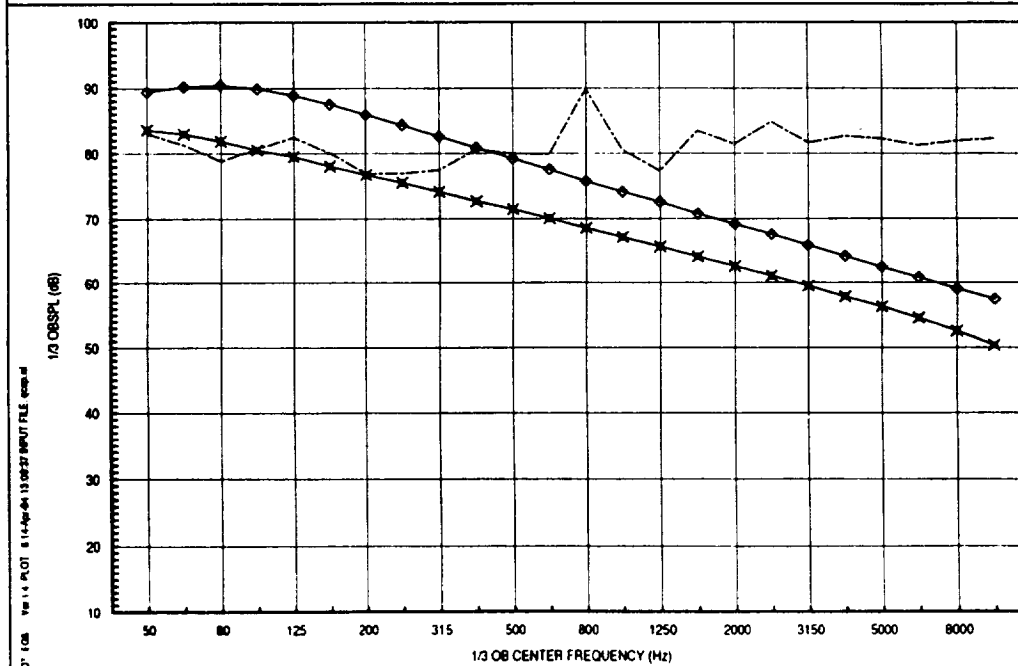


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(NO PROG VER SPECIFIED)

150.0 Deg. Sensor

ANOPP versus JTFXFN PREDICTION  
QCSEE JET, 150 FT ARC, APPROACH CONDITION



ANOPPLOT.EG3 Ver 1.4 PLOT 6 14-Apr-84 13:08:07 INPUT FILE egob.pl

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EGS LB 4 SJ 04/08/84 (EGSREP XCPOST 4 SJ 04/08/84 on c0424)  
(NO PROG VER SPECIFIED)

***Appendix I***  
***Combustor Noise Spectral Comparisons, 120 degrees***

***Appendix I Contents***

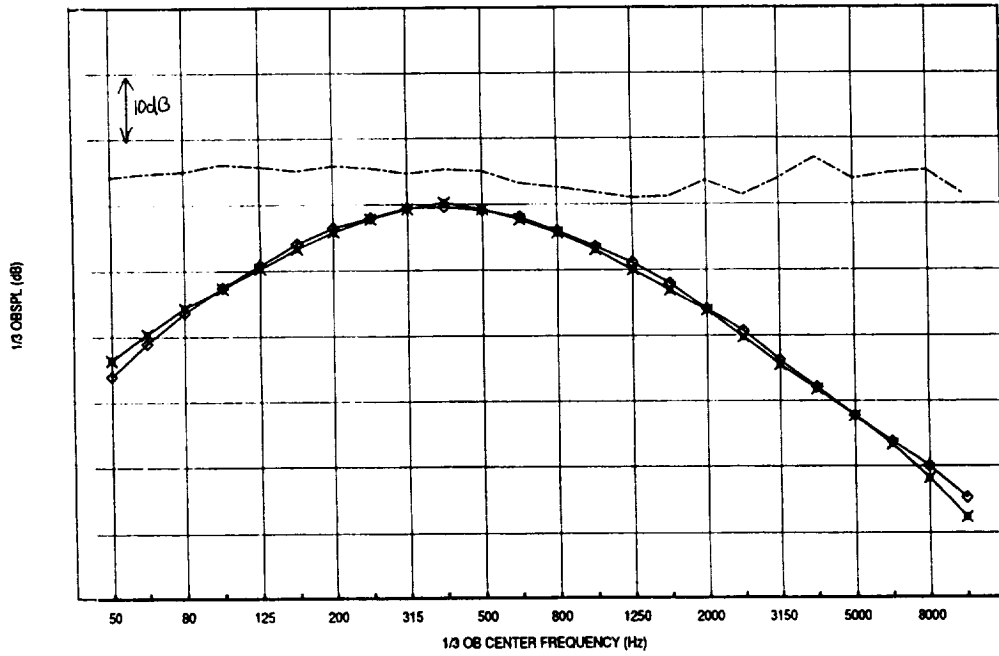
<b>Page</b>	<b>Engine</b>	<b>Condition</b>
121	CF6-80C2	cutback
121	CF6-80C2	approach
122	E <sup>3</sup>	cutback
122	E <sup>3</sup>	approach
123	QCSEE	cutback
123	QCSEE	approach

***Key to Plots:***

dashed line = total measured engine data  
 X or filled square = GE combustor noise  
 diamonds or open square = ANOPP combustor noise (GECOR) prediction

120.0 Deg Sensor

### ANOPP versus JTFXFN PREDICTION CF6 COMBUSTOR, 150 FT ARC, CUTBACK CONDITION



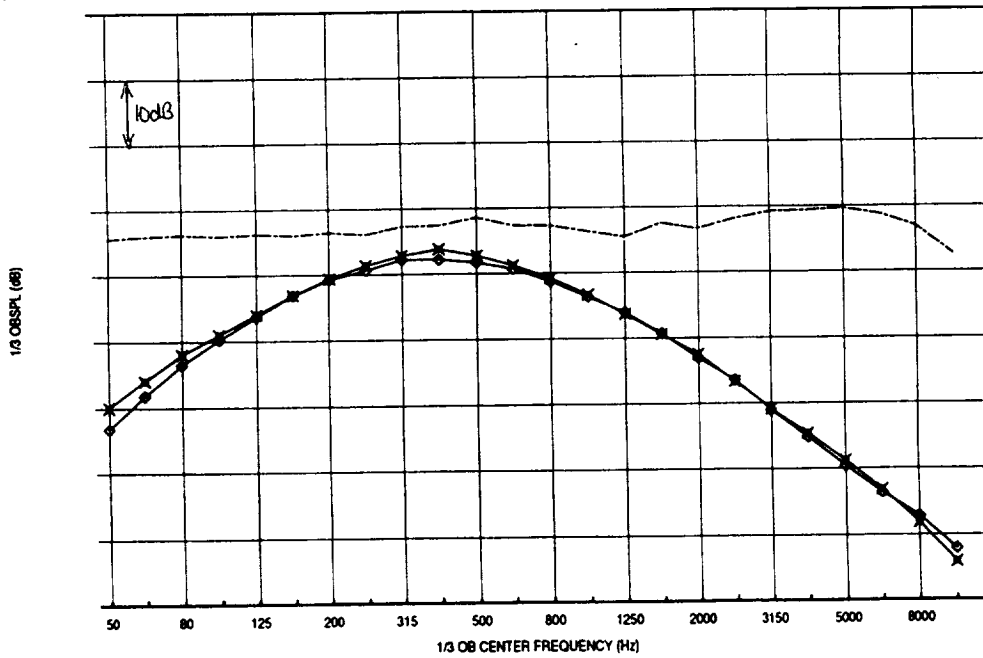
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120.0 Deg Sensor

### ANOPP versus JTFXFN PREDICTION CF6 COMBUSTOR, 150 FT ARC, APPROACH CONDITION

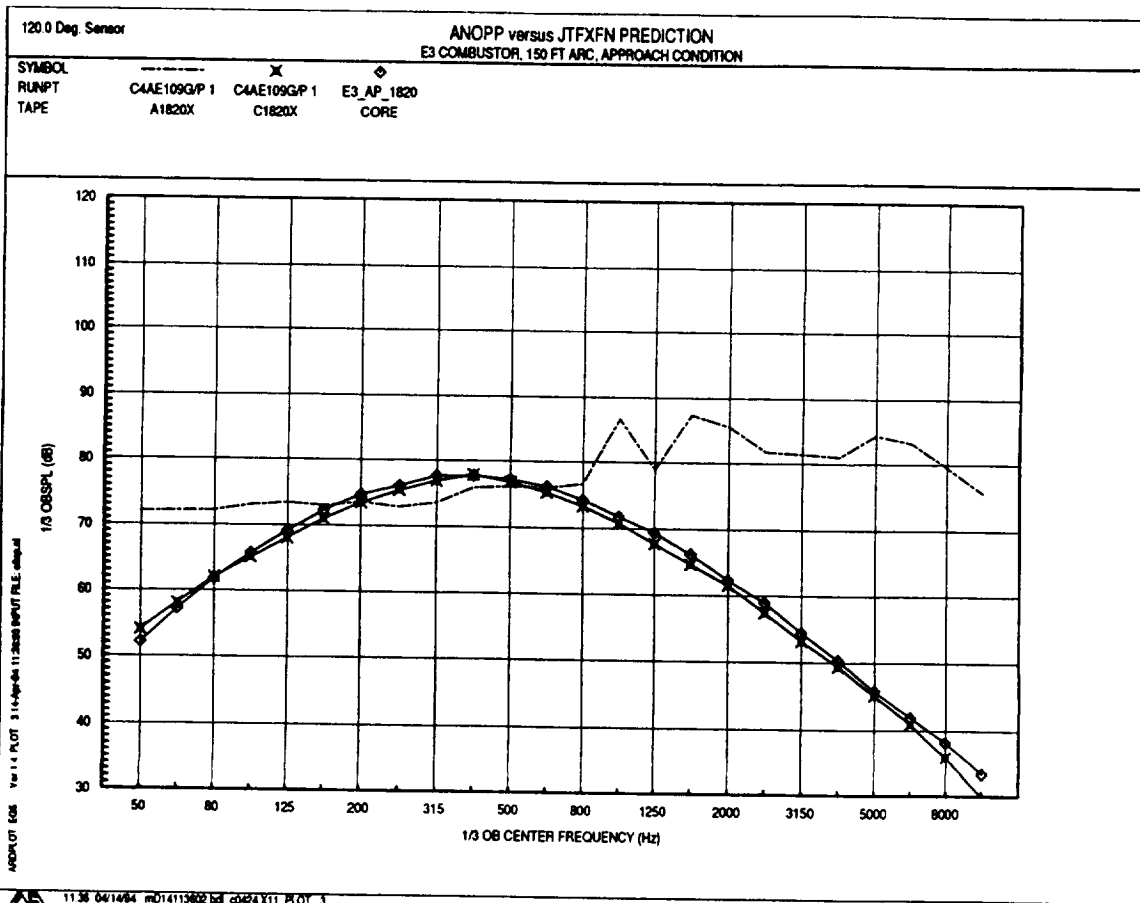
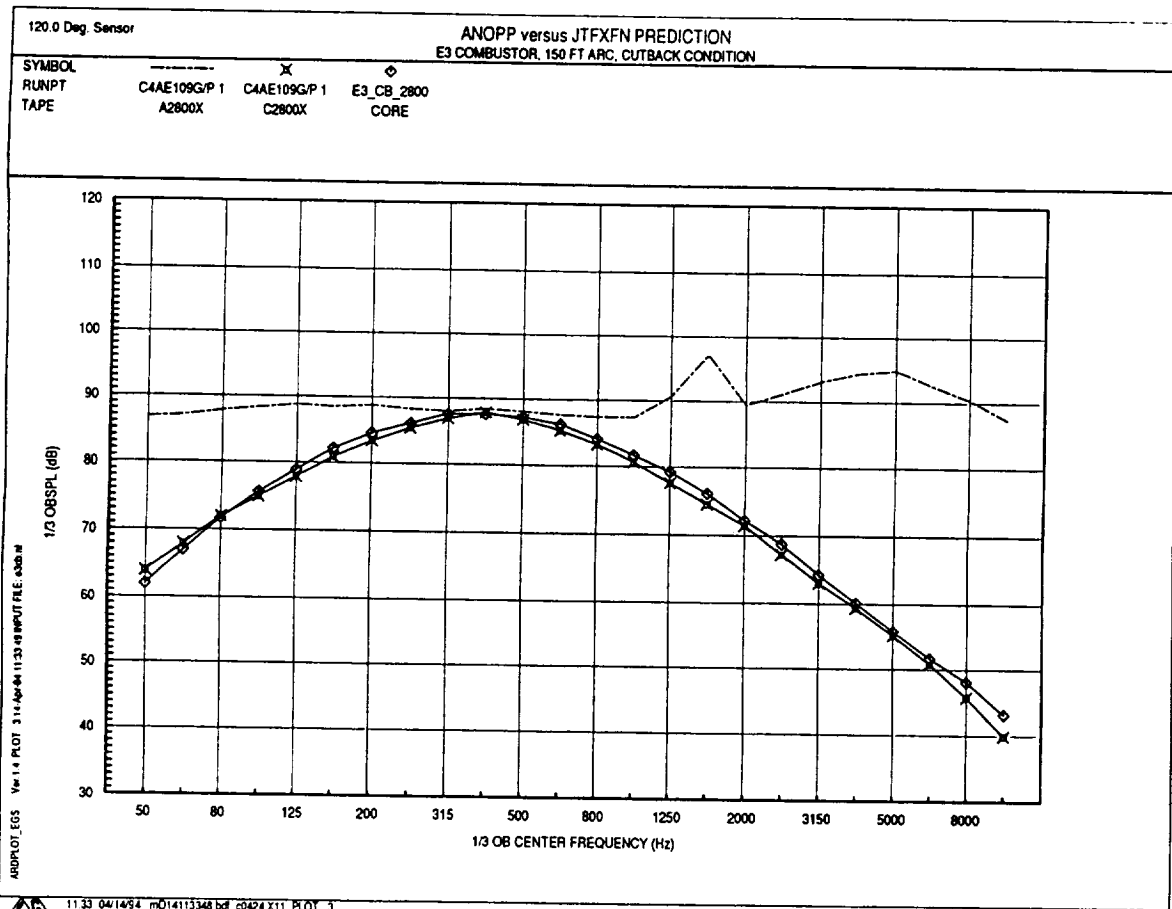


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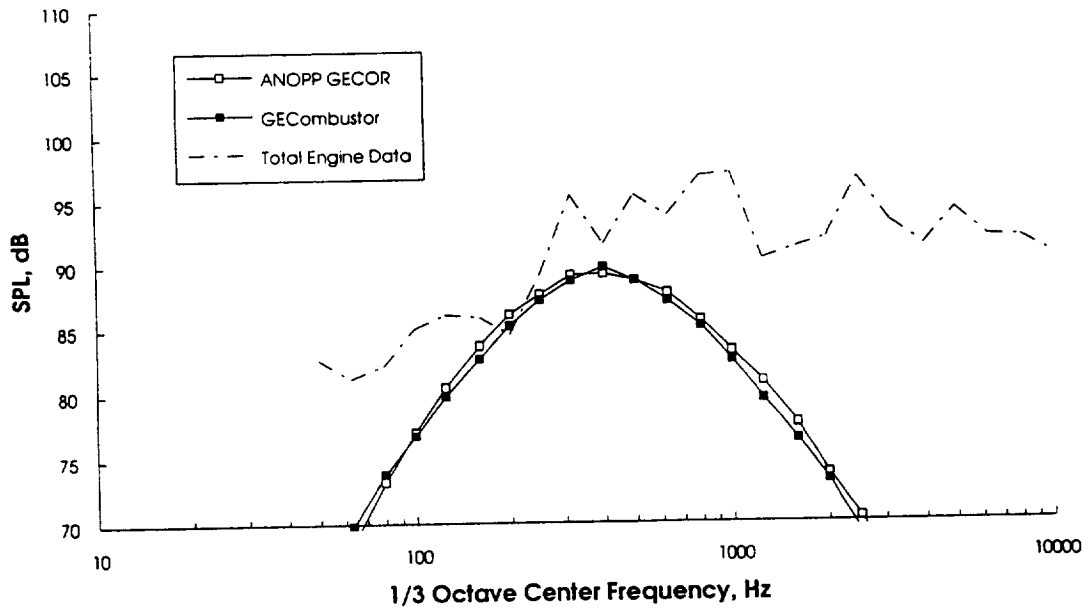
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(NO PROG VER SPECIFIED)





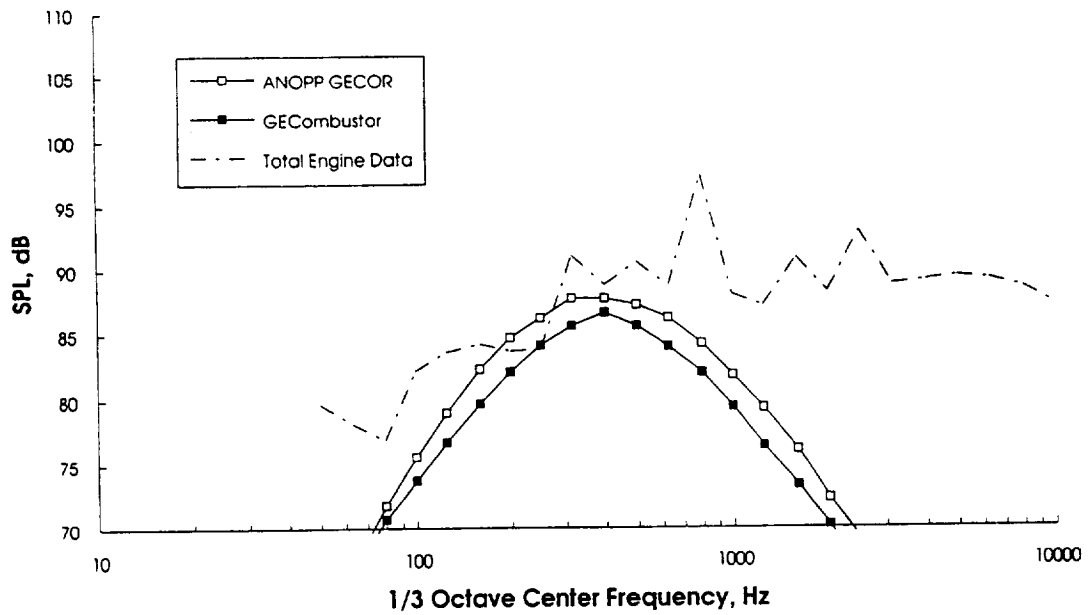
### Task 24 ANOPP Assessment: Combustor Noise

QCSEE, Cutback, 150 ft arc, 120 deg



### Task 24 ANOPP Assessment: Combustor Noise

QCSEE, Approach, 150 ft arc, 120 deg



**Appendix J**  
***Turbine Noise Spectral Comparisons, 120 degrees***

**Appendix J Contents**

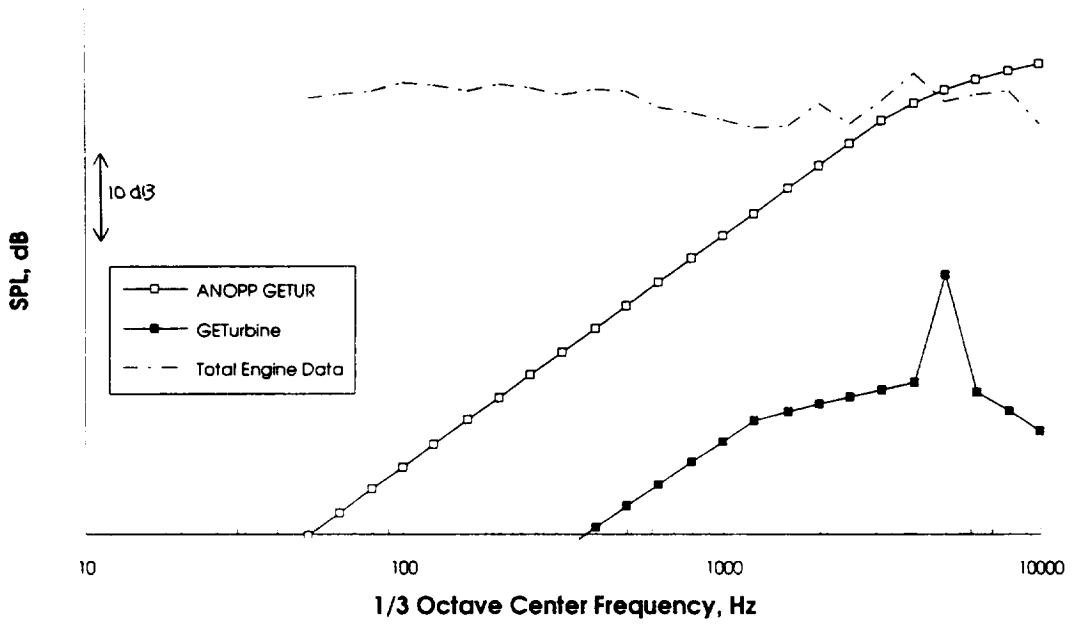
<b>Page</b>	<b>Engine</b>	<b>Condition</b>
125	CF6-80C2	cutback
125	CF6-80C2	approach
126	E <sup>3</sup>	cutback
126	E <sup>3</sup>	approach
127	QCSEE	cutback
127	QCSEE	approach

**Key to Plots:**

dashed line       = total measured engine data  
filled squares     = GE turbine noise  
open squares      = ANOPP turbine noise (GETUR) prediction

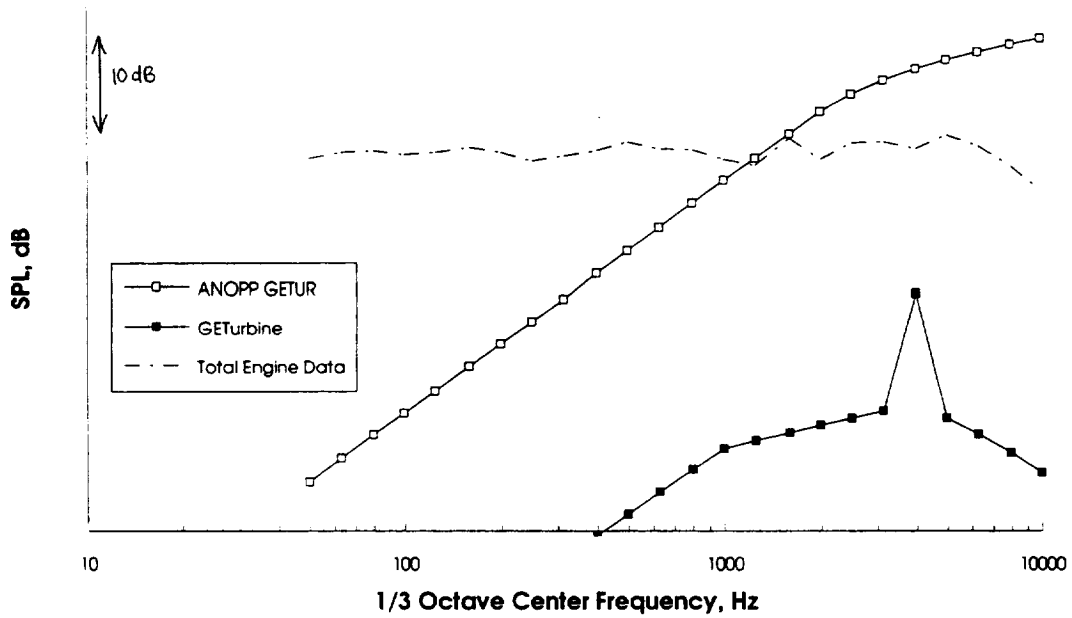
### Task 24 ANOPP Assessment: Turbine Noise

CF6-80C2, Cutback, 150 ft arc, 120 deg



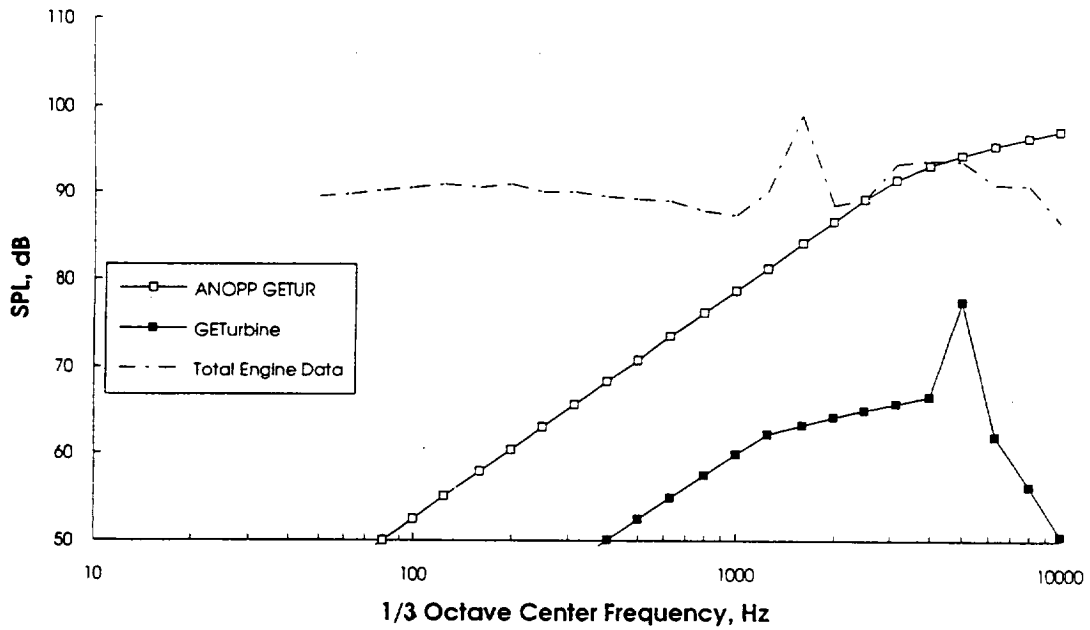
### Task 24 ANOPP Assessment: Turbine Noise

CF6-80C2, Approach, 150 ft arc, 120 deg



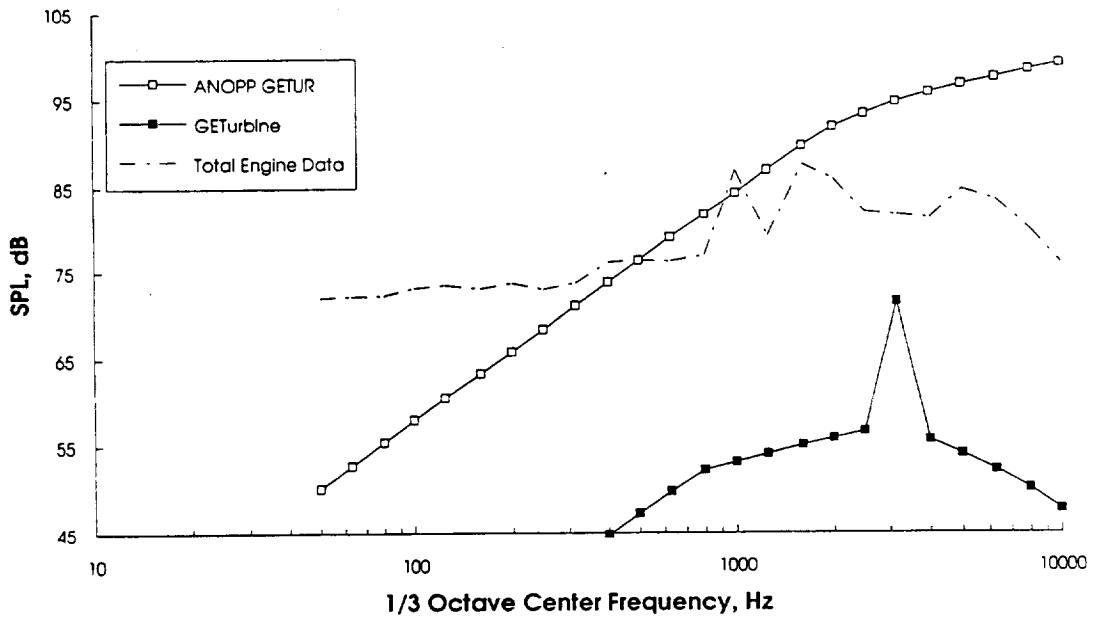
### Task 24 ANOPP Assessment: Turbine Noise

E3, Cutback, 150 ft arc, 120 deg



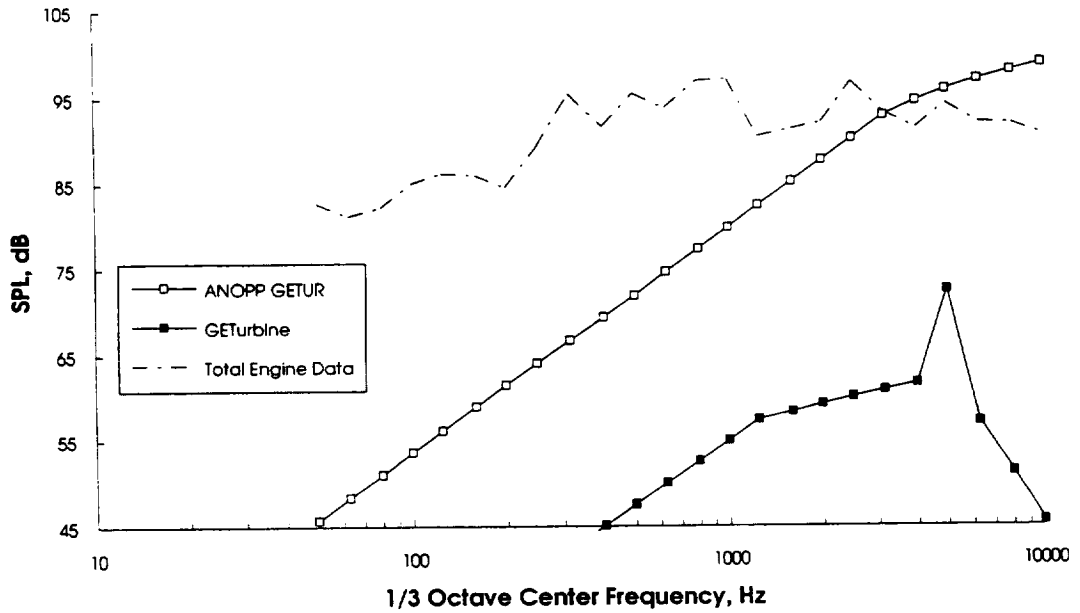
### Task 24 ANOPP Assessment: Turbine Noise

E3, Approach, 150 ft arc, 120 deg



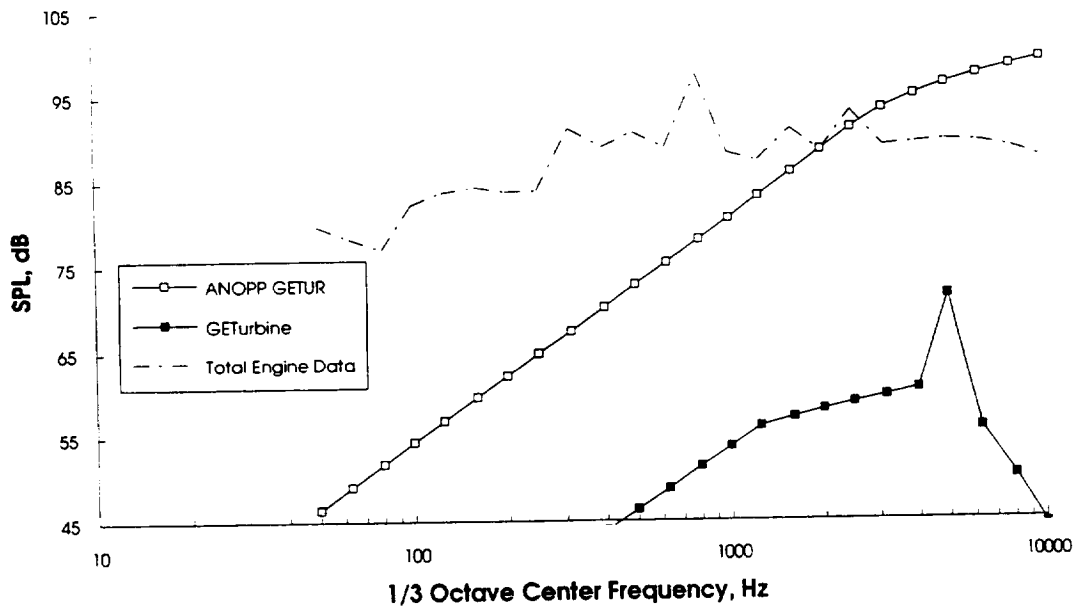
### Task 24 ANOPP Assessment: Turbine Noise

QCSEE, Cutback, 150 ft arc, 120 deg



### Task 24 ANOPP Assessment: Turbine Noise

QCSEE, Approach, 150 ft arc, 120 deg



***Appendix K***  
***Directivity, CF6-80C2 and QCSEE***

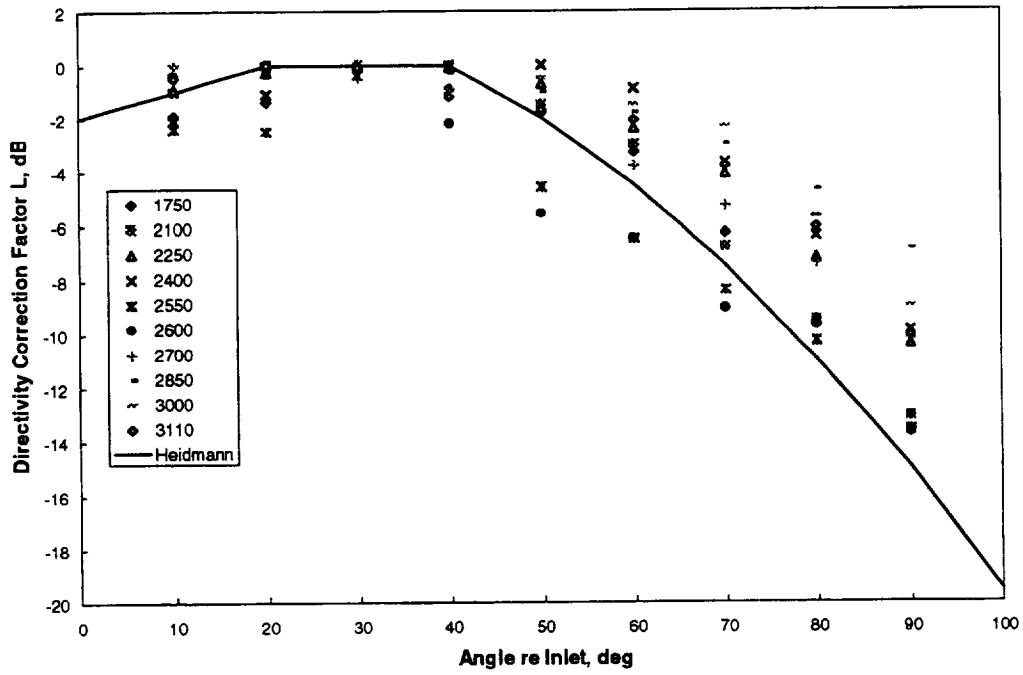
***Appendix K Contents***

<b>Page</b>	<b>Noise Component</b>	<b>Engine</b>
129	Fan Inlet Broadband	CF6-80C2
129	Fan Inlet Broadband	QCSEE
130	Fan Inlet Tone	CF6-80C2
130	Fan Inlet Tone	QCSEE
131	Fan Exhaust Broadband	CF6-80C2
131	Fan Exhaust Broadband	QCSEE
132	Fan Exhaust Tone	CF6-80C2
132	Fan Exhaust Tone	QCSEE

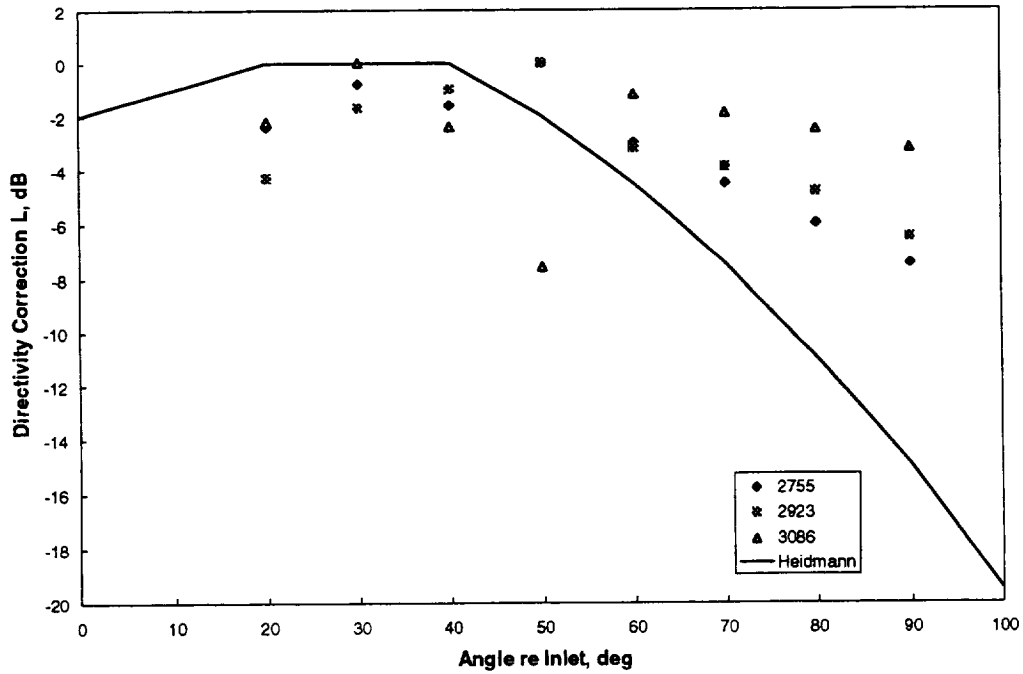
***Key to Plots:***

all symbols = total measured engine data, all speeds  
 solid line = Heidmann method

Fan Inlet Broadband Directivity Correction, CF6-80C2

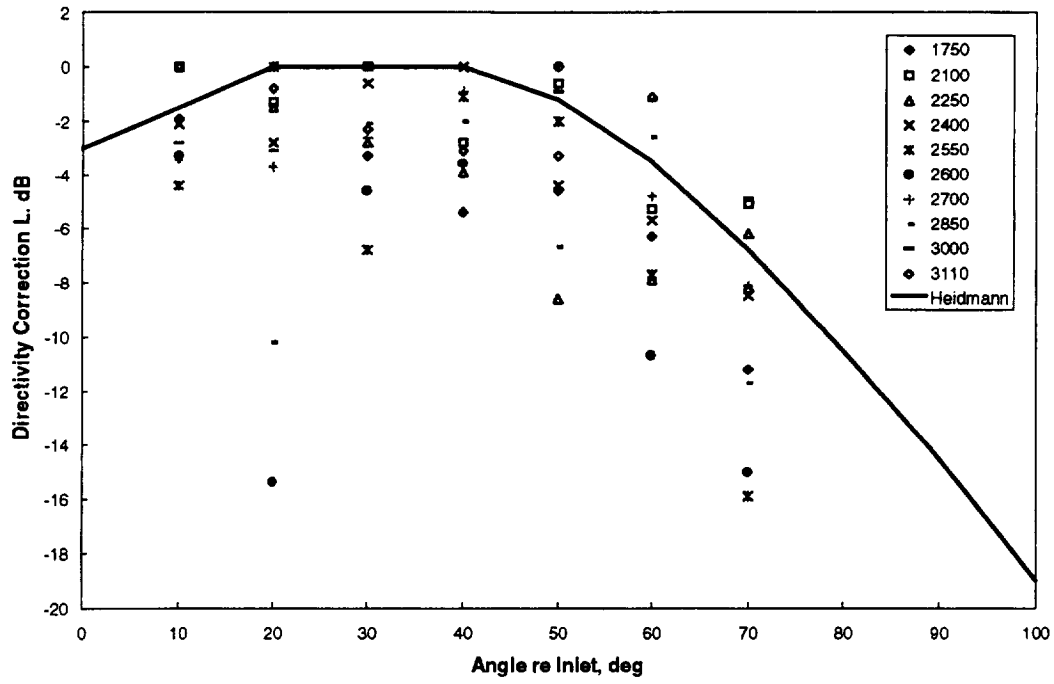


Fan Inlet Broadband Directivity Correction, QCSEE

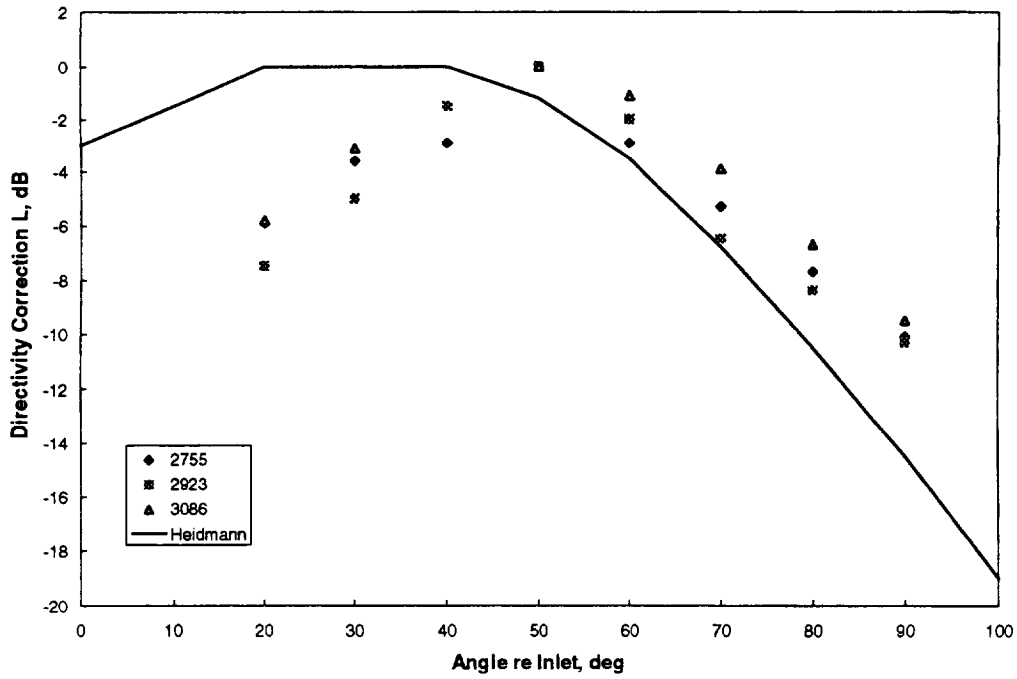




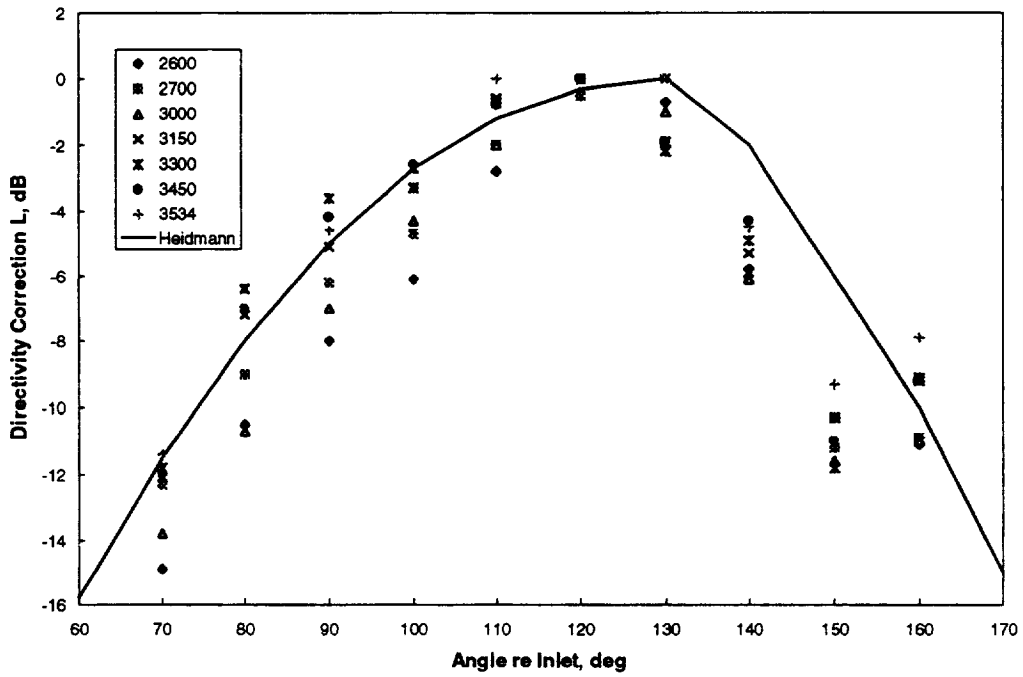
Fan Inlet Tone Directivity Correction, CF6-80C2



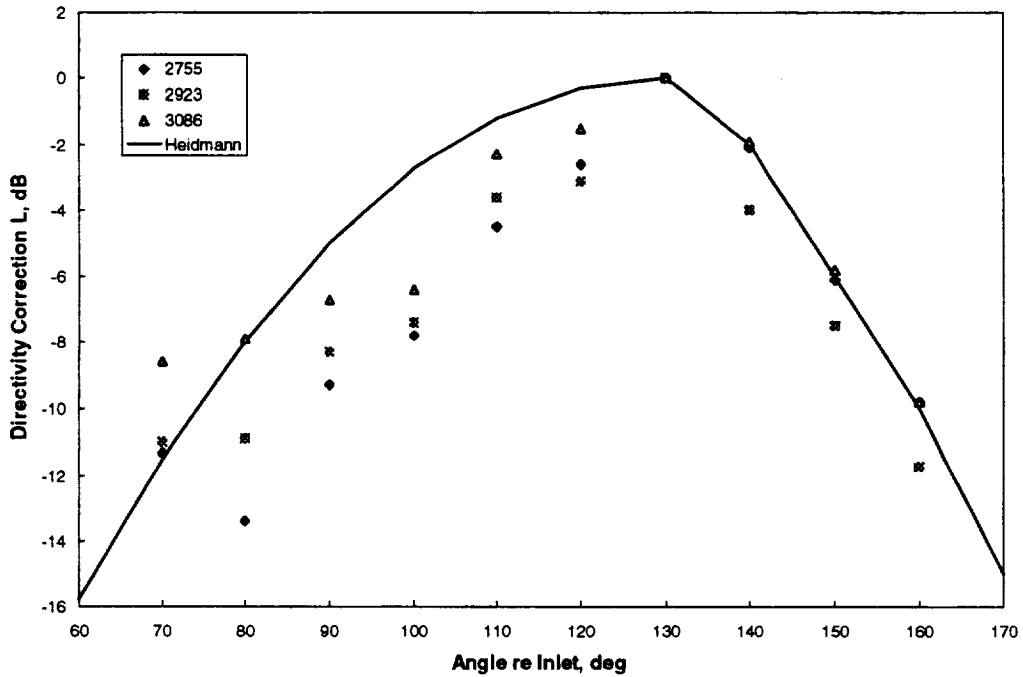
Fan Inlet Tone Directivity Correction, QCSEE



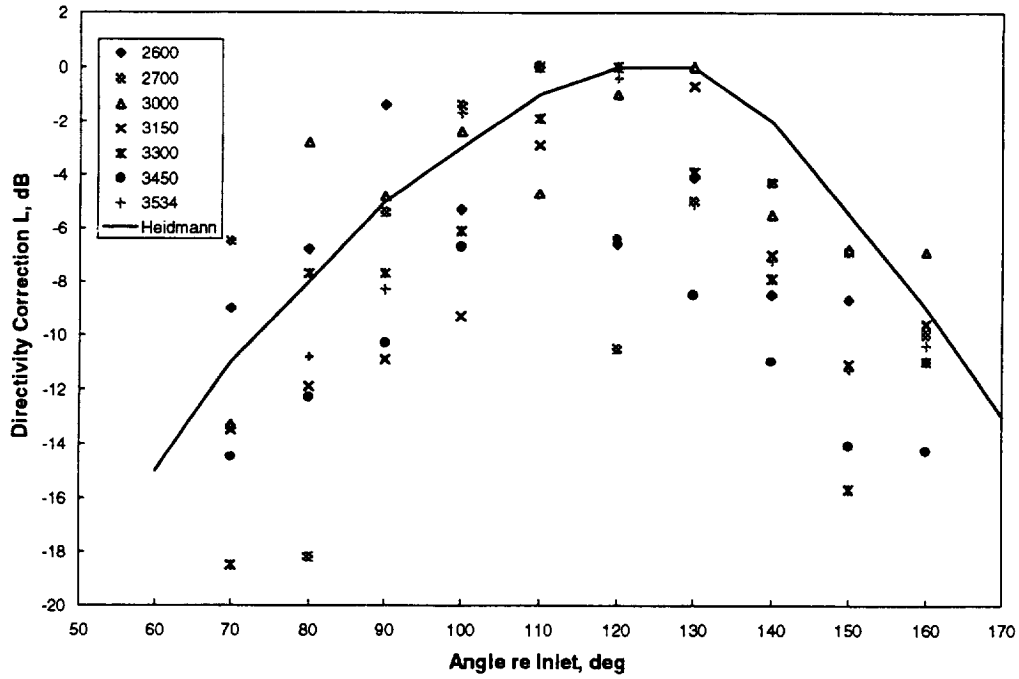
Fan Exhaust Broadband Directivity Correction, CF6-80C2



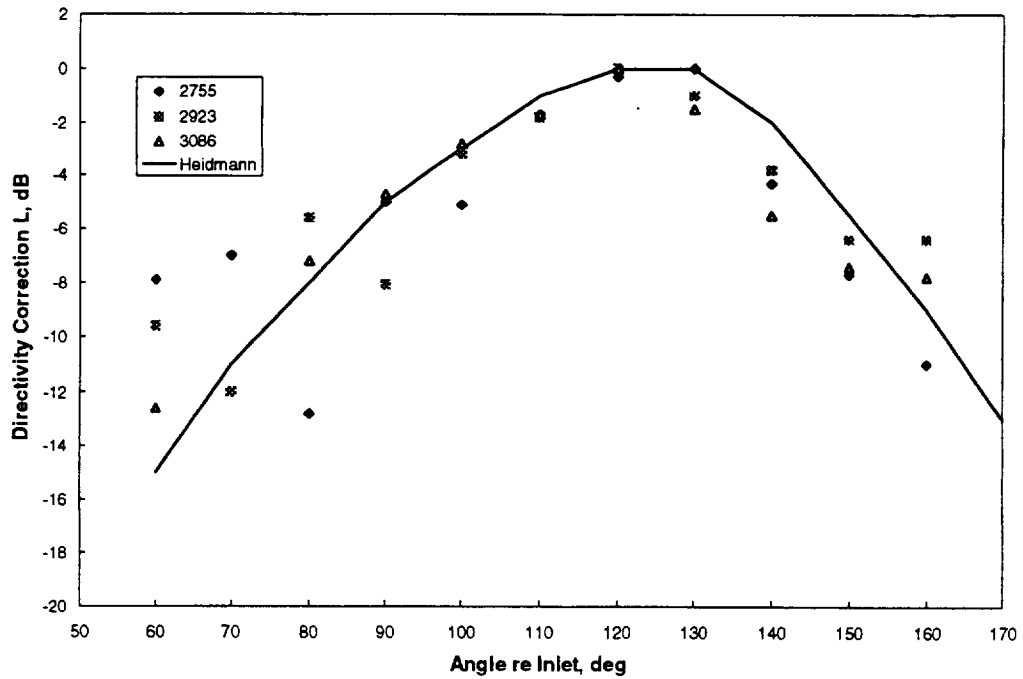
Fan Exhaust Broadband Directivity Correction, QCSEE



Fan Exhaust Tone Directivity Correction, CF6-80C2



Fan Exhaust Tone Directivity Correction, QCSEE



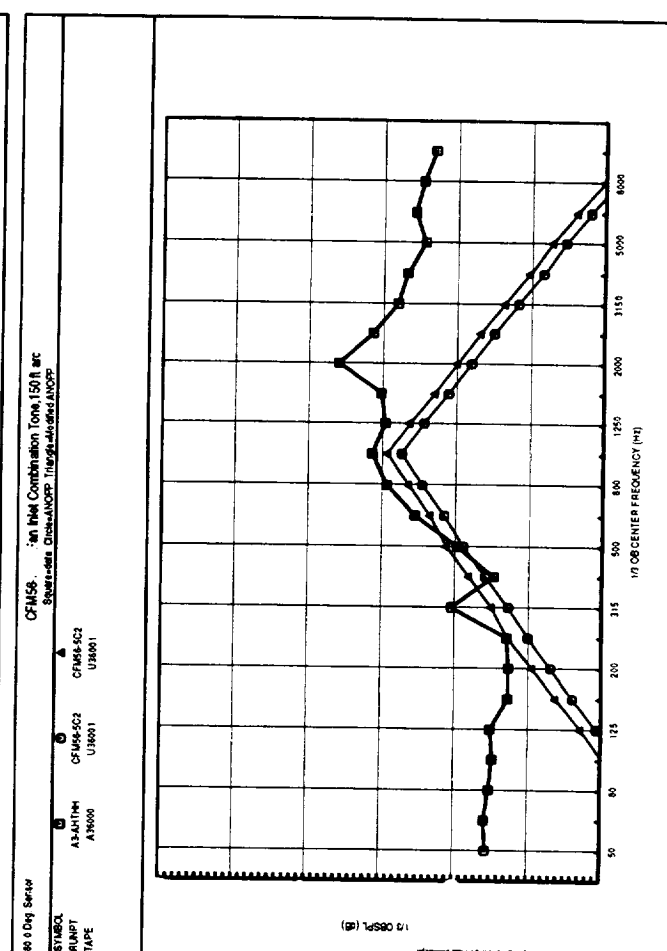
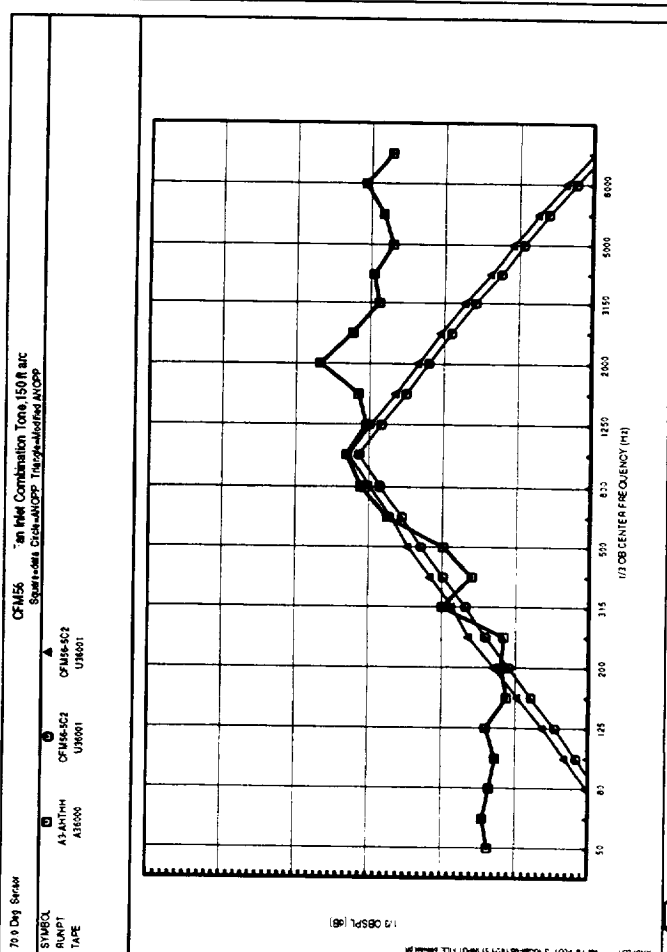
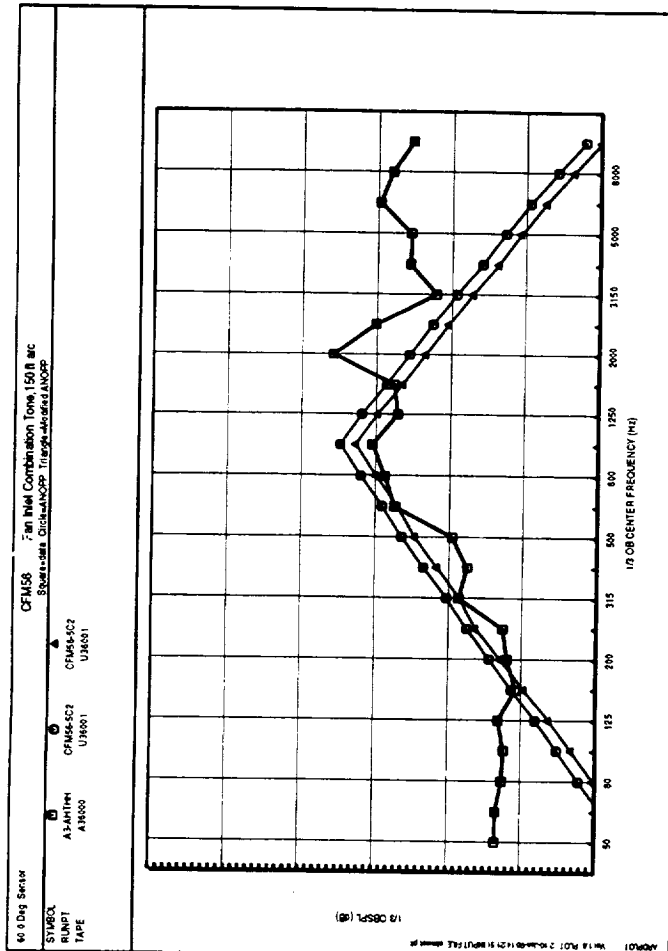
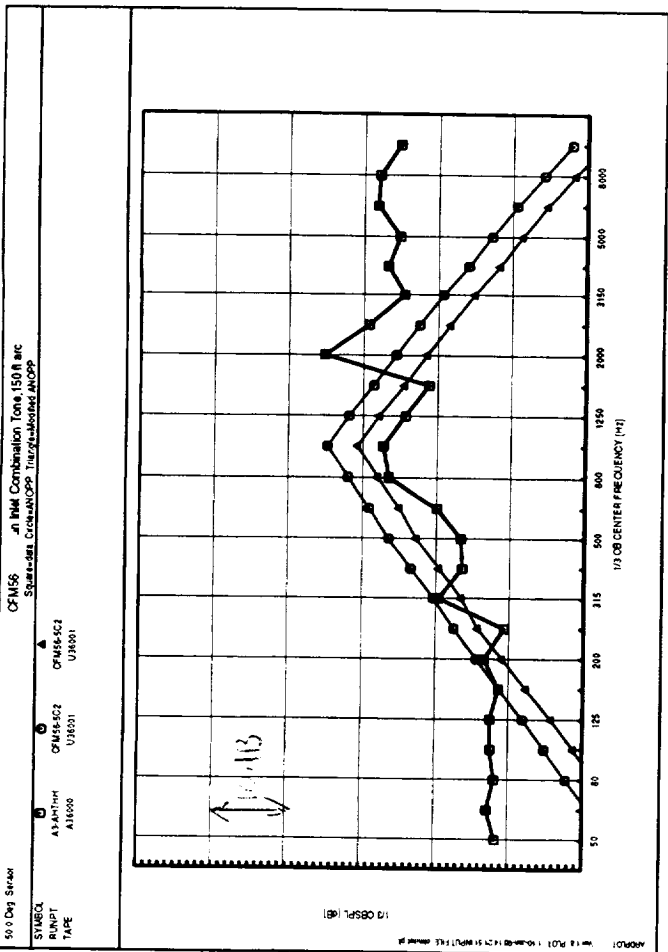
***Appendix L***  
***Combination Tone Noise Spectra - CFM56***

***Appendix L Contents***

<b>Page</b>	<b>Fan Speed, rpm</b>	<b>Angles</b>
134	3600	50-80
135	3900	50-80
136	4050	50-80
137	4150	50-80
138	4250	50-80
139	4350	50-80
140	4450	50-80
141	4550	50-80

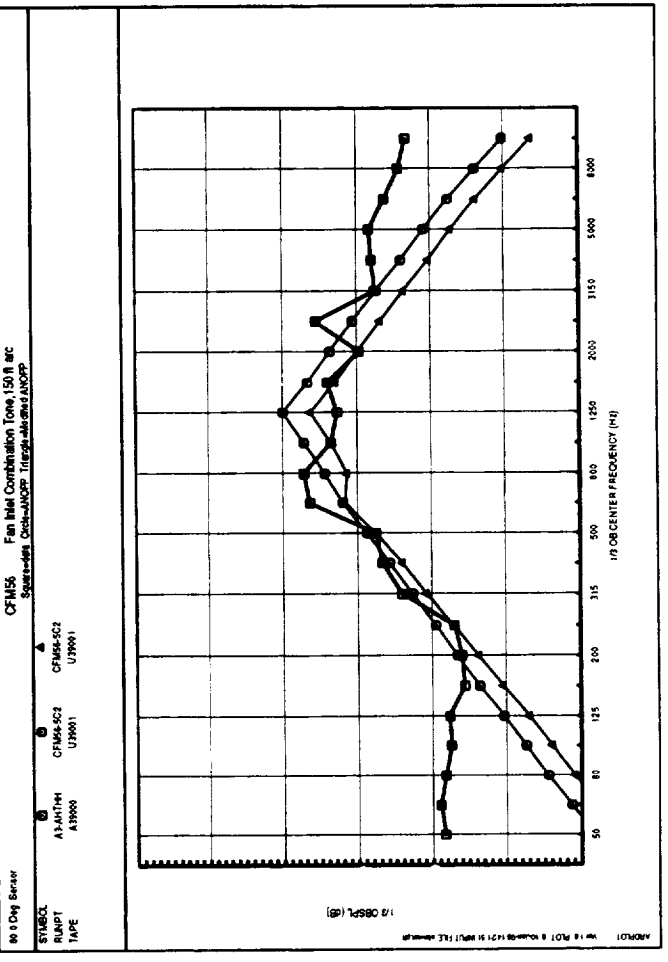
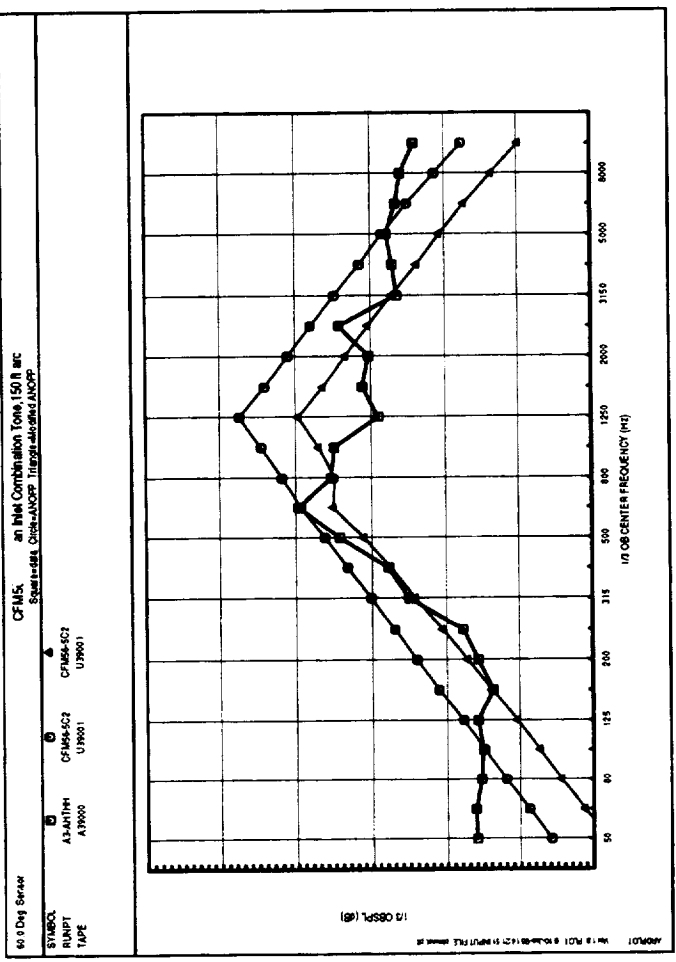
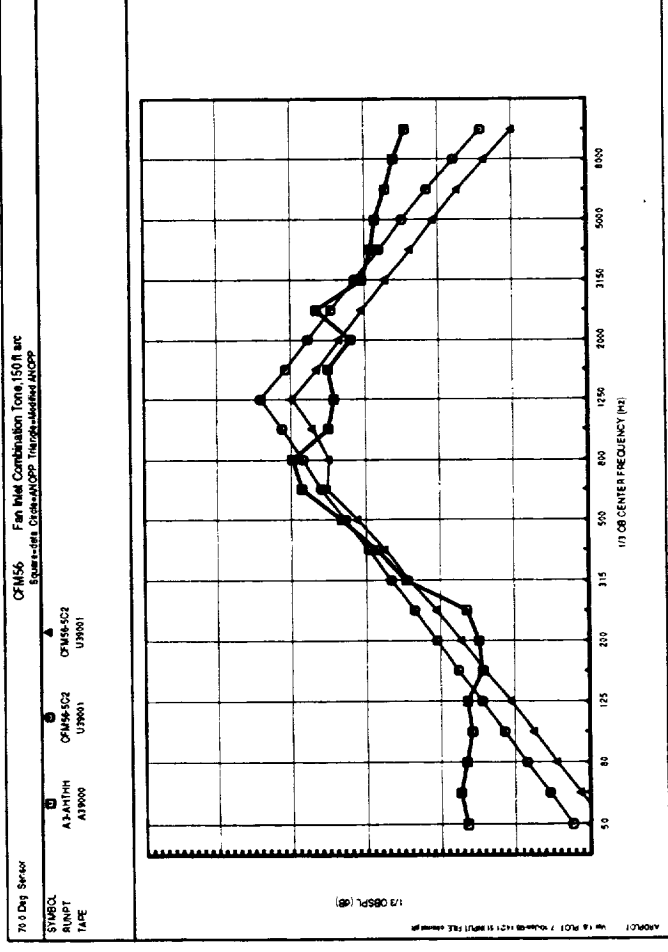
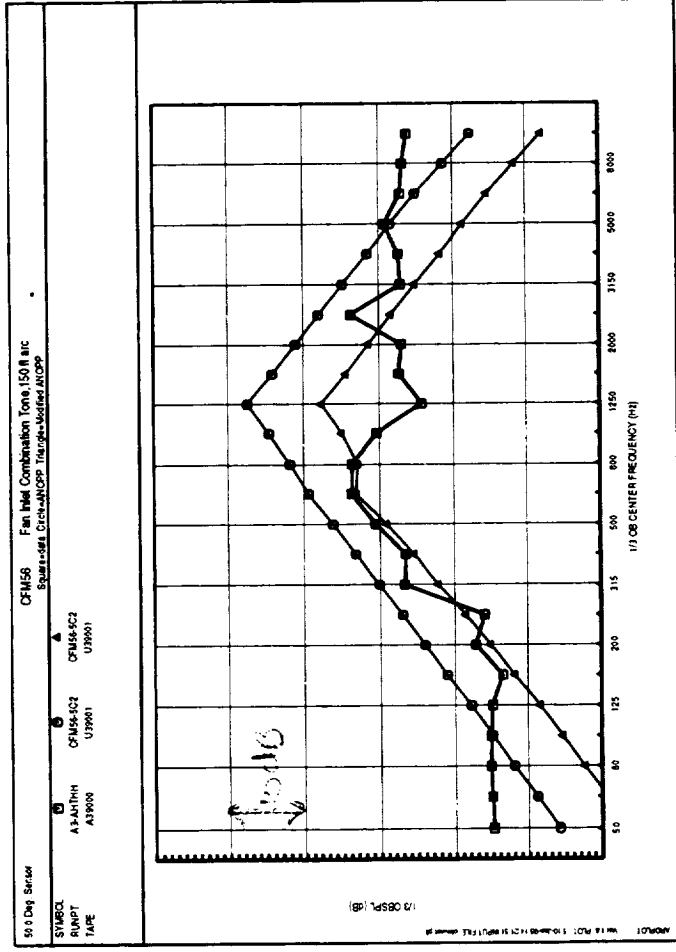
***Key to Plots:***

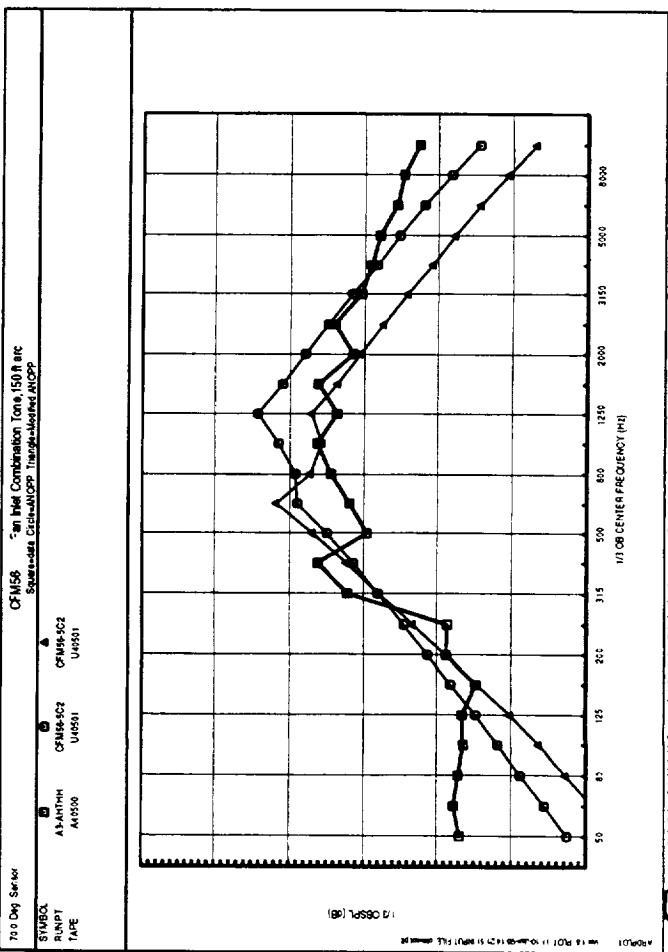
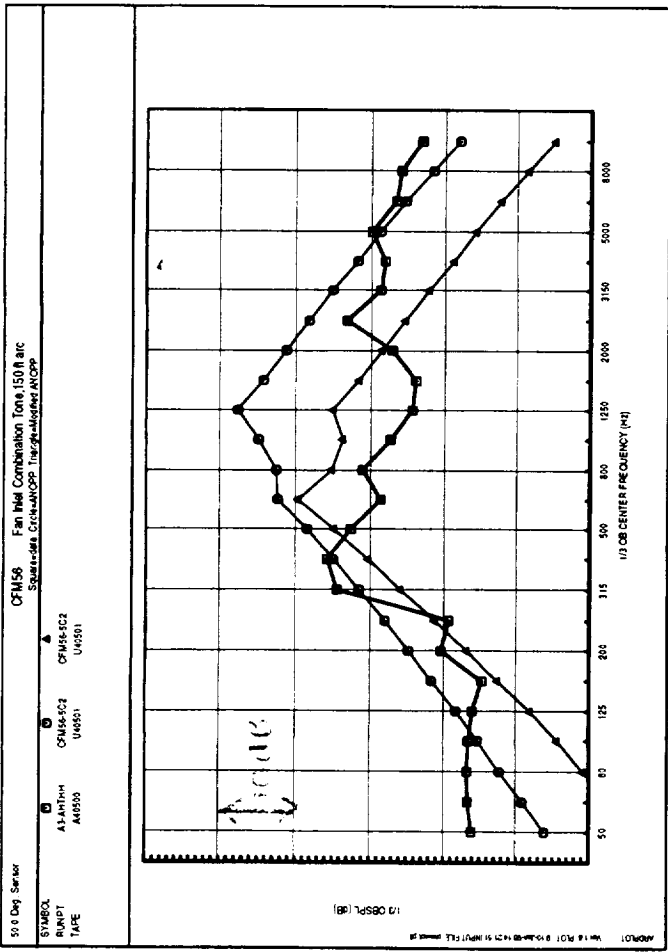
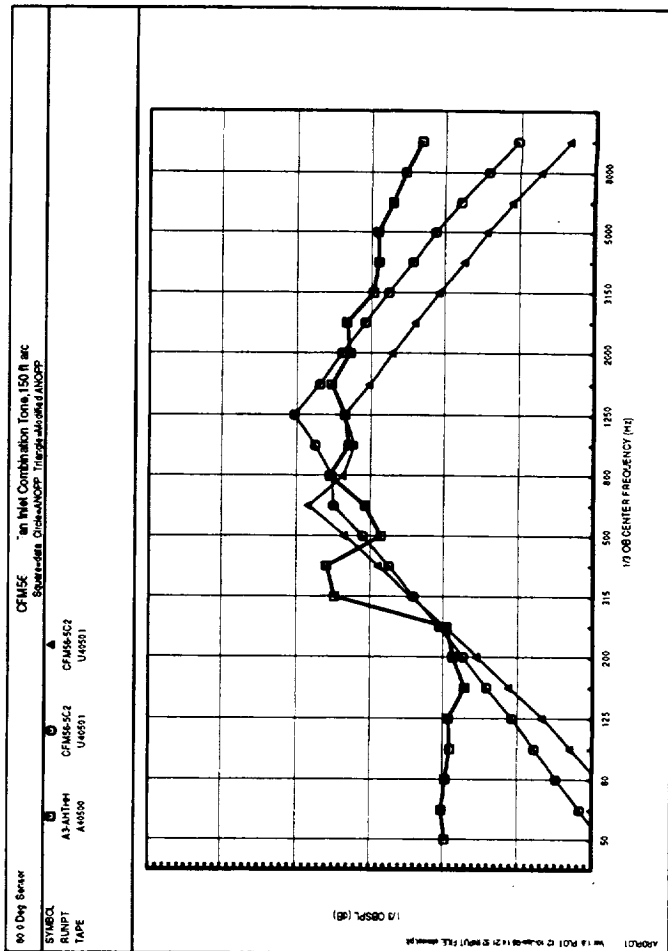
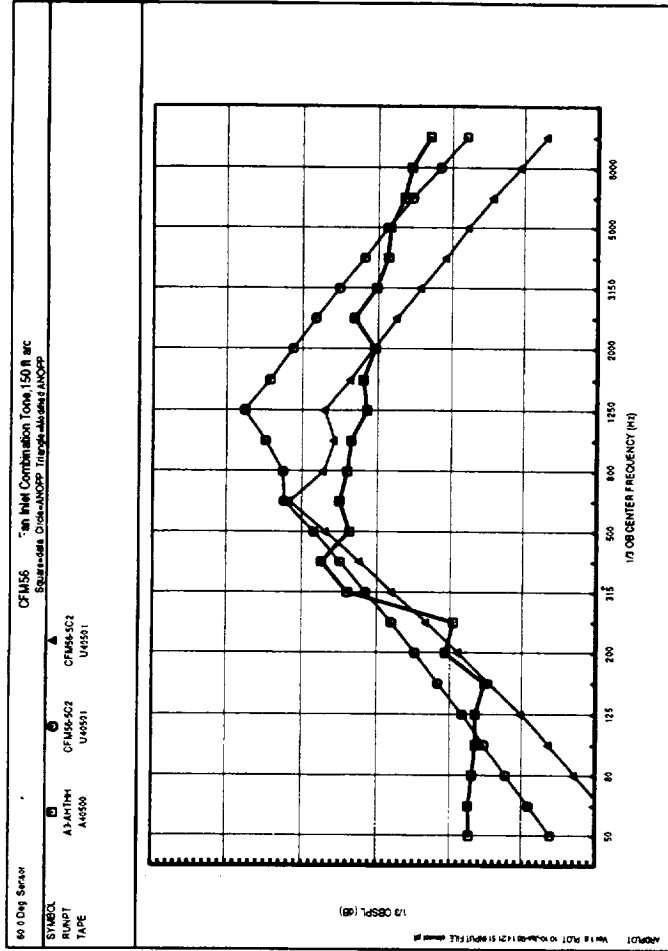
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circles = Heidmann method  
triangles = modified Heidmann method

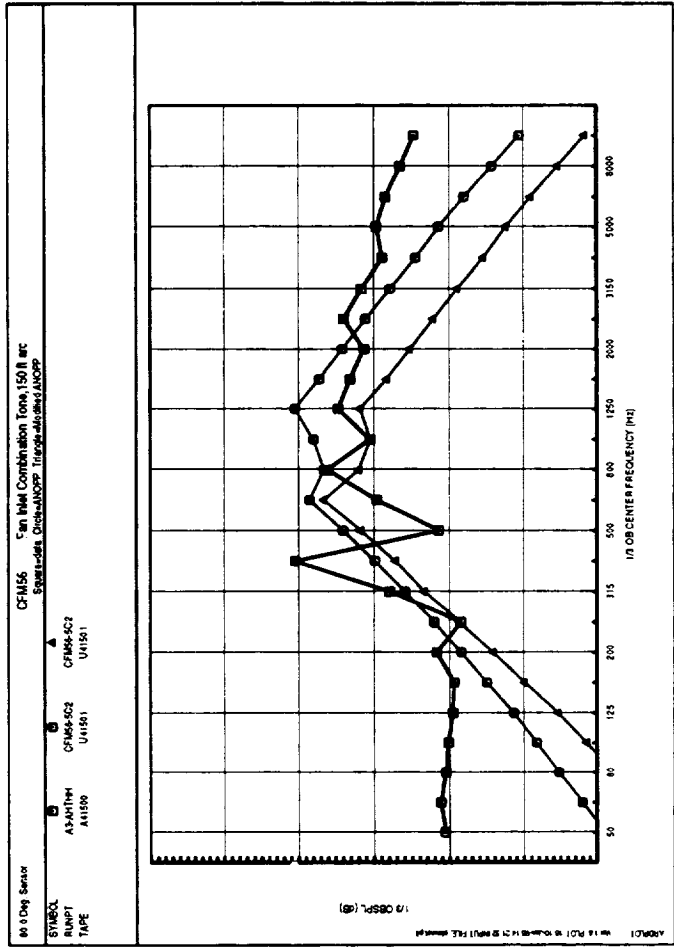
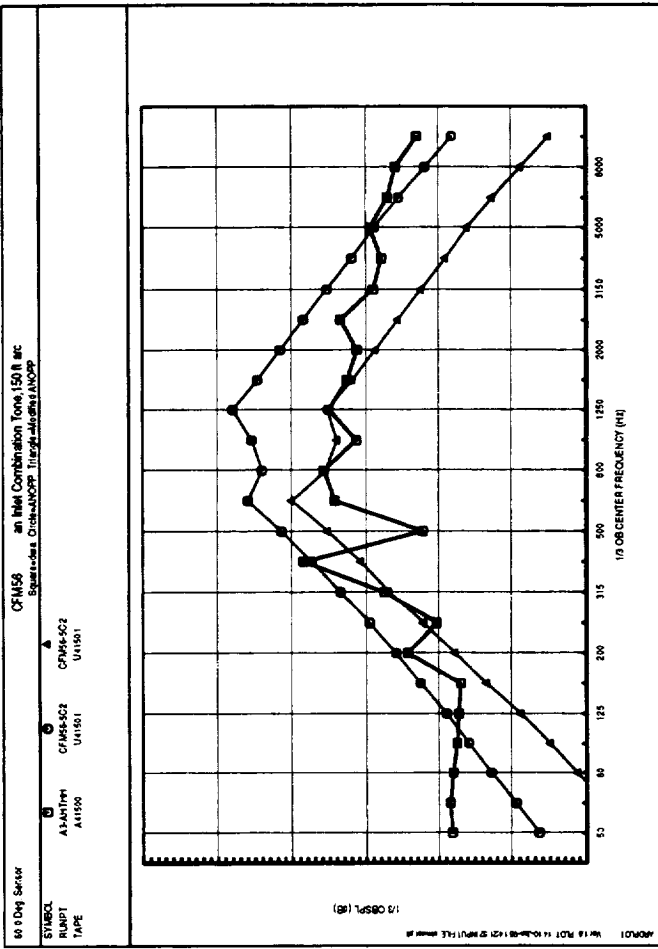
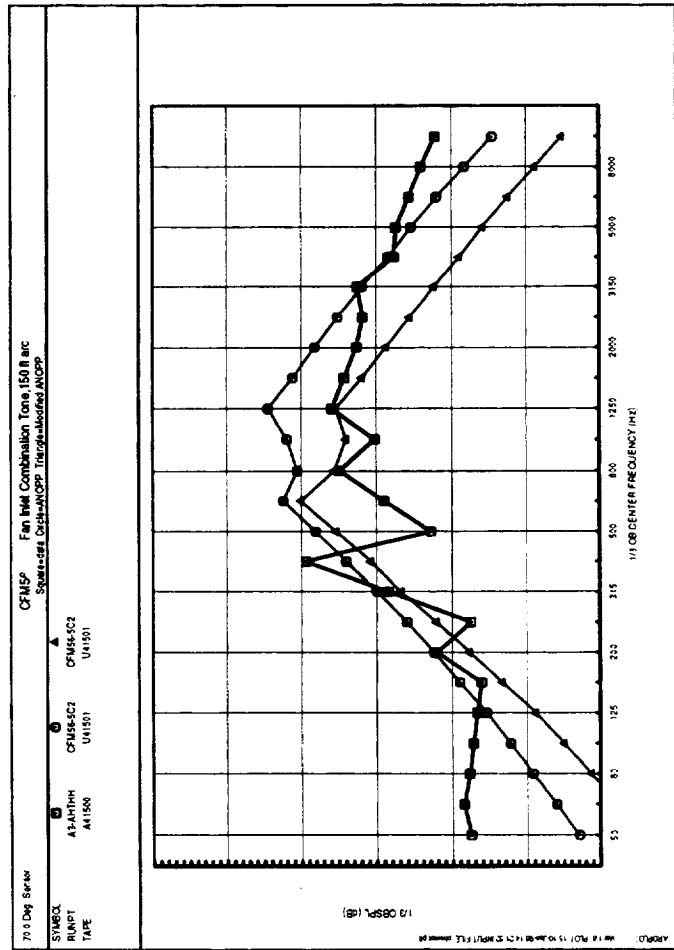
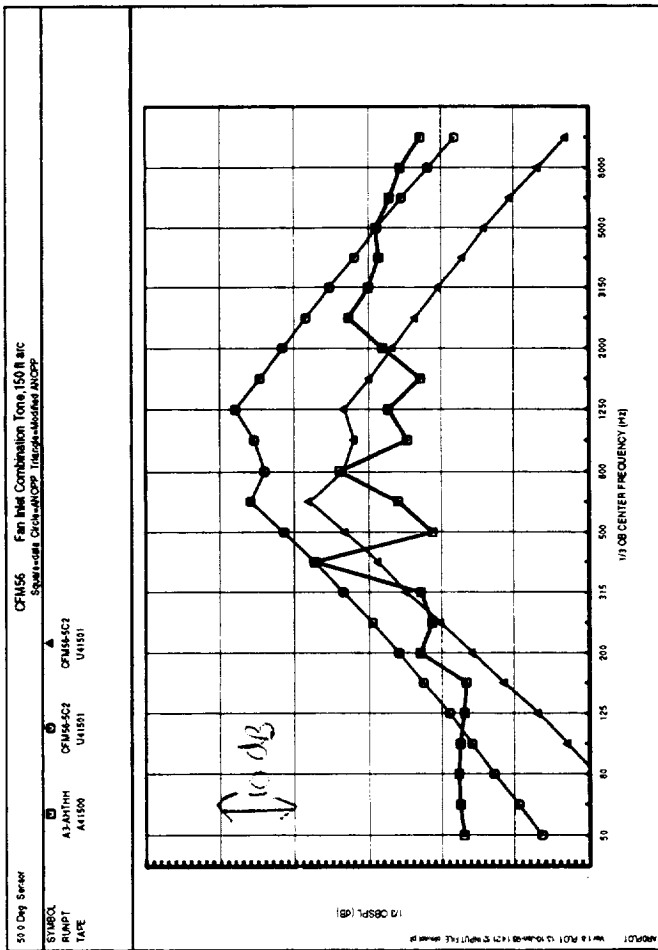


1421 01/10/96 ma10142150.pdf kordos@c0424 X11 PLOT 1  
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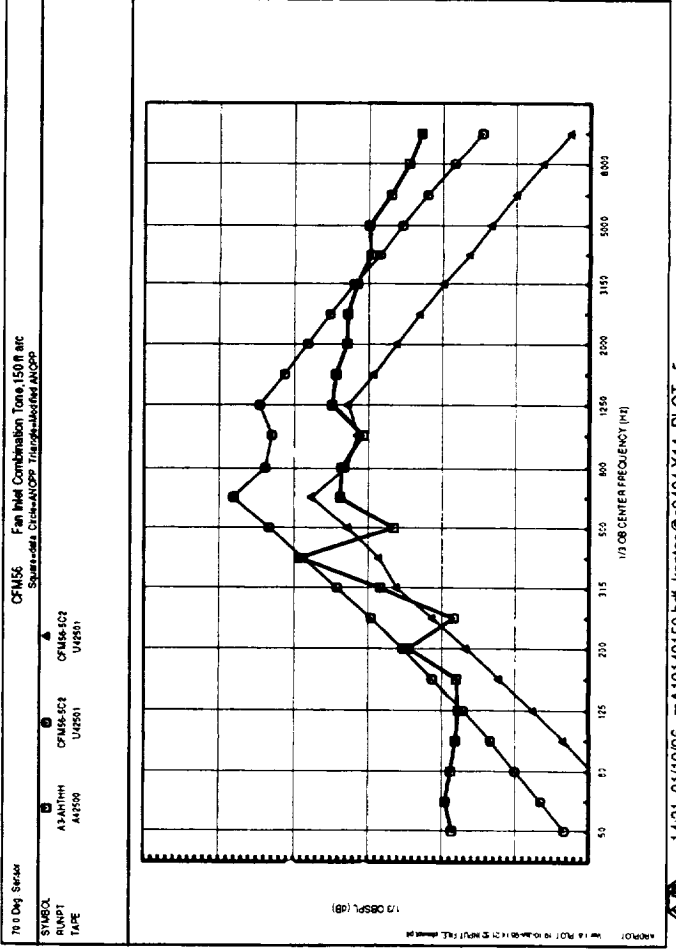
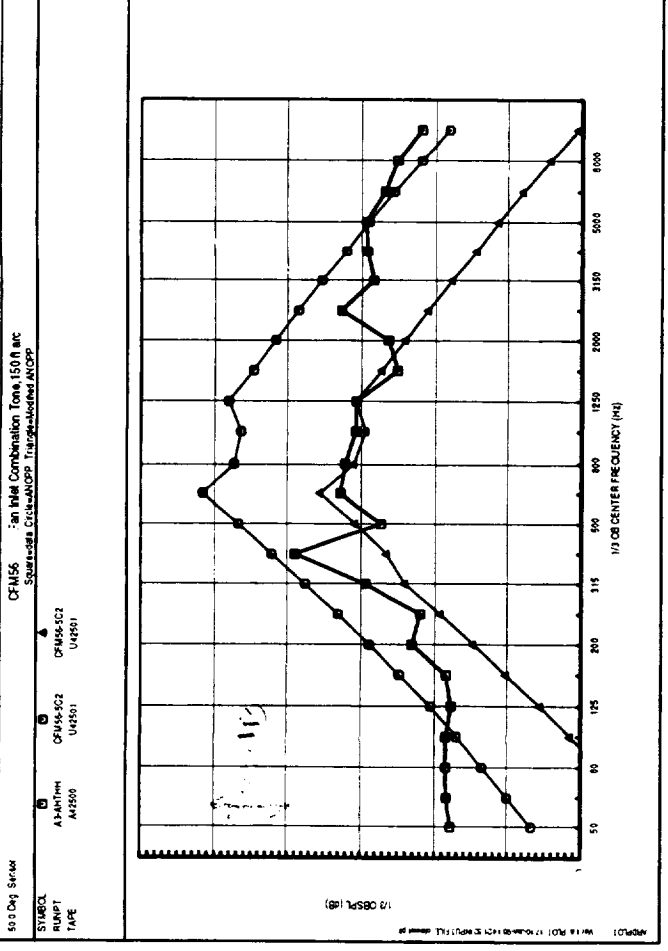
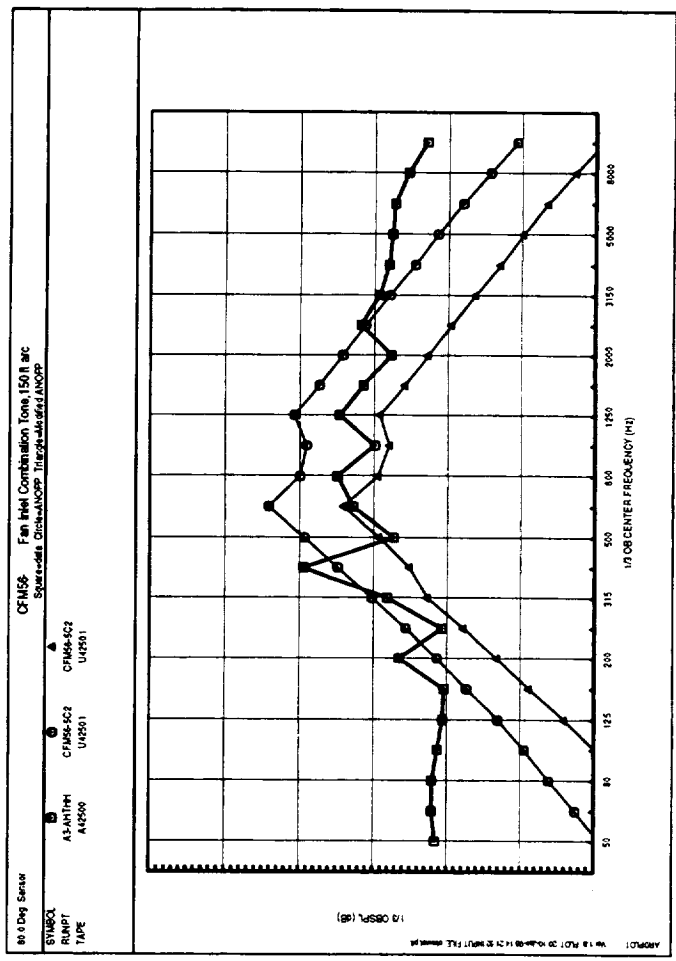
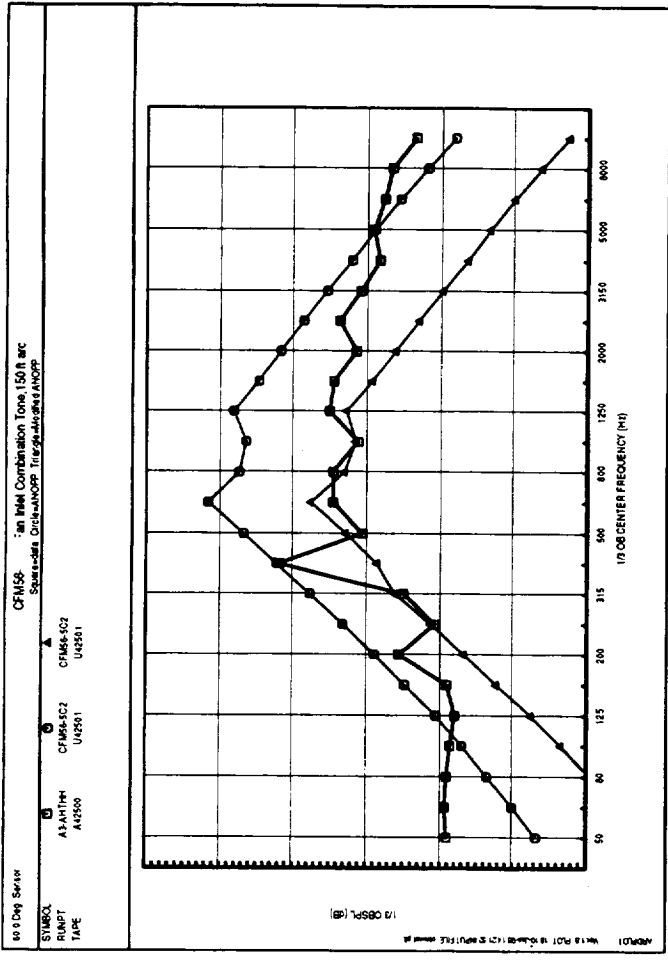


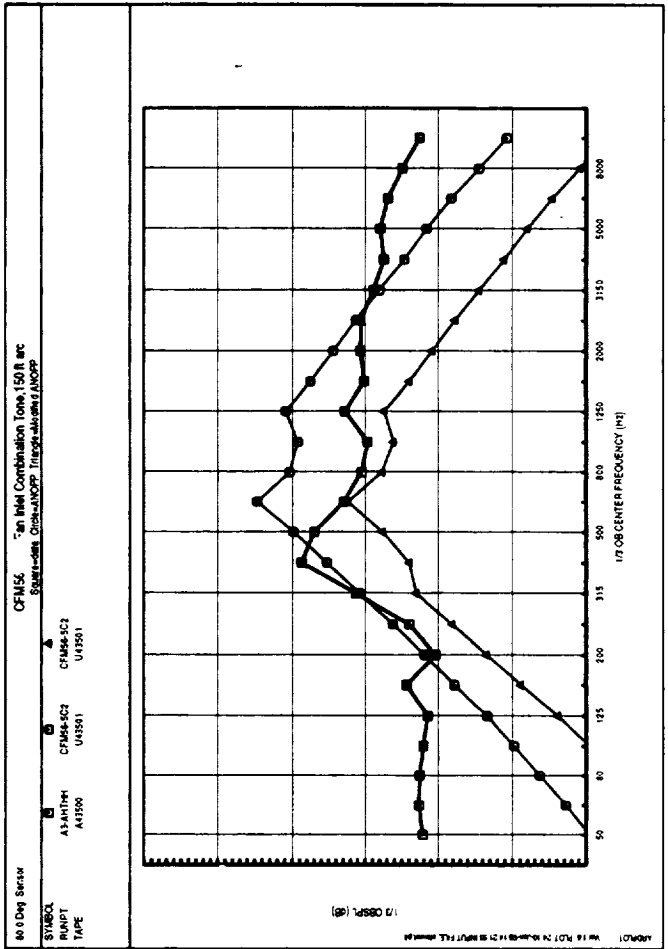
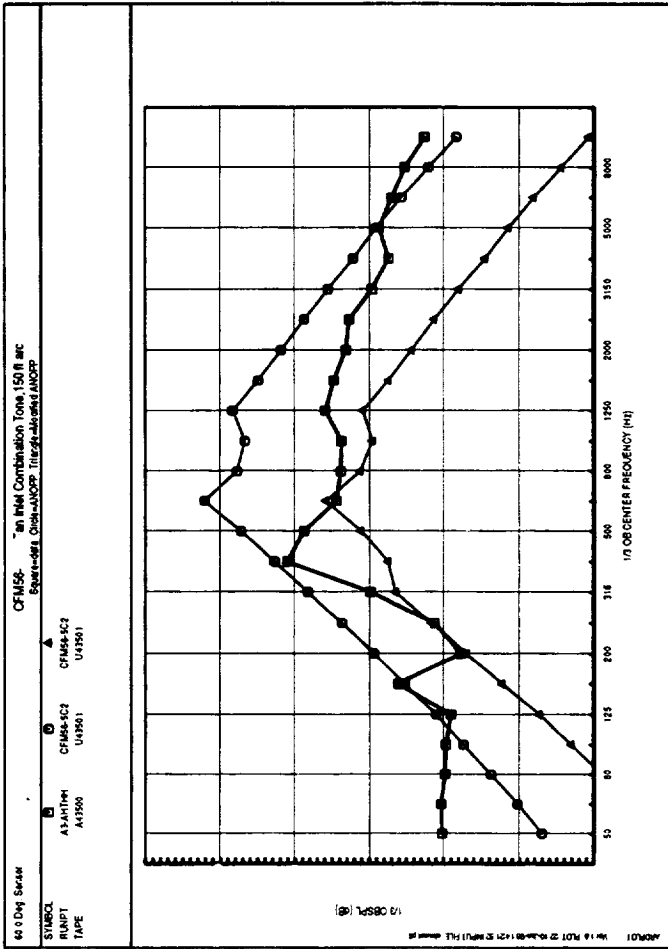
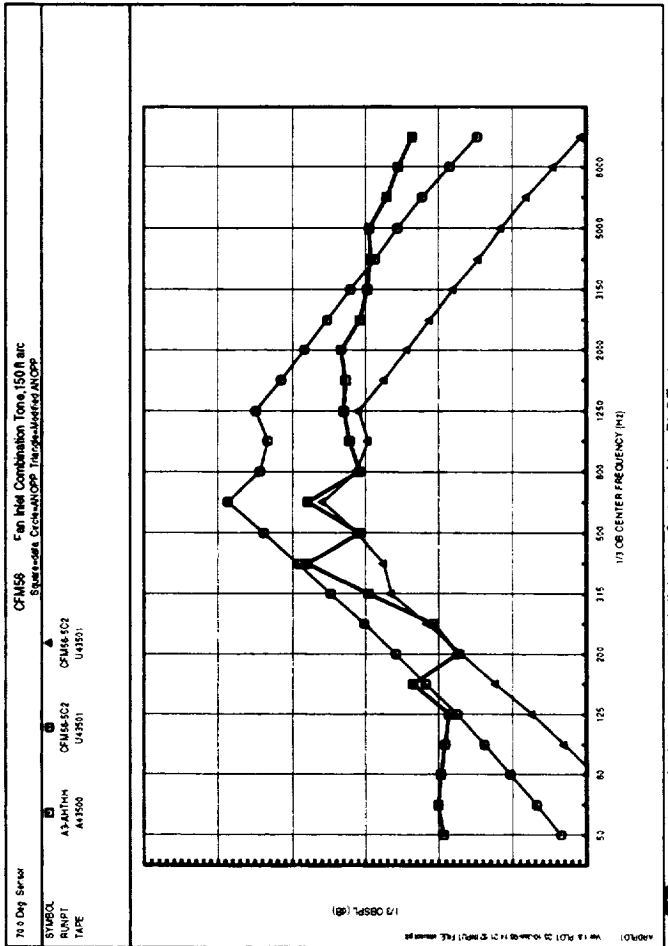
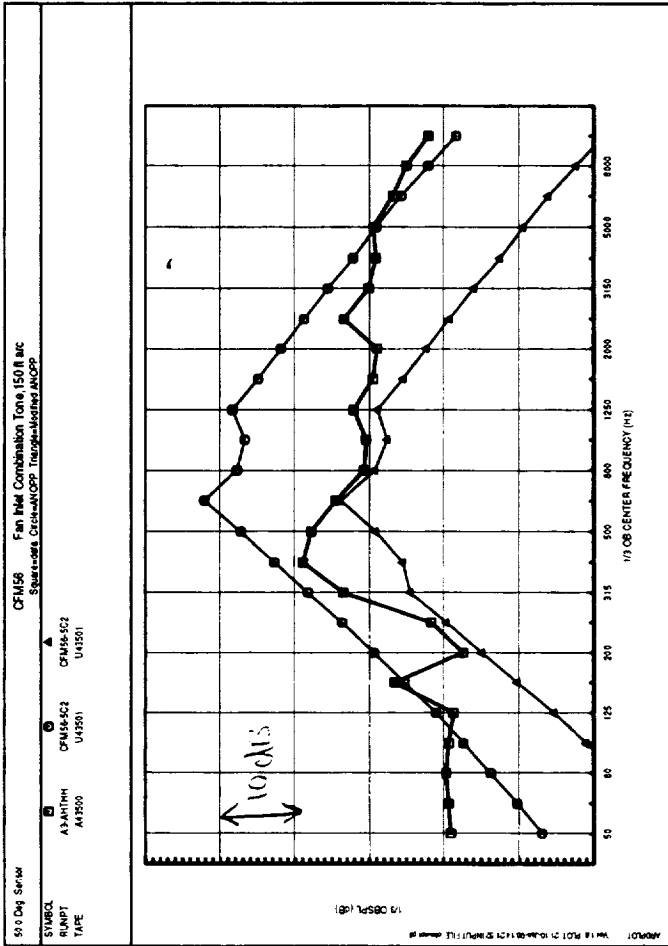










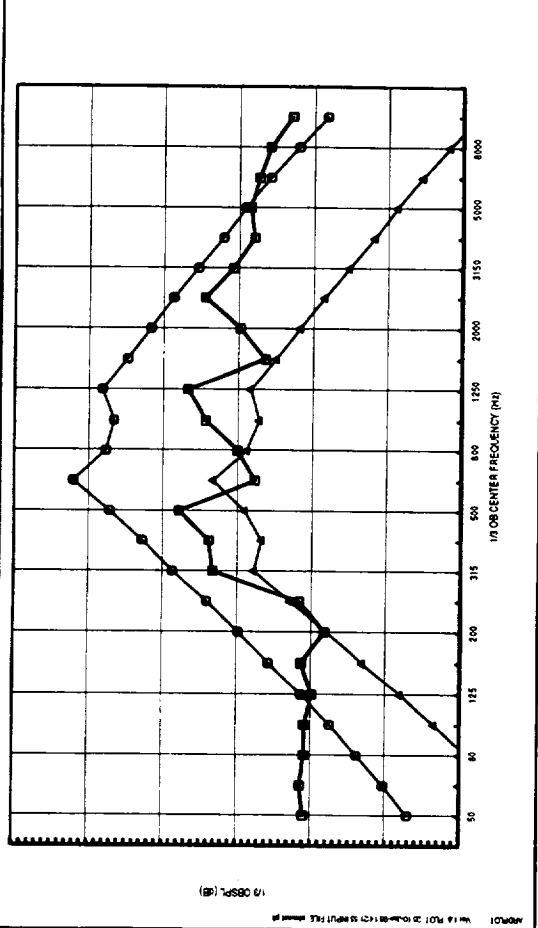


130

90 Deg Sensor

CFM56 Fan Inlet Combination Tone, 150 ft arc  
 Square-Root Correction, Triangular Arc

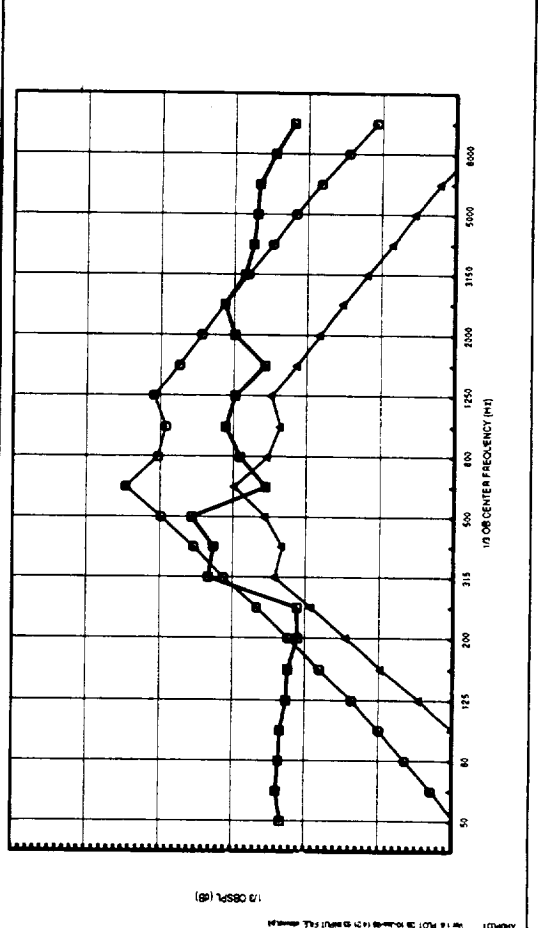
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90 Deg Sensor

CFM56 Fan Inlet Combination Tone, 150 ft arc  
 Square-Root Correction, Triangular Arc

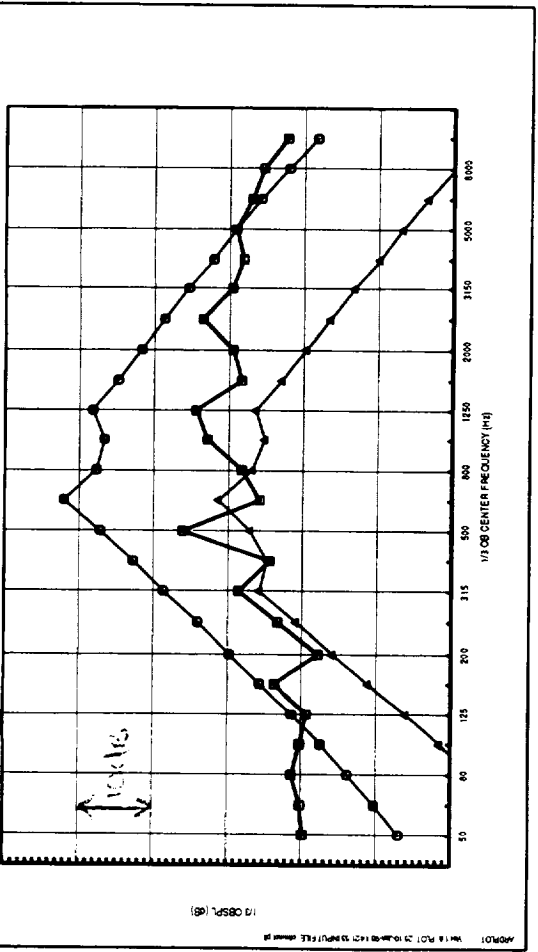
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90 Deg Sensor

CFM56 Fan Inlet Combination Tone, 150 ft arc  
 Square-Root Correction, Triangular Arc

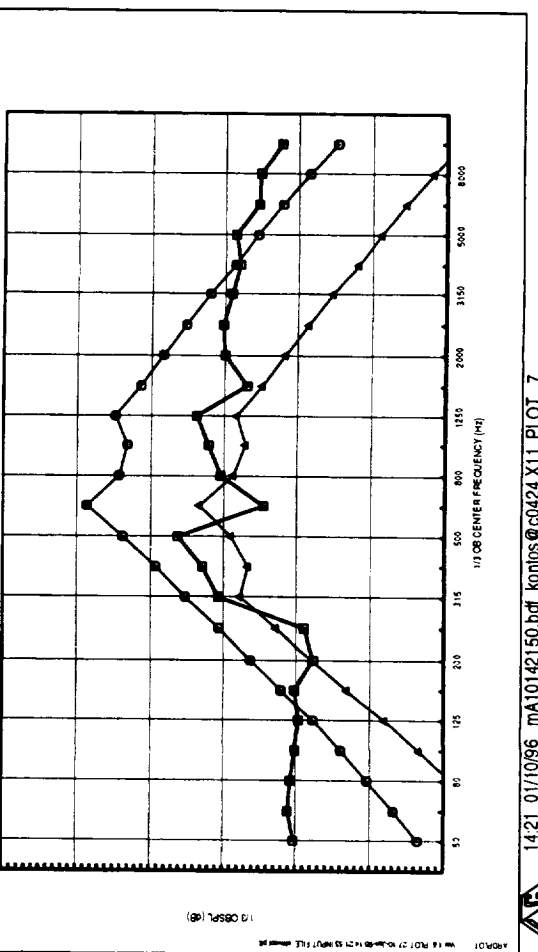
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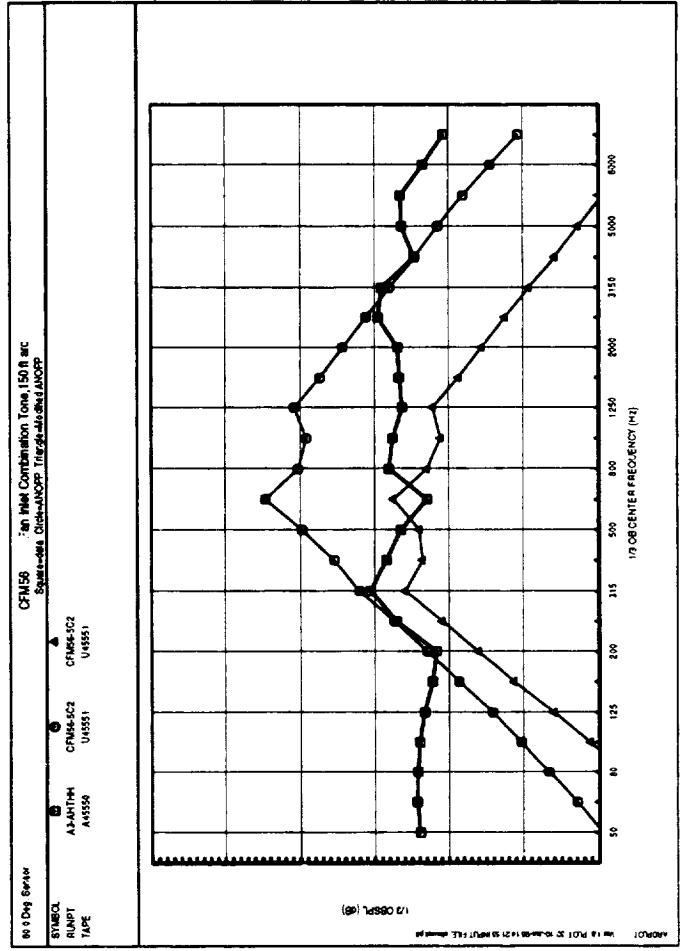
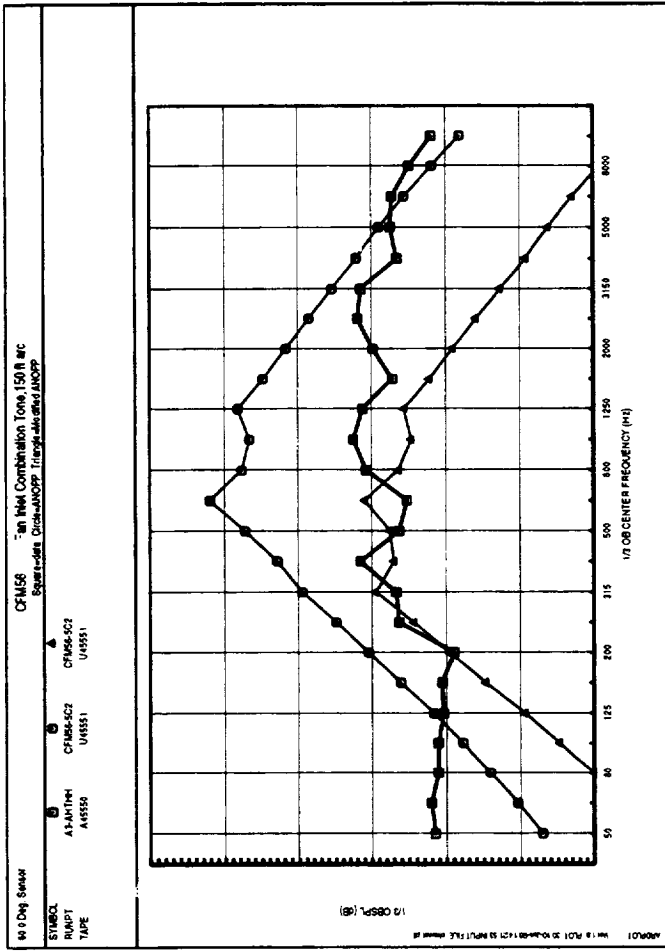
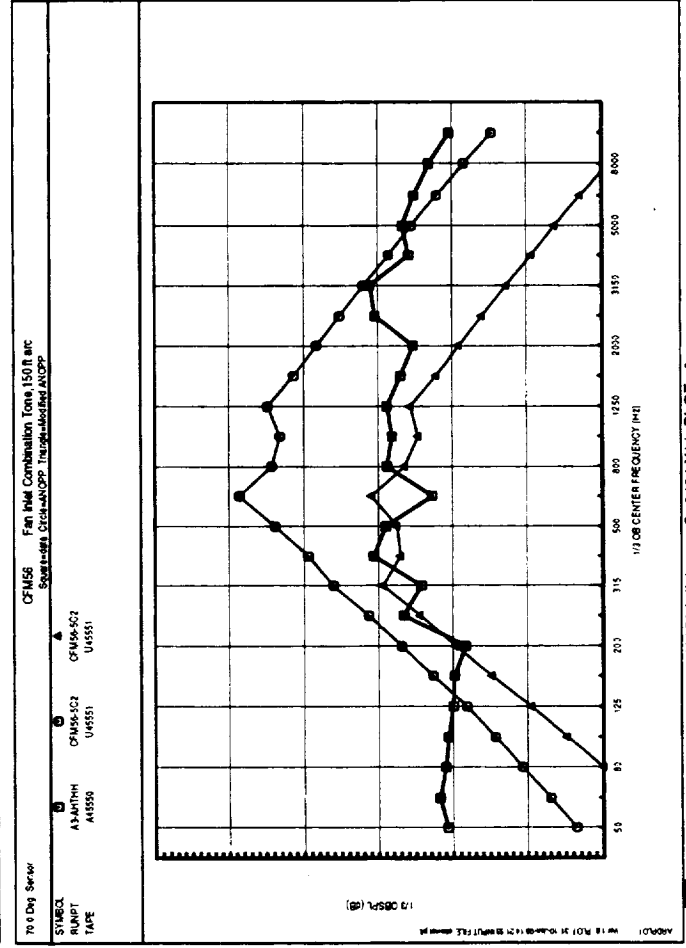
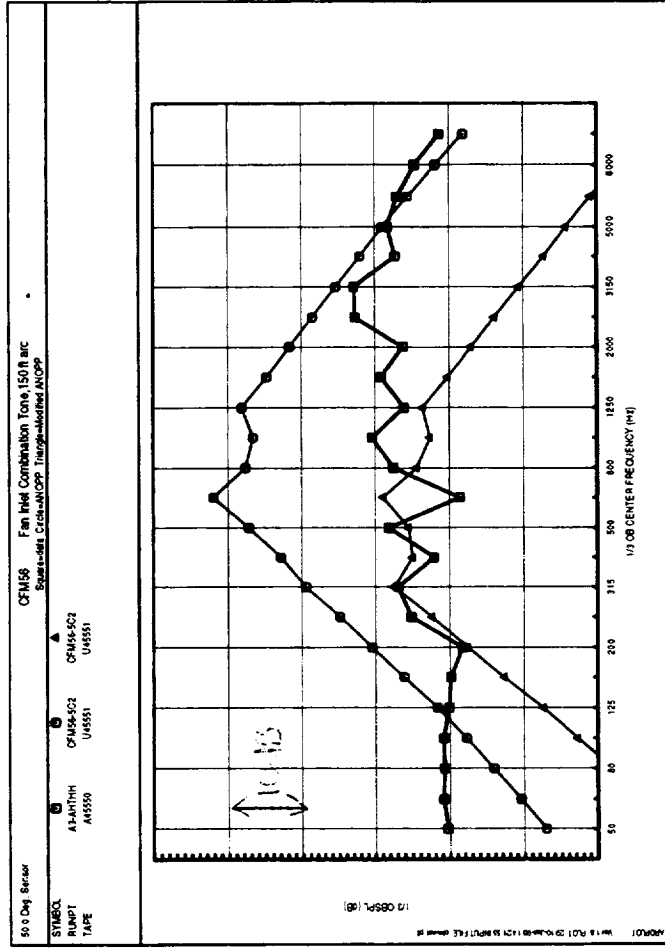


90 Deg Sensor

CFM56 Fan Inlet Combination Tone, 150 ft arc  
 Square-Root Correction, Triangular Arc

SYMBOL: ▲  
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 TAPE: A44500 U44501





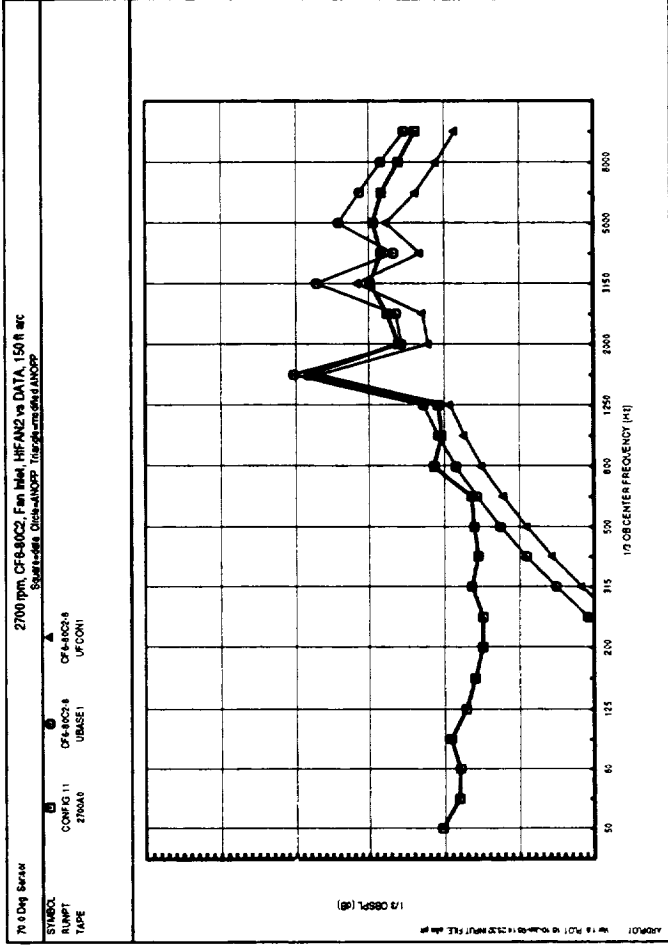
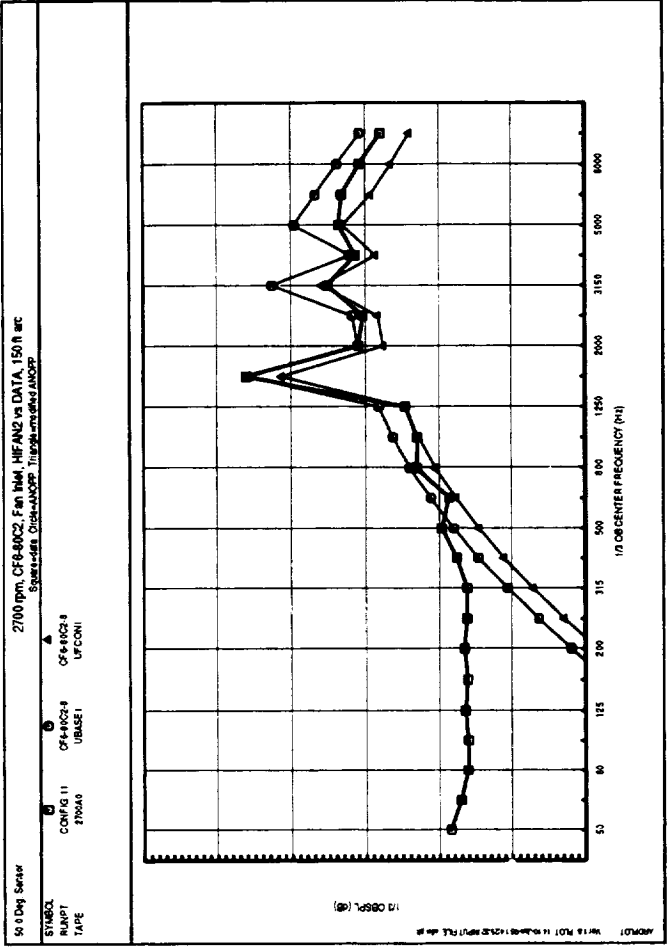
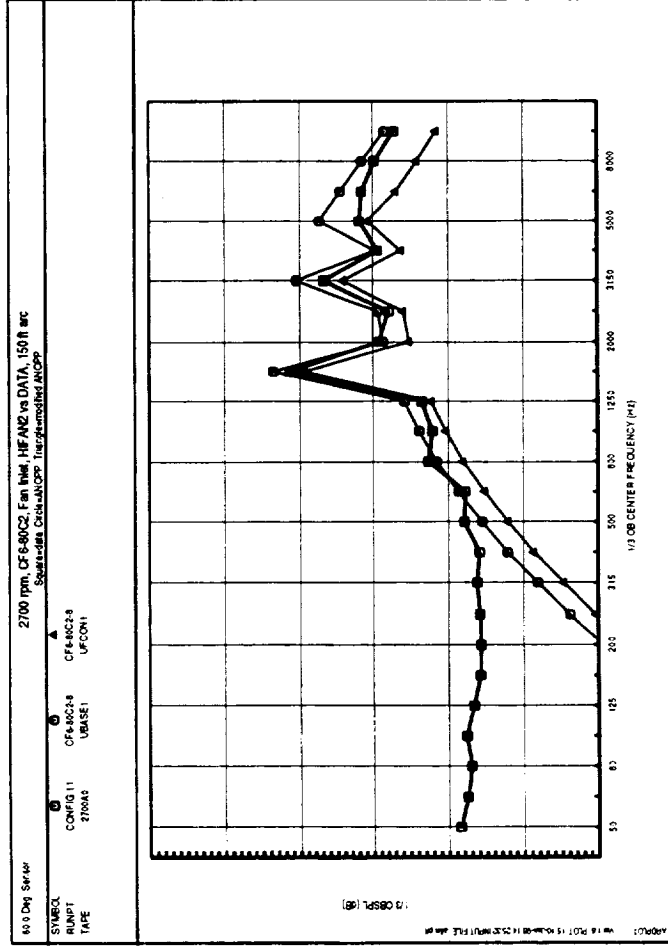
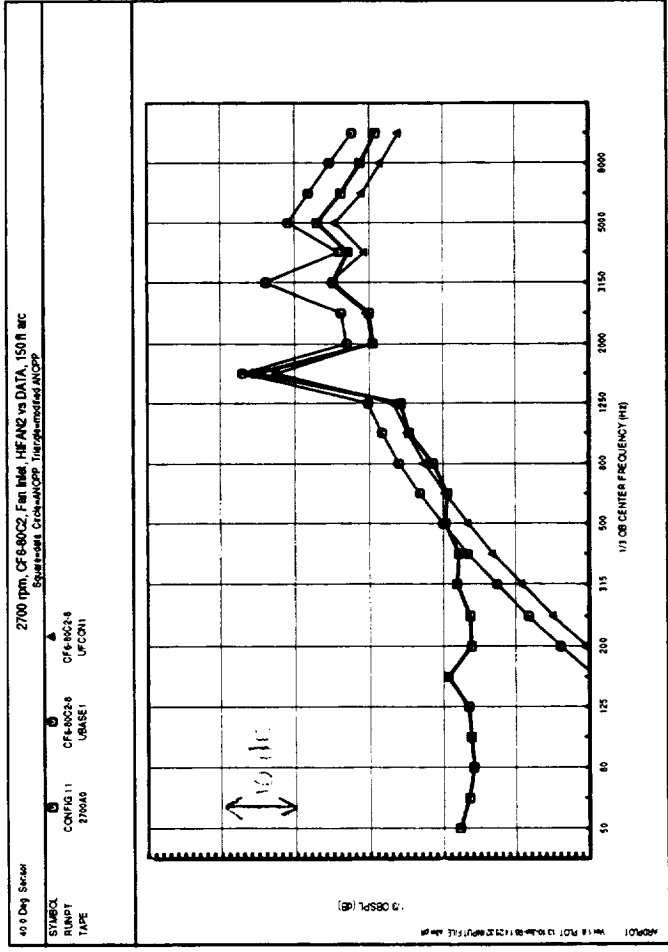
***Appendix M***  
***Combination Tone Noise Spectra - CF6-80C2***

***Appendix M Contents***

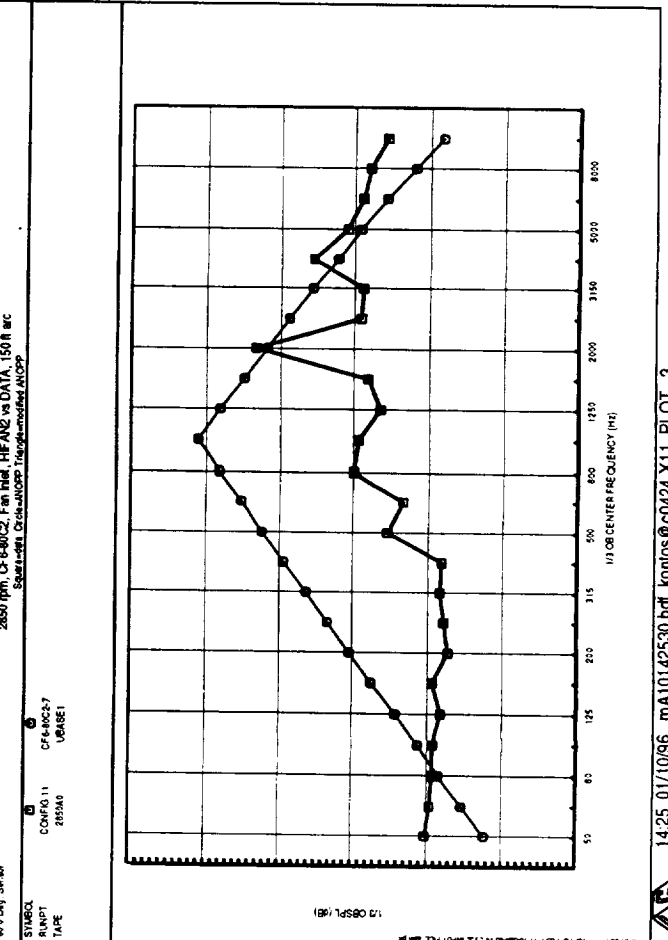
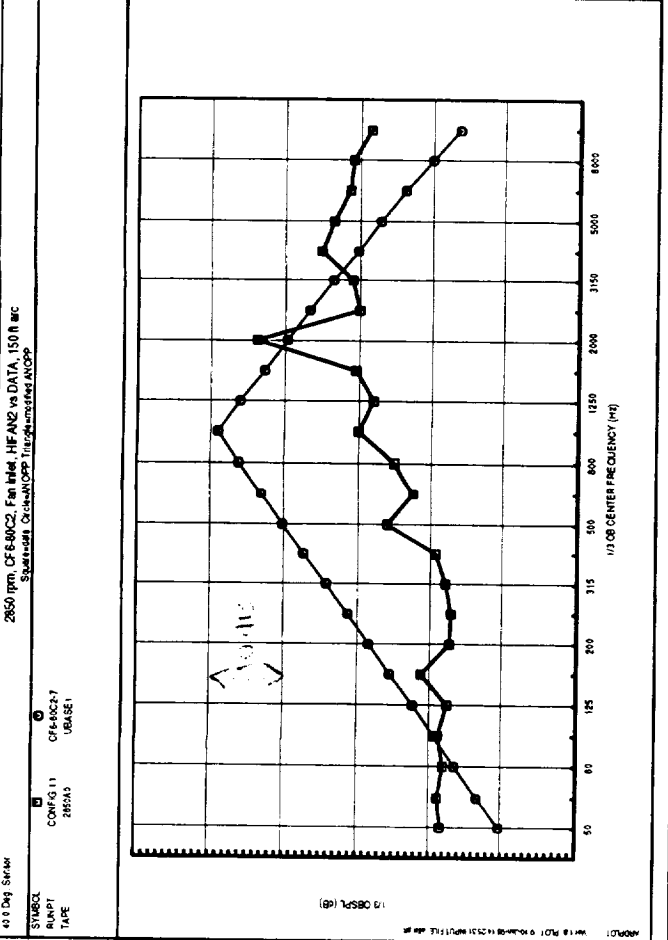
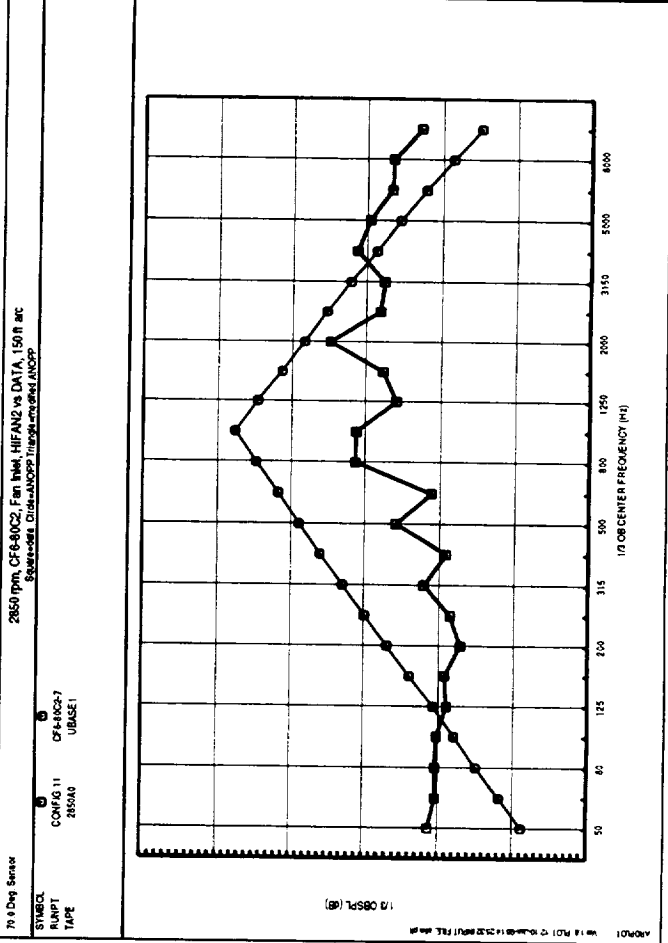
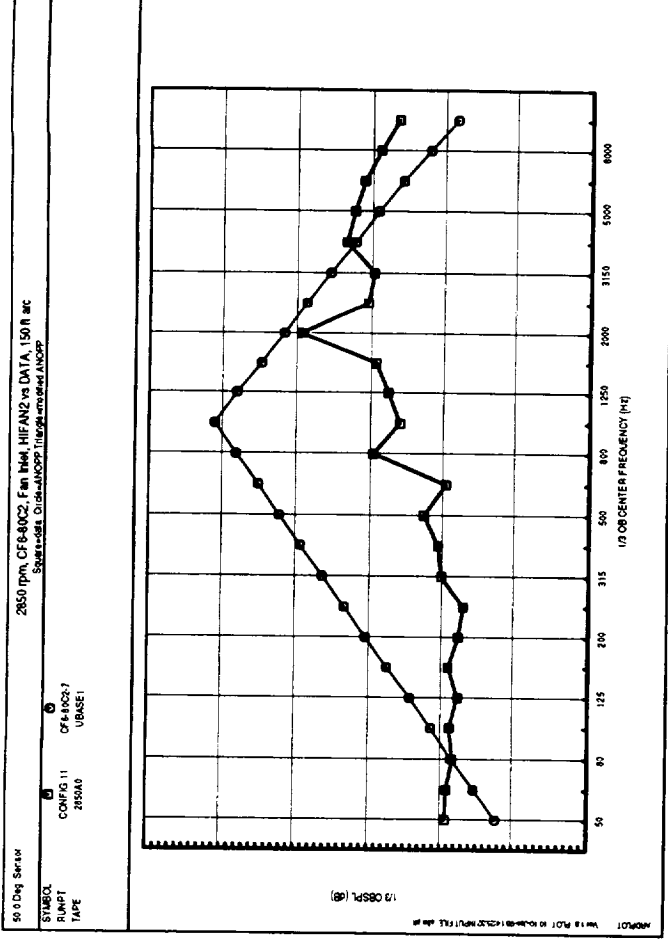
<b>Page</b>	<b>Fan Speed, rpm</b>	<b>Angles</b>
143	2700	40-70
144	2850	40-70
145	3000	40-70
146	3110	40-70

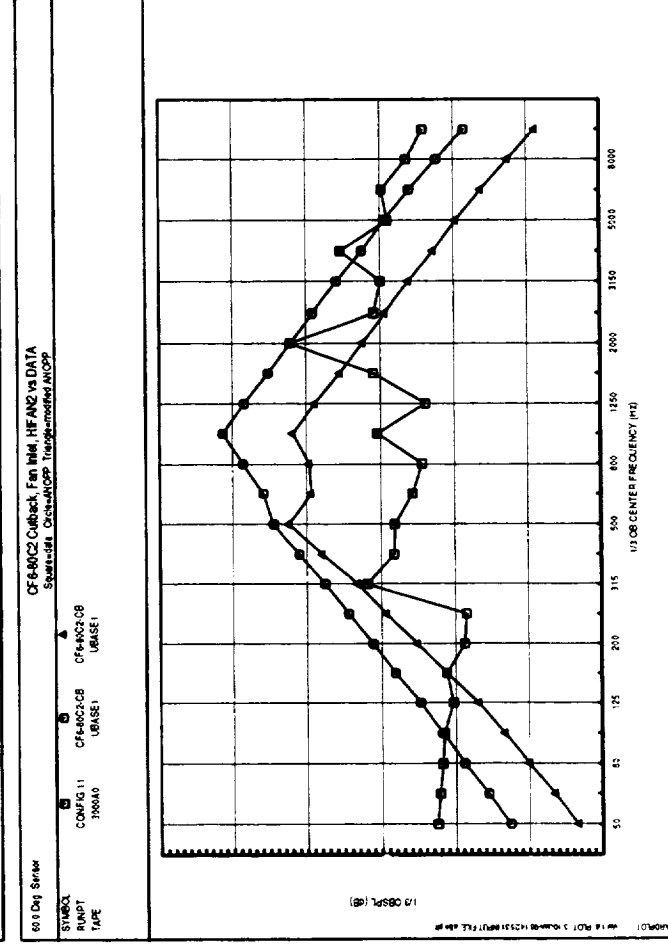
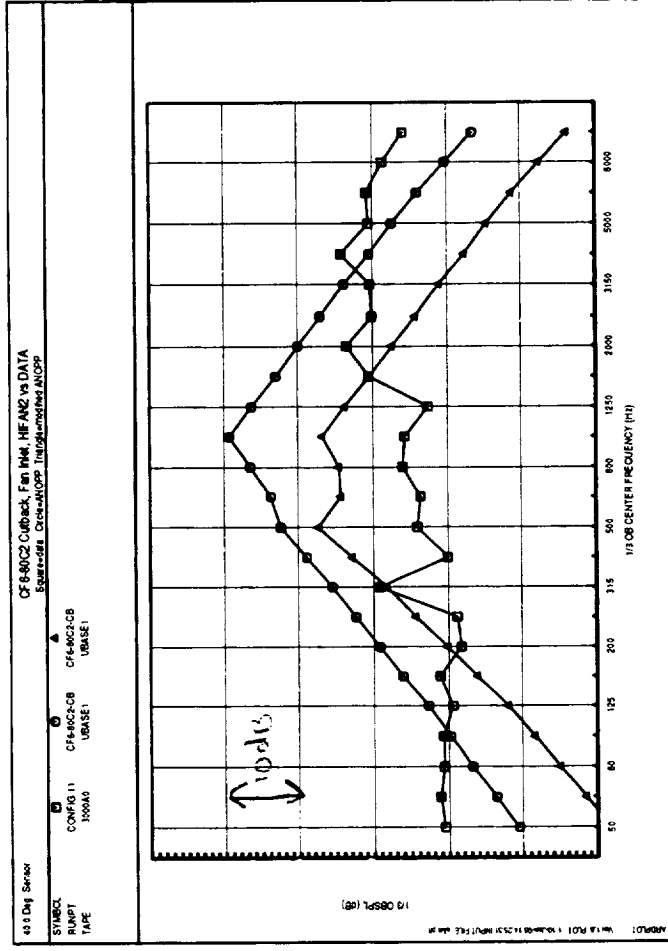
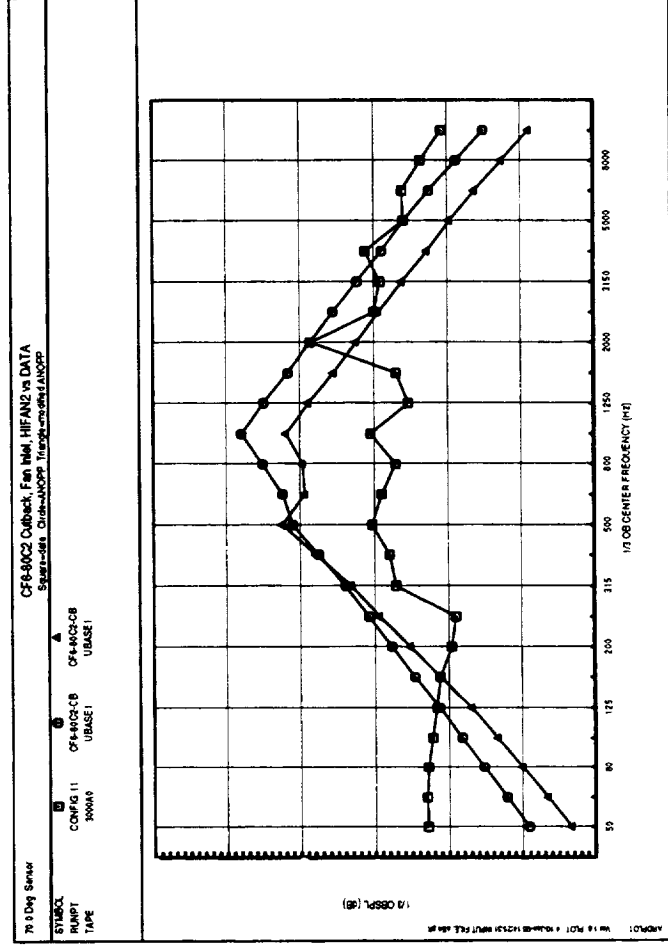
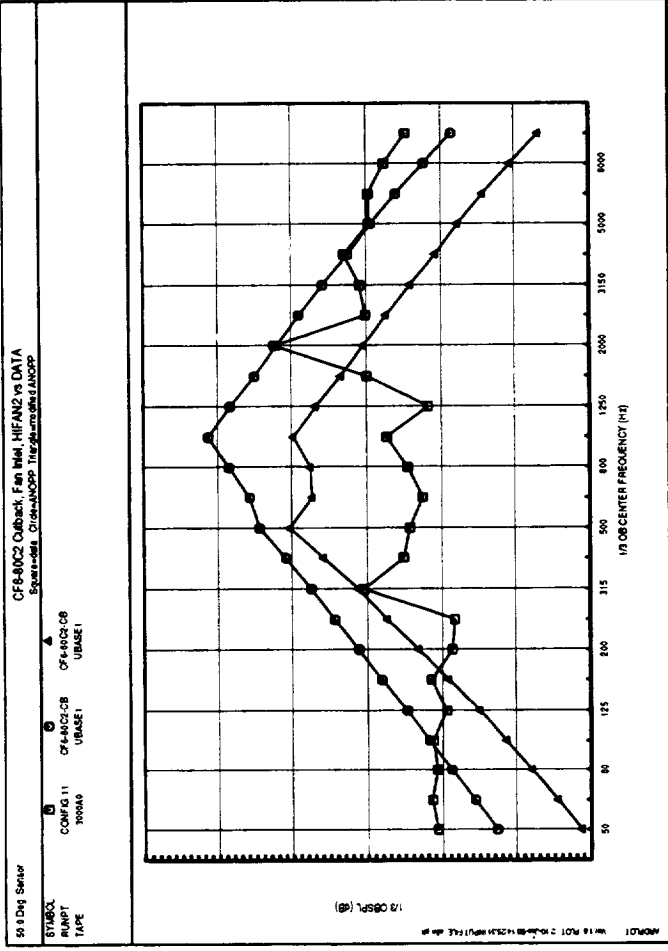
***Key to Plots:***

squares = total measured engine data  
circles = Heidmann method  
triangles = modified Heidmann method

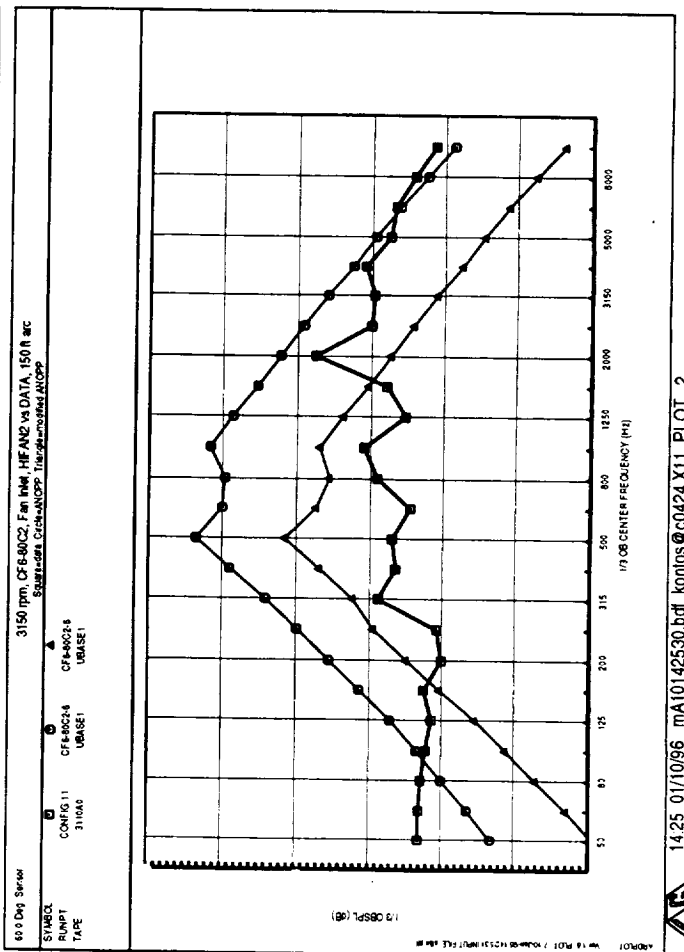
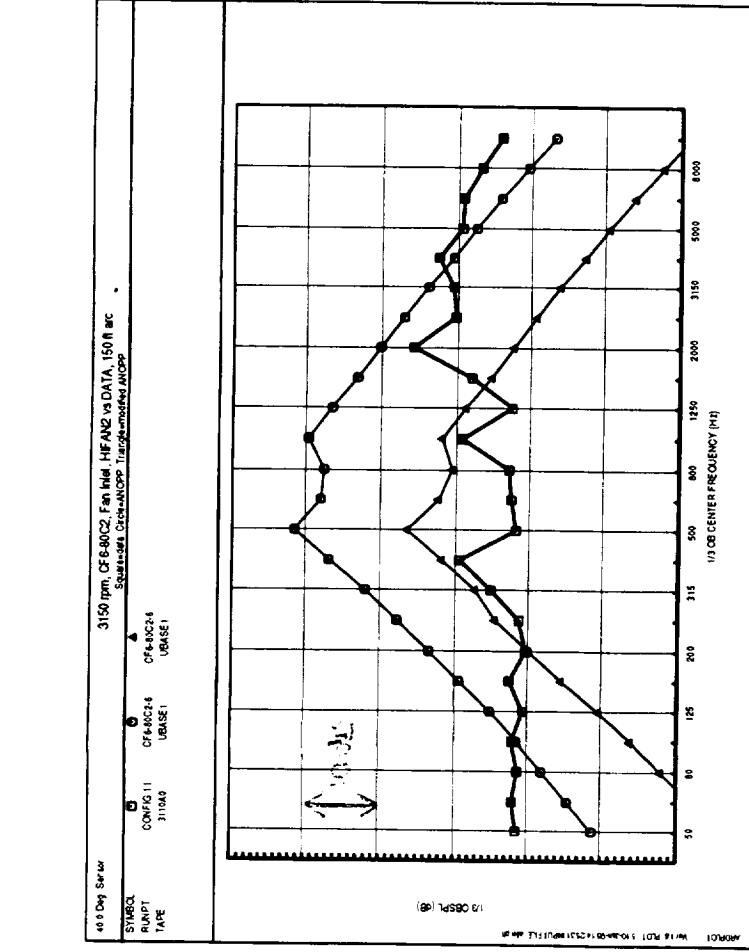
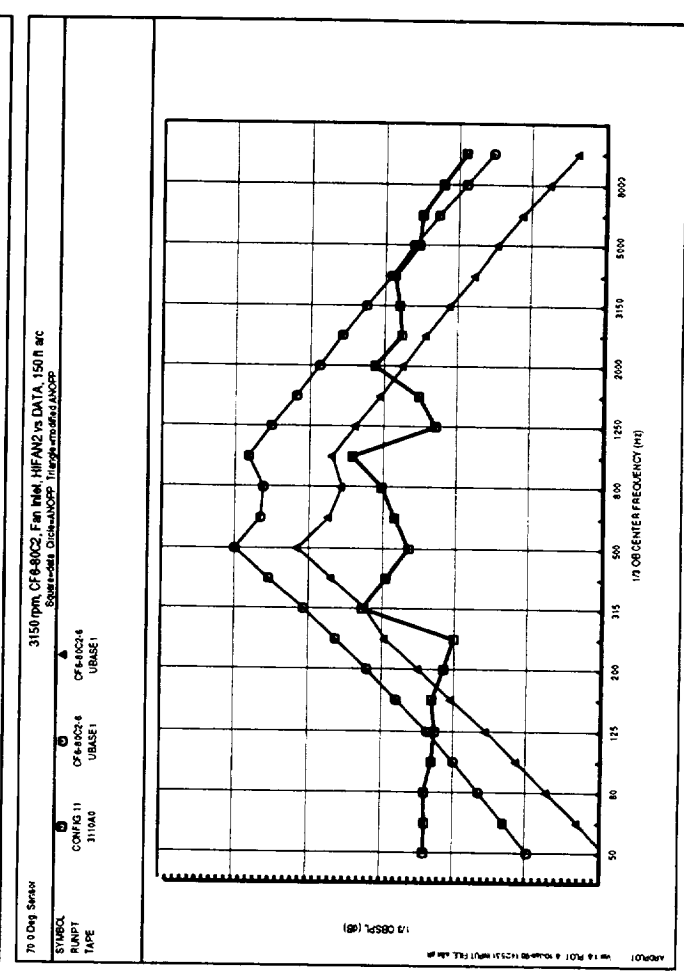
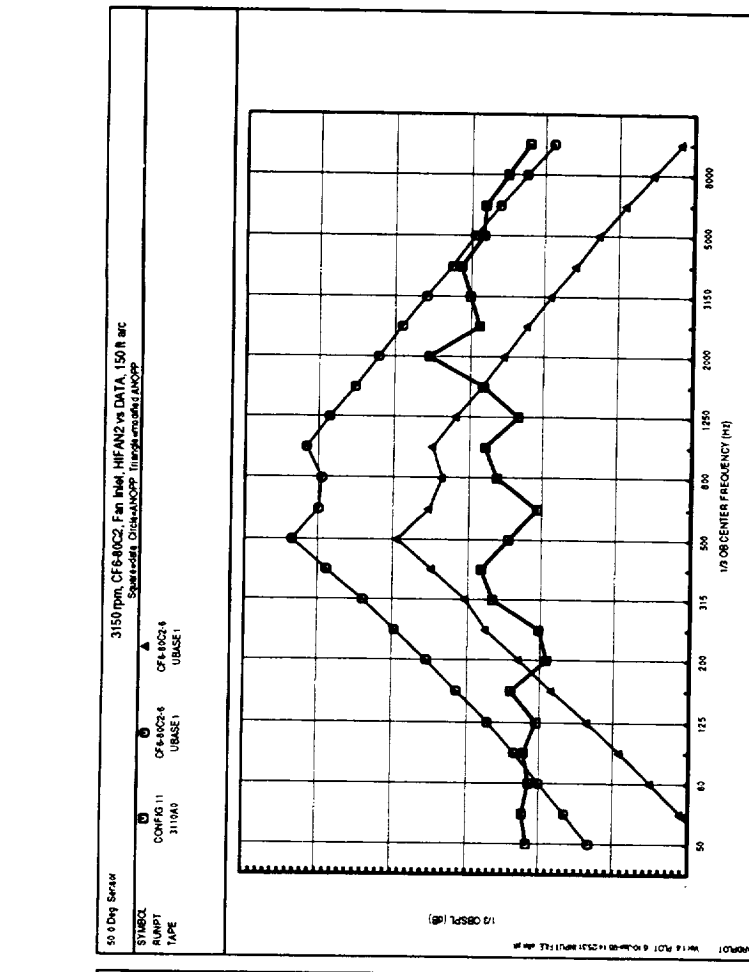


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 (NO PROG. VER. SPECIFIED)





## **6.0 References**

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13. ABSTRACT (Maximum 200 words)  Recent experience using ANOPP to predict turbofan engine flyover noise suggests that it over-predicts overall EPNL by a significant amount. An improvement in this prediction method is desired for system optimization and assessment studies of advanced UHB engines. An assessment of the ANOPP fan inlet, fan exhaust, jet, combustor, and turbine noise prediction methods is made using static engine component noise data from the CF6-80C2, E <sup>3</sup> , and QCSEE turbofan engines. It is shown that the ANOPP prediction results are generally higher than the measured GE data, and that the inlet noise prediction method (Heidmann method) is the most significant source of this overprediction. Fan noise spectral comparisons show that improvements to the fan tone, broadband, and combination tone noise models are required to yield results that more closely simulate the GE data. Suggested changes that yield improved fan noise predictions but preserve the Heidmann model structure are identified and described. These changes are based on the sets of engine data mentioned, as well as some CFM56 engine data that was used to expand the combination tone noise database. It should be noted that the recommended changes are based on an analysis of engines that are limited to single stage fans with design tip relative mach numbers greater than one.			
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