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NASA Contractor Report 202309

Improved NASA-ANOPP Noise Prediction Computer Code for Advanced Subsonic Propulsion Systems Volume 2: Fan Suppression Model Development

K. B. Kontos, R. E. Kraft, and P. R. Gliebe
GE Aircraft Engines
Cincinnati, OH

December, 1996

Prepared for
NASA Lewis Research Center
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Task Order Number 24

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Nomenclature

a_n	Fan inlet correlation coefficients, $n = 1,2,3,4,5$
ANOPP.....	Aircraft Noise Prediction Program
b_n	Fan exhaust correlation coefficients, $n = 1,2,3,4,5$
BPF.....	blade passing frequency
c	ambient speed of sound, ft/s
D	fan diameter, ft
dB.....	decibel
GE.....	General Electric
h	equivalent fan exhaust duct height, ft
L	effective length of fan inlet acoustic treatment, ft
l	effective length of fan exhaust acoustic treatment, ft
M_t	fan blade tip Mach number
MPT.....	multiple pure tone
NASA.....	National Aeronautics and Space Administration
PWL.....	Sound Power Level, dB (re 10^{-13} watts)
SDOF.....	Single Degree of Freedom
SPL.....	Sound Pressure Level, dB
UHB.....	Ultra High Bypass
2DOF.....	Two Degree of Freedom
λ	wavelength, ft
θ	Angle relative to engine inlet, deg.

1.0 Summary

ANOPP (Aircraft Noise Prediction Program) is an industry-wide tool used to predict turbofan engine flyover noise in system noise optimization studies. Its goal is to provide the best currently available methods for source noise prediction. As part of a program to improve the fan source noise model, GE was given the task to develop fan inlet and fan exhaust noise suppression models that are based on simple engine and acoustic geometry inputs.

Using four different databases from large commercial turbofan engines, models for fan inlet and fan exhaust suppression were developed. The models can be used to predict sound power level suppression and sound pressure level suppression at a position specified relative to the engine inlet.

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 in to 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 and the desire to refine ANOPP for the completion of advanced UHB studies, GE was provided with the task of developing fan inlet and fan exhaust suppression models. This work was completed as follow-on work to a prior task and is described in Volume 1 of this report (Kontos, 1996). In the initial task order, various engine source noise models were evaluated relative to GE data and methods, and the Heidmann method (Heidmann, 1979) for fan noise prediction was modified to yield results that were in closer agreement with large commercial turbofan acoustic data.

This report (Volume 2) describes how four commercial engine databases were used to develop fan inlet and fan exhaust suppression models. Correlations with suppression were sought using such variables as fan blade tip speed, treatment length, treatment design, duct height, etc. The suppression models are designed for use in ANOPP as a tool in system noise optimization studies that involve geometric changes to the acoustic treatment and/or the engine nacelle. The current capabilities of ANOPP (which predicts engine noise for hardwall nacelles only) are thereby enhanced to include the effects of acoustic treatment.

3.0 Analysis

A summary of general engine and acoustic treatment geometry information for the four inlet suppression database engines is given in Table 3.0.1. A similar summary is shown in Table 3.0.2 for the fan exhaust suppression database engines.

Table 3.0.1 Fan Inlet Database

	Engine A	Engine B	Engine C	Engine D
L/D	.33	.22	.25	.42
D, ft	5.0	5.0	6.0	7.75
design	2DOF	2DOF	2DOF	2DOF
Effective Area, ft²	27.5	17.3	34	68
Effective Tuning Frequency, Hz	3150	3150	2500	2000
L (effective), ft	1.75	1.1	1.5	3.25

Table 3.0.2 Fan Exhaust Database

	Engine E	Engine F	Engine G	Engine H
L/h	1.41	2.85	1.9	4.65
h (effective), ft	1.08	0.8	0.78	1.3
design	SDOF	SDOF	SDOF	SDOF
Effective Area, ft²	42.3	43.0	76.4	124.2
Effective Tuning Frequency, Hz	2000	3150	2500	2000
L (effective), ft	1.58	2.28	1.49	6.05

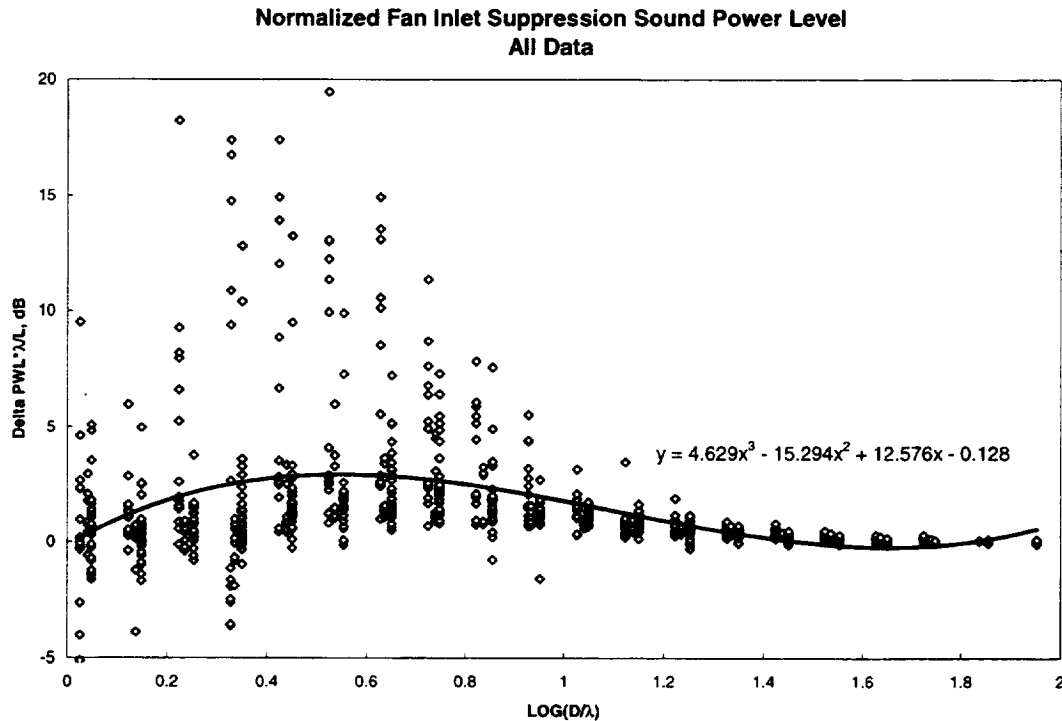
Details of the analysis procedure and results are explained in the rest of this section. Generally, the following procedure was applied in the development of each suppression model:

1. Suppressions correlated on a sound power level basis.
2. Applied these correlations to collapse sound pressure level suppression data.
3. Used results to develop a suppression model.
4. Model tested against data set.

3.1 Fan Inlet Sound Power Level Suppression Correlation

Normalized delta sound power levels (hardwall-treated) for all data points (4 engines, all speeds) are plotted in Figure 3.1.1. The ordinates are normalized by the factor of λ/L (wavelength/effective treatment length). The abscissas are normalized by $\log(D/\lambda)$, where D is the engine inlet diameter in feet and λ is the wavelength in feet. A polynomial curve-fit of this data and the corresponding equation are also shown.

Figure 3.1.1

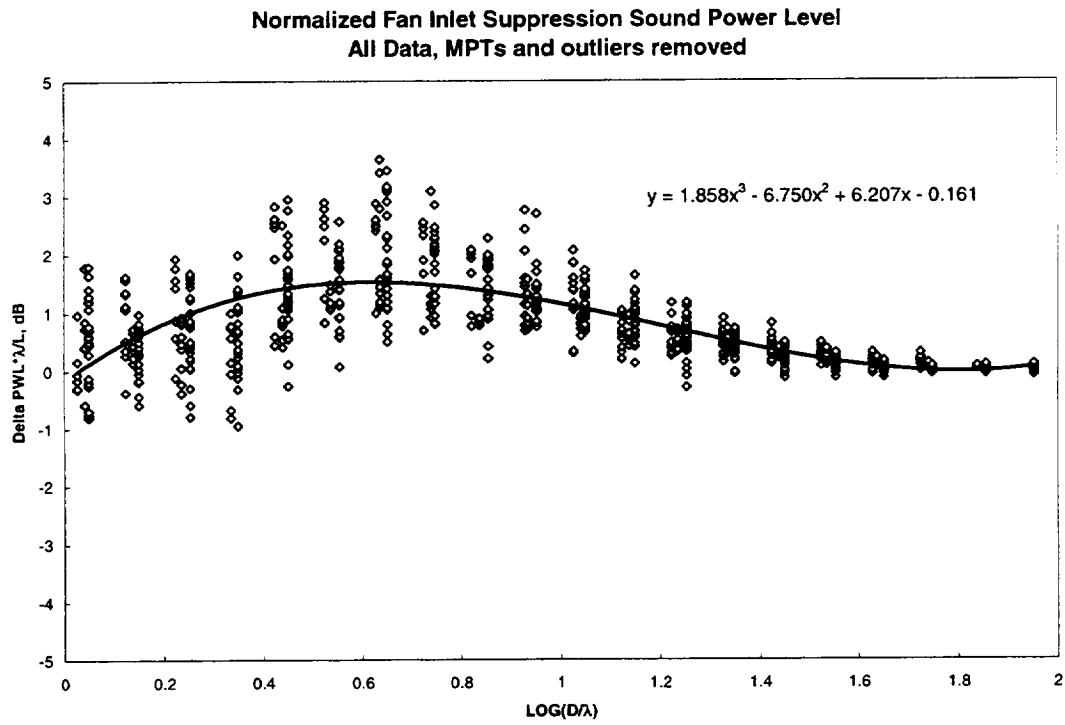


In order to achieve a better curve-fit, some of the data points were eliminated from the above set through a statistical process of removing random and systematic "errors", and the application of Chauvenet's Criterion for rejection of data (Meyer, 1975):

1. Discrepant data associated with Multiple Pure Tones (MPTs) were removed.
2. Discrepant data that could be attributed solely to one engine were removed.
3. Remaining data that were determined to be statistical outliers (more than 3 standard deviations from the mean value) were removed.

Figure 3.1.2 shows the same data as shown in Figure 3.1.1, after the above process was applied to statistically clean-up the data.

Figure 3.1.2



Figures 3.1.3 and 3.1.4 show the standard deviations and sample size of the normalized suppressions at each frequency, before and after the clean-up process. These charts show that very little data was eliminated, but that the standard deviations were significantly reduced.

Figure 3.1.3

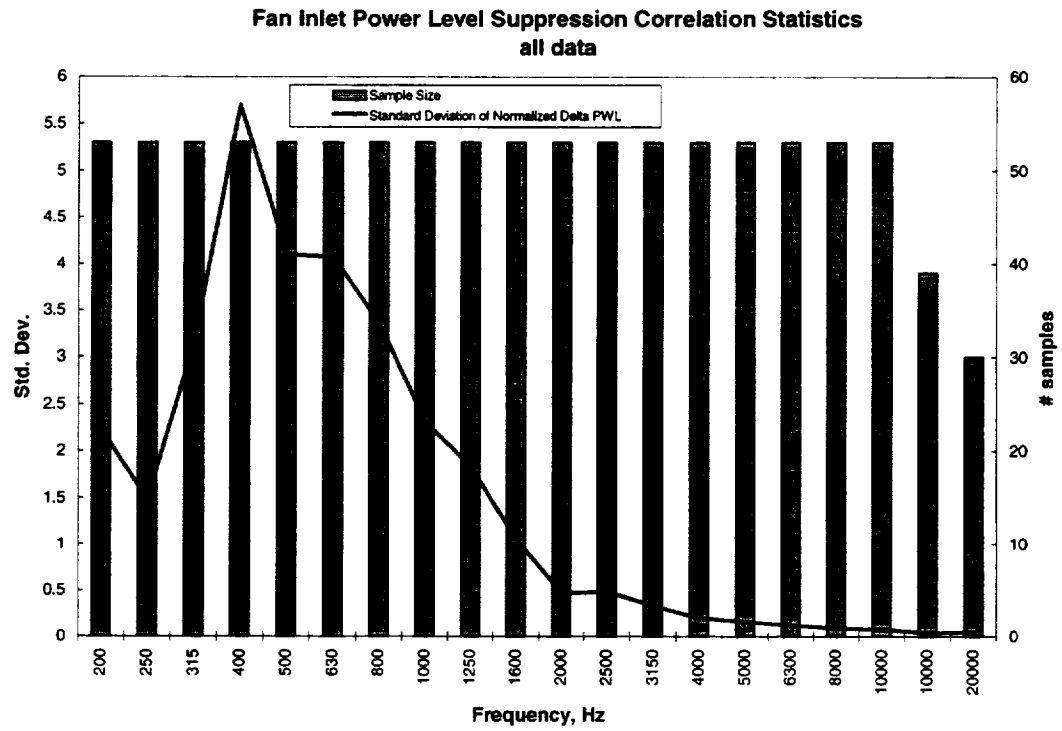
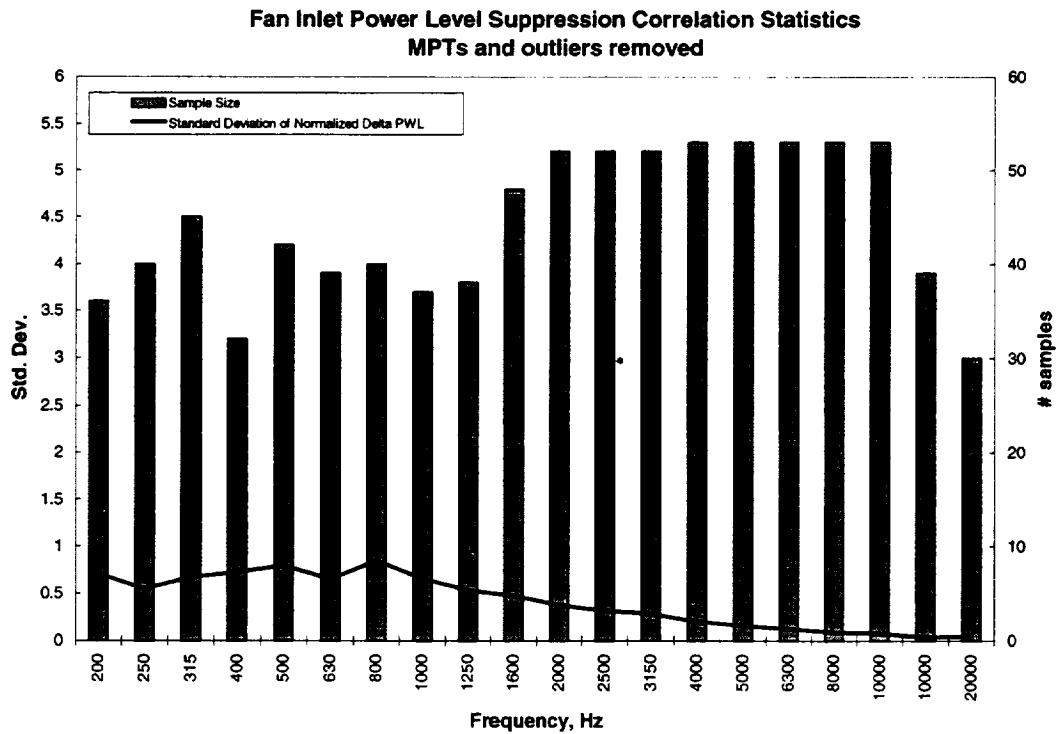


Figure 3.1.4



3.2 Fan Inlet Sound Pressure Level Suppression Correlation

The fan inlet sound pressure level suppressions were found to be normalized best by the same relationship that was used to correlate the inlet sound power level suppressions as described in the previous section. Figures 3.2.1 - 3.2.9 show the entire set of normalized inlet delta sound pressure level data, for angles relative to the engine inlet of 10°- 90°. A polynomial curve fit and corresponding equation are shown for the data at each angle. These charts represent the finalized data set. Similar charts that show the entire data set (prior to statistical data point elimination) are given in Appendix A. Charts which show the differences in sample size and standard deviation before and after the data elimination at each angle are shown in Appendix B.

Figure 3.2.1

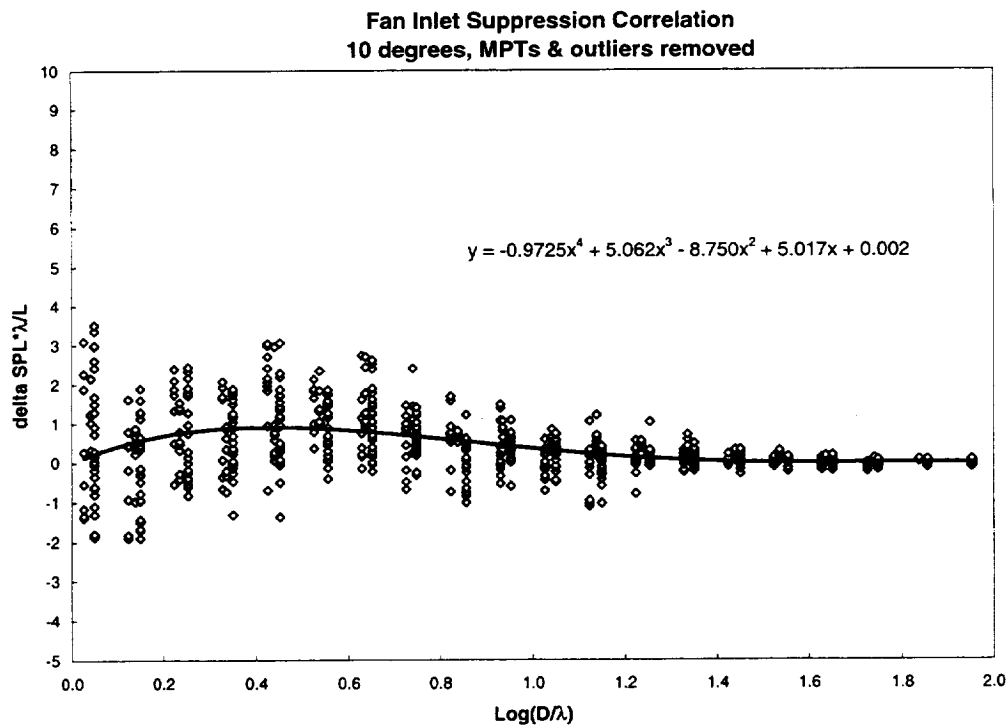


Figure 3.2.2

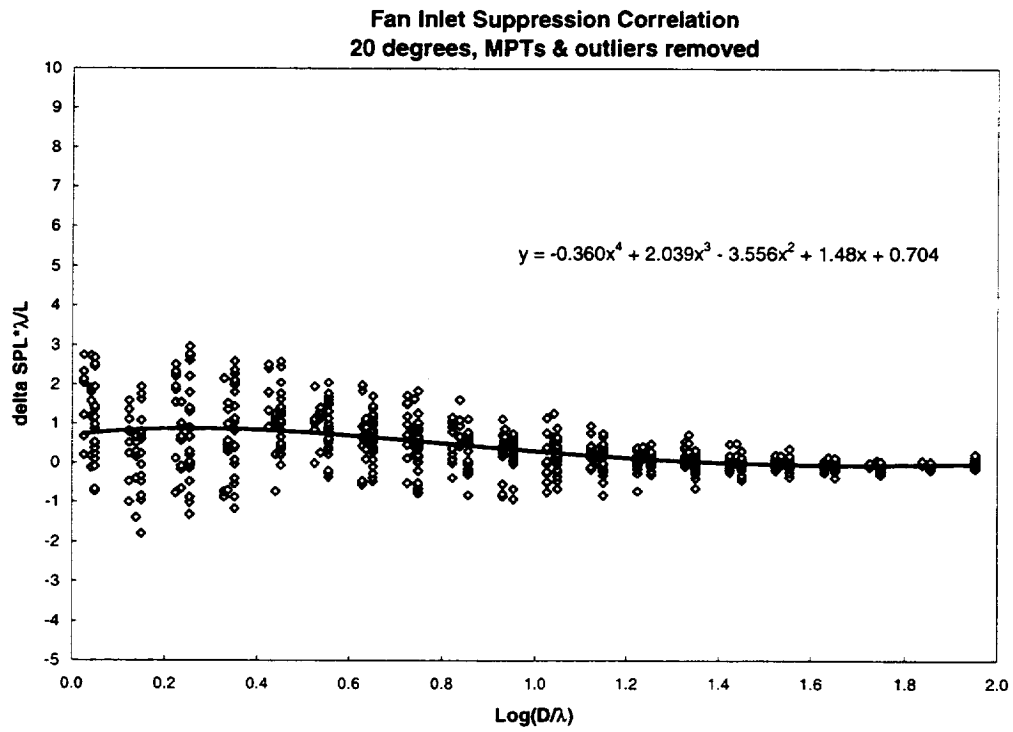


Figure 3.2.3

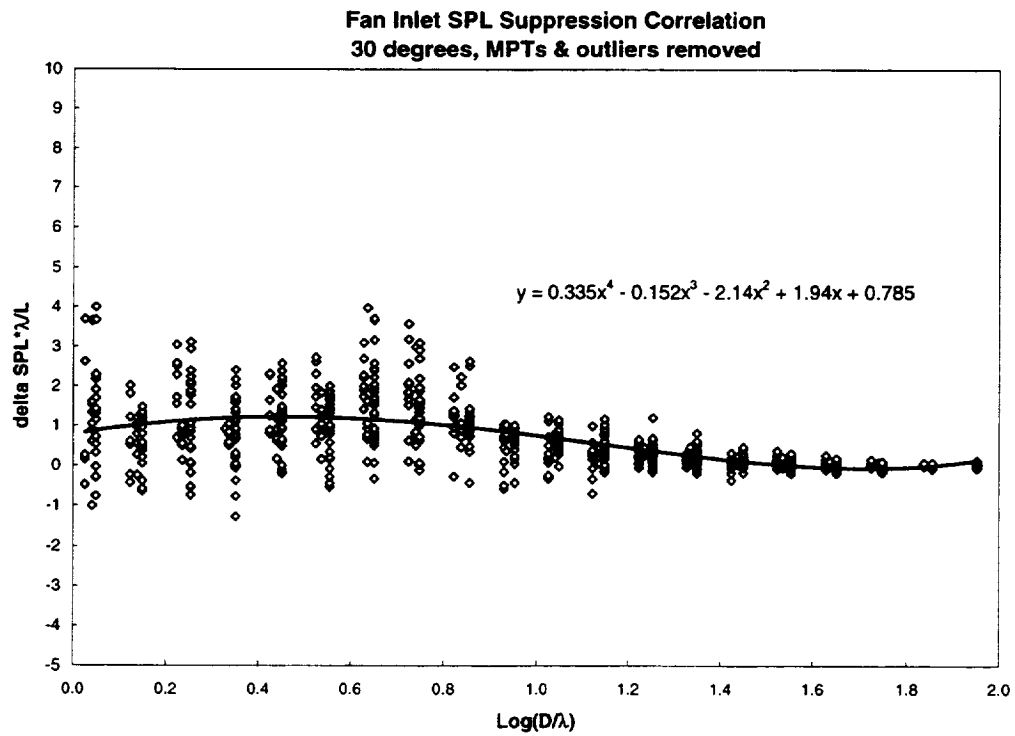


Figure 3.2.4

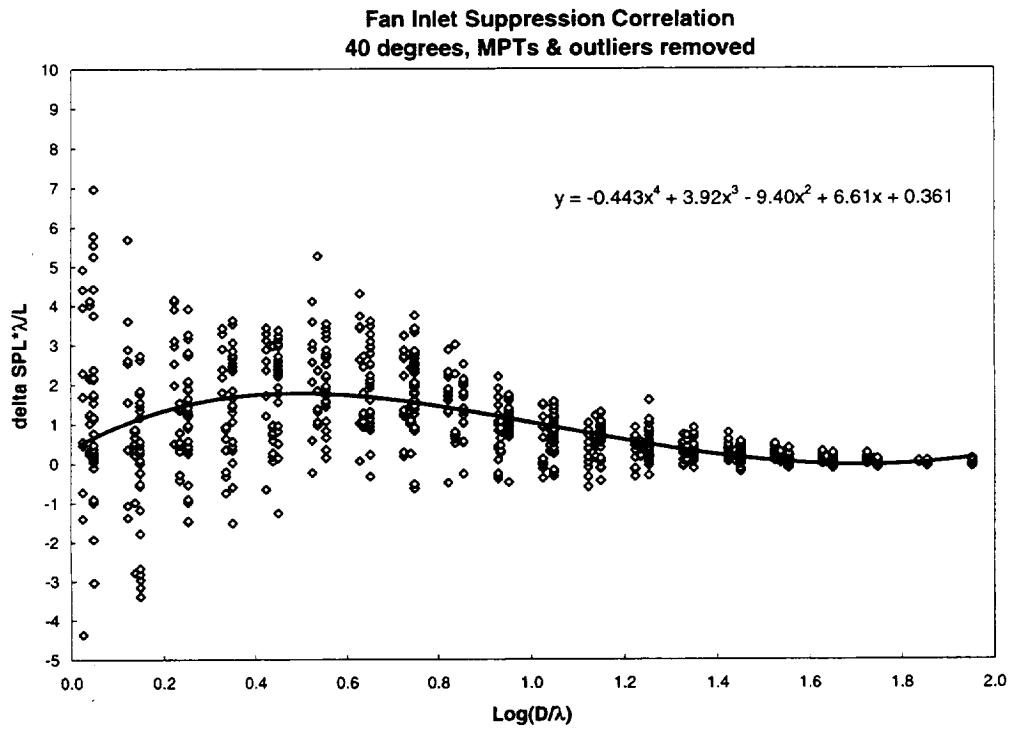


Figure 3.2.5

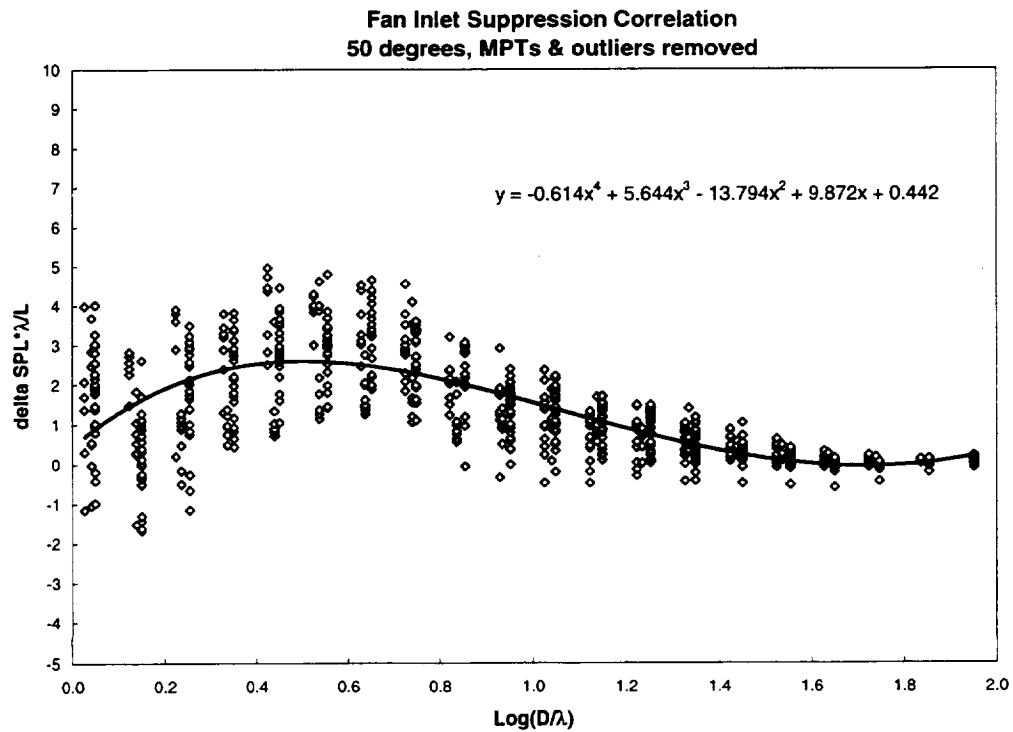


Figure 3.2.6

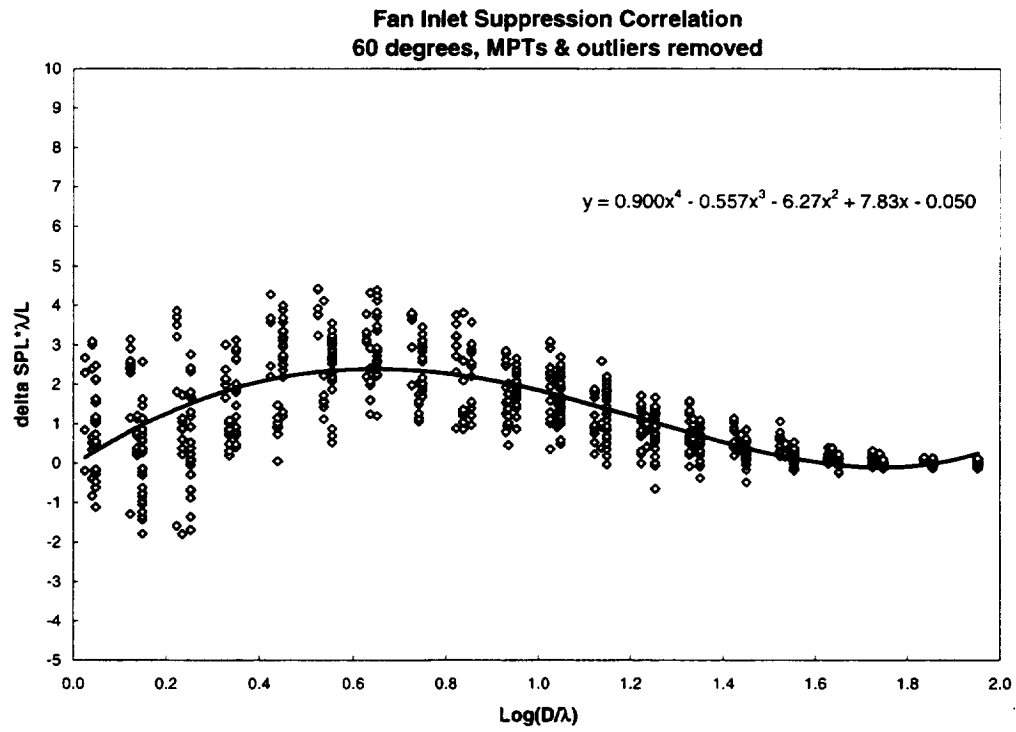


Figure 3.2.7

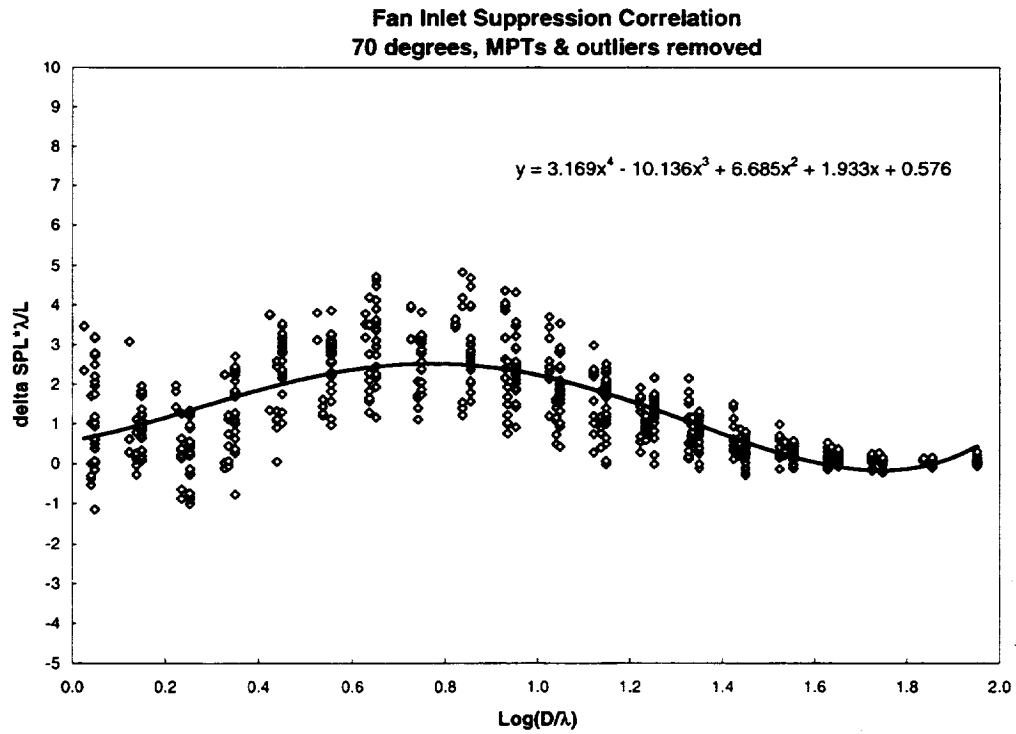


Figure 3.2.8

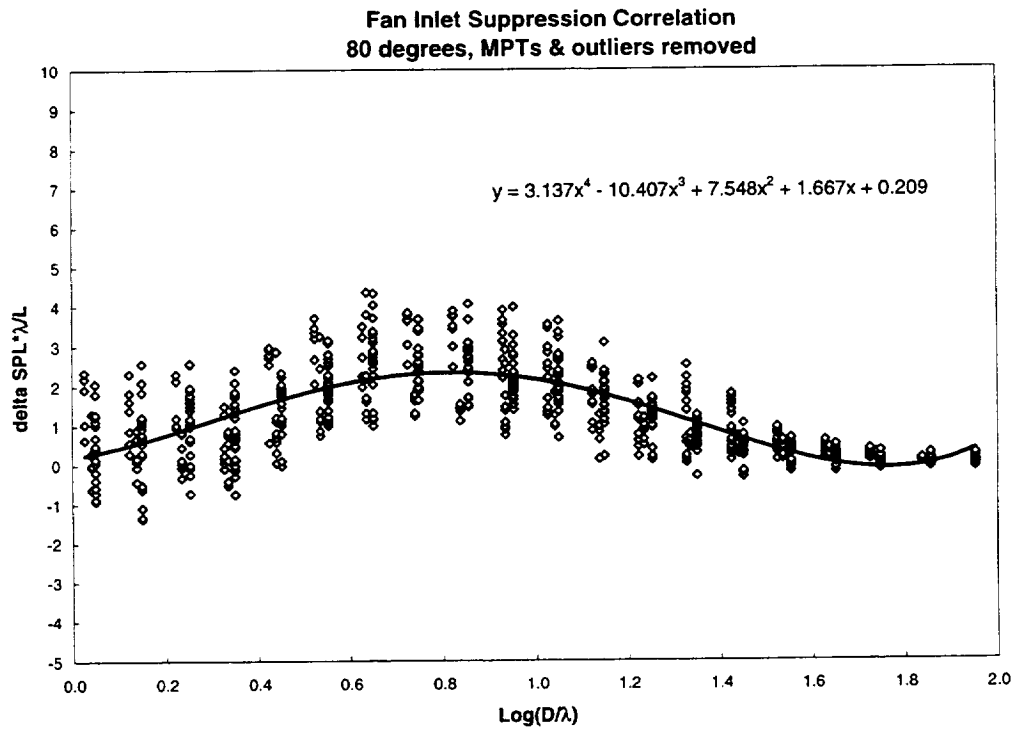
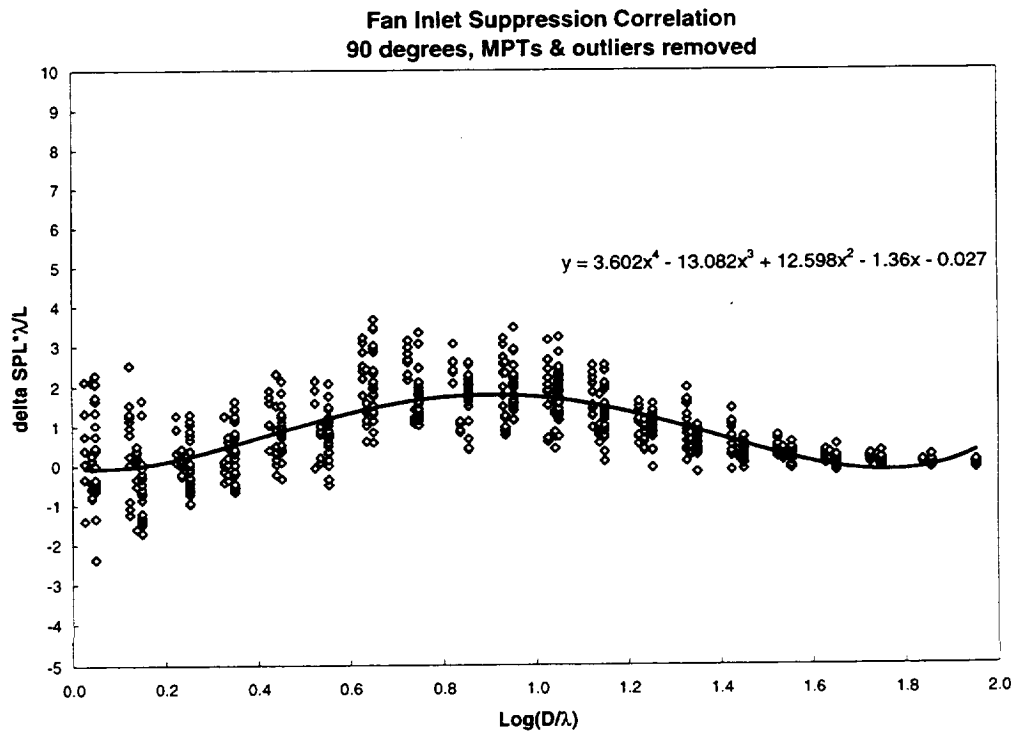


Figure 3.2.9



The polynomial curve fit for the data at each angle in Charts 3.2.1 - 3.2.9 is of the form:

$$a_1x^4 + a_2x^3 + a_3x^2 + a_4x + a_5 \quad (1)$$

A mathematical curve fit of each coefficient (for all angles) was made in order to determine the relationship between suppression and directivity. Figures 3.2.10 - 3.2.14 show plots for each of the coefficients at all angles, and the mathematical curve fits that were calculated from these points.

Figure 3.2.10

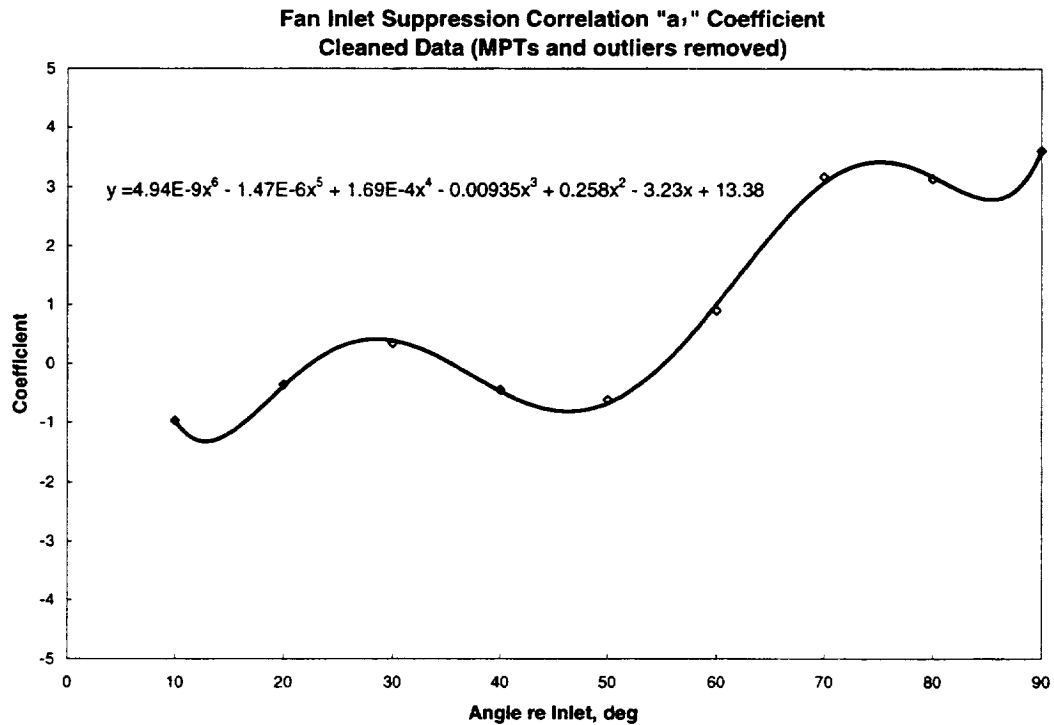


Figure 3.2.11

**Fan Inlet Suppression Correlation "a₂" Coefficient
Cleaned Data (MPTs and outliers removed)**

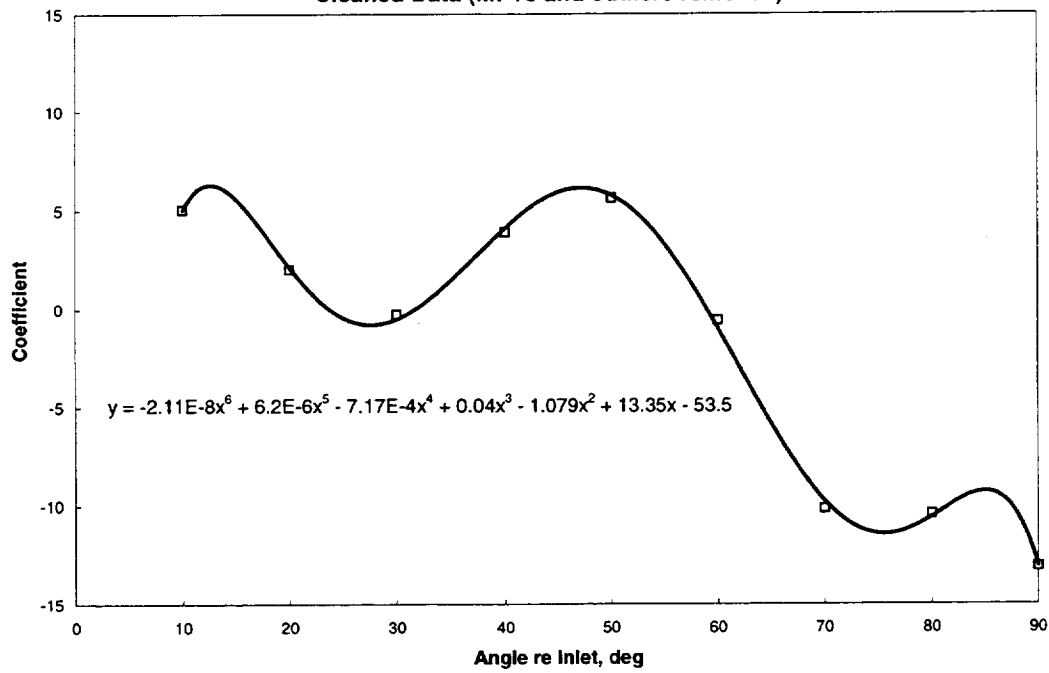


Figure 3.2.12

**Fan Inlet Suppression Correlation "a₃" Coefficient
Cleaned Data (MPTs and outliers removed)**

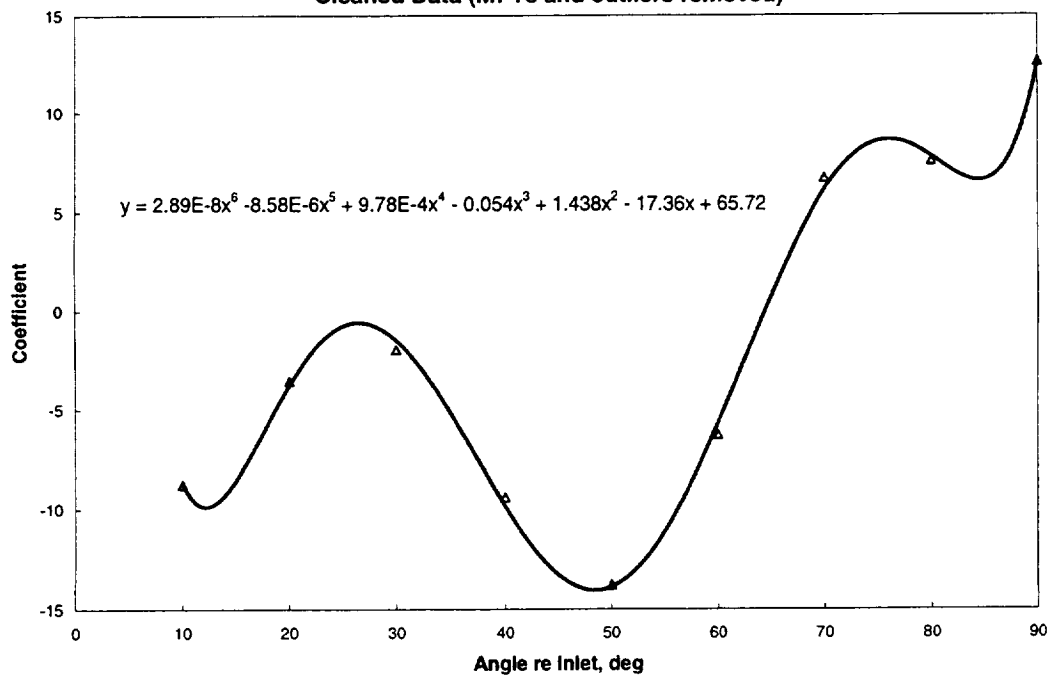


Figure 3.2.13

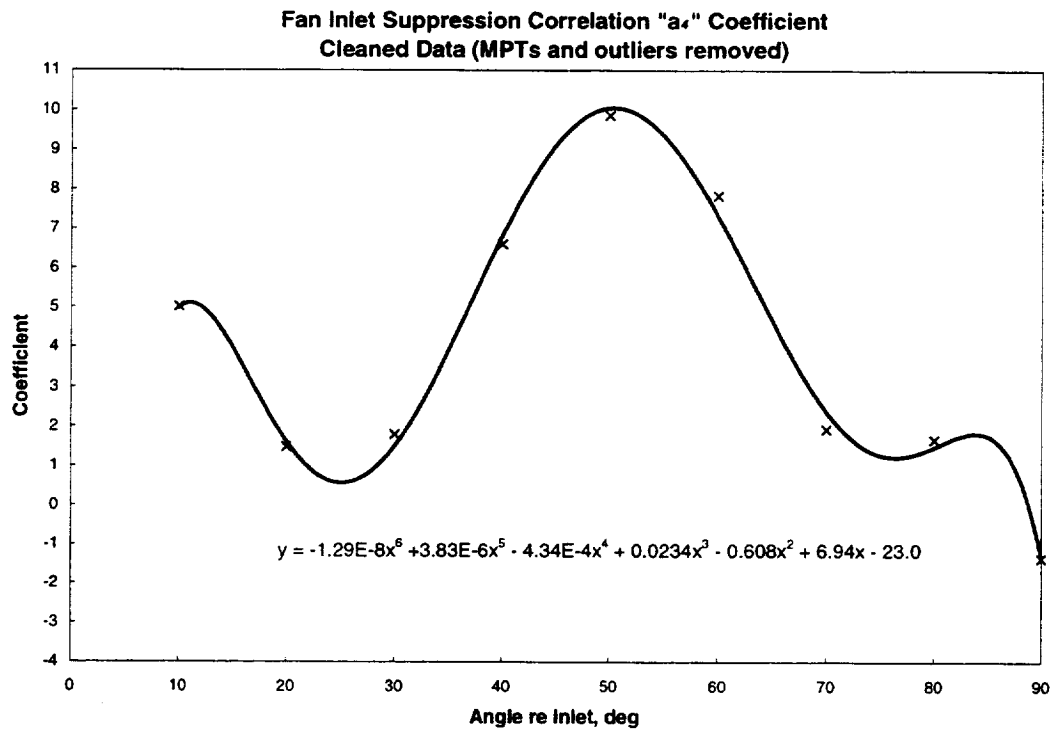
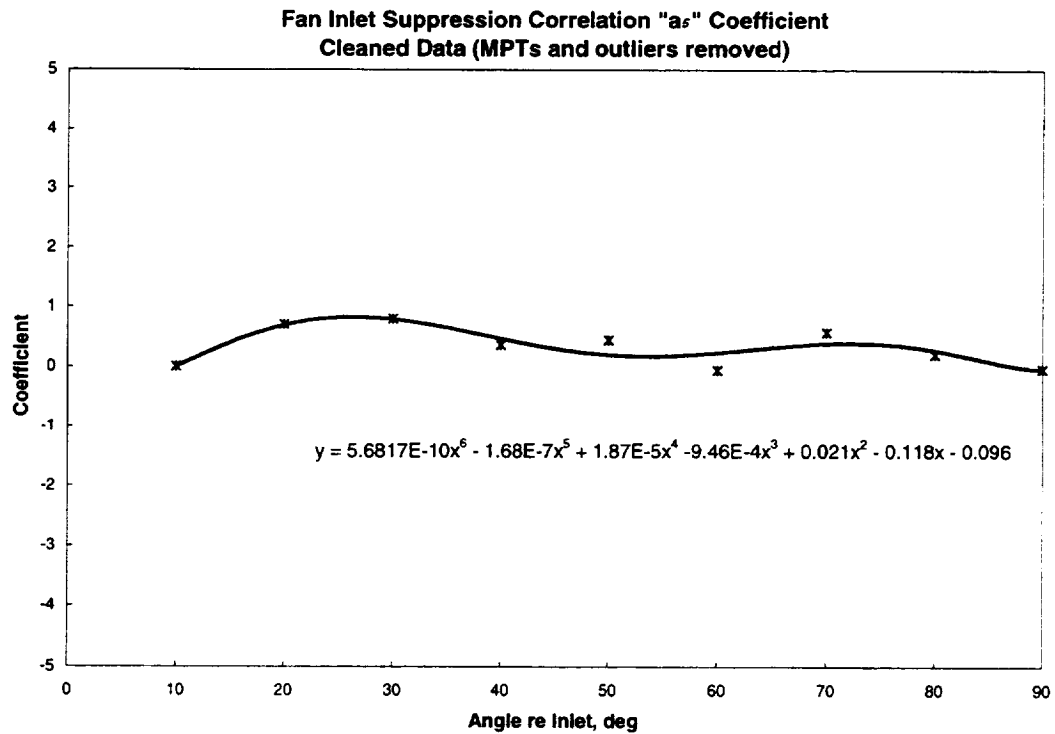


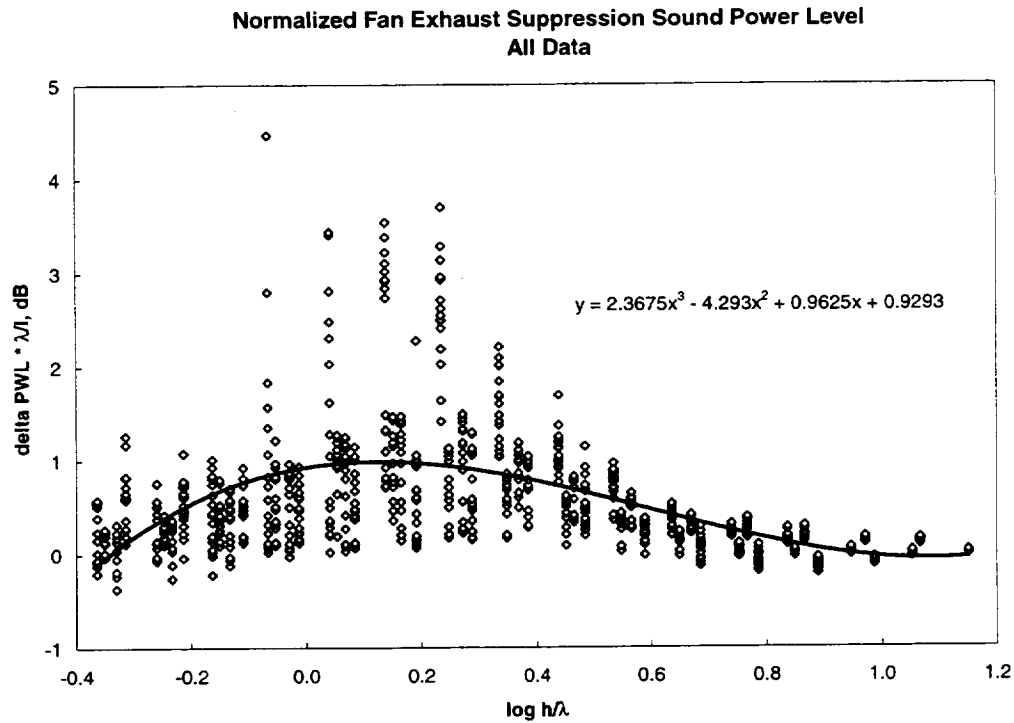
Figure 3.2.14



3.3 Fan Exhaust Sound Power Level Suppression Correlation

Normalized delta sound power levels (hardwall-treated) for all data points (4 engines, all speeds) are plotted in Figure 3.3.1. The ordinates are normalized by the factor of λ/l (wavelength/effective treatment length). The abscissas are normalized by $\log(h/\lambda)$, where h is the equivalent exhaust duct height in feet and λ is the wavelength in feet. A polynomial curve-fit of this data and the corresponding equation are also shown.

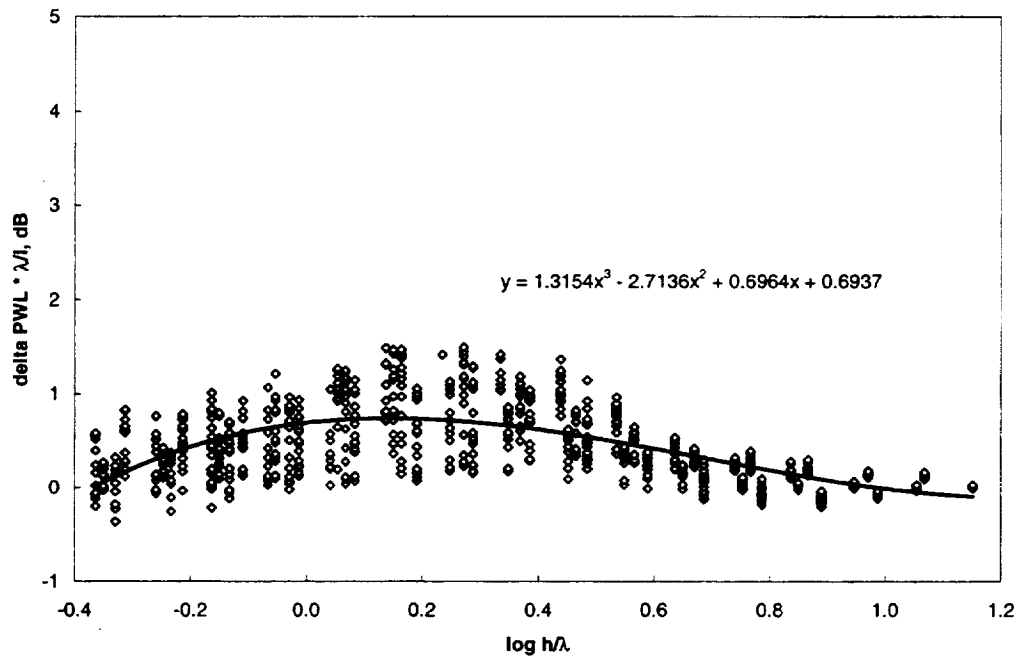
Figure 3.3.1



In order to achieve a better curve-fit, some of the data points were eliminated through the statistical process described in Section 3.1. Figure 3.3.2 shows the same data, subsequent to the clean-up.

Figure 3.3.2

**Normalized Fan Exhaust Suppression Sound Power Level
MPTs and outliers removed**



Figures 3.3.3 and 3.3.4 show the standard deviations and sample size of the normalized suppressions at each frequency, before and after the clean-up process. These charts show that very little data was eliminated, but that the standard deviations were significantly reduced.

Figure 3.3.3

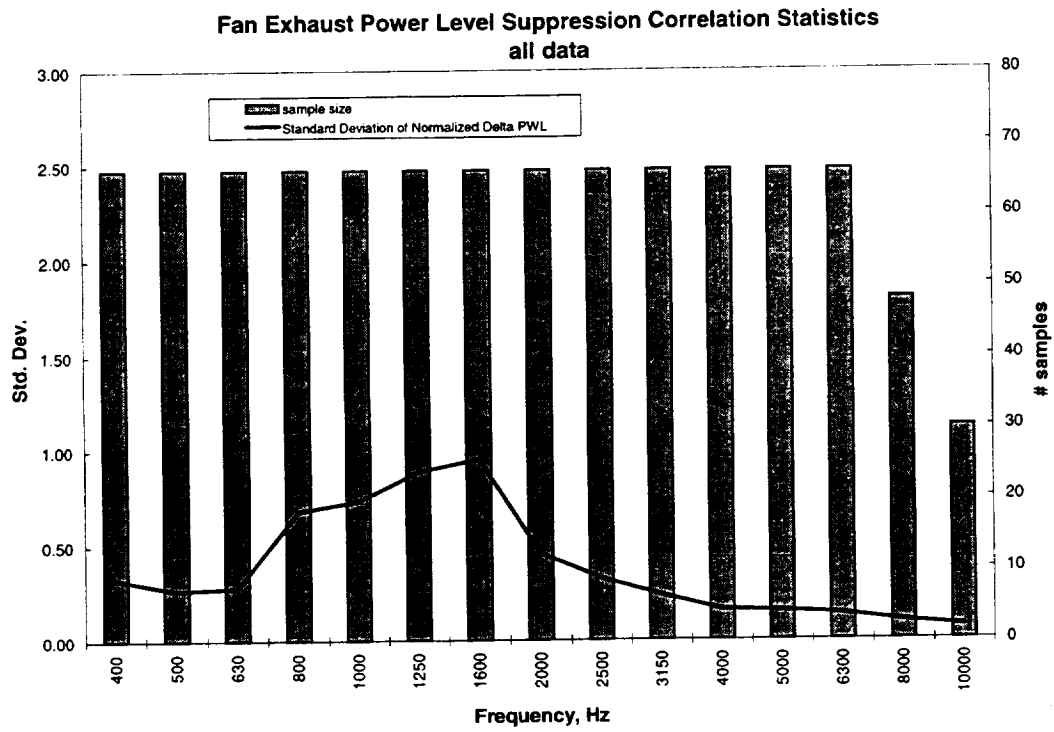
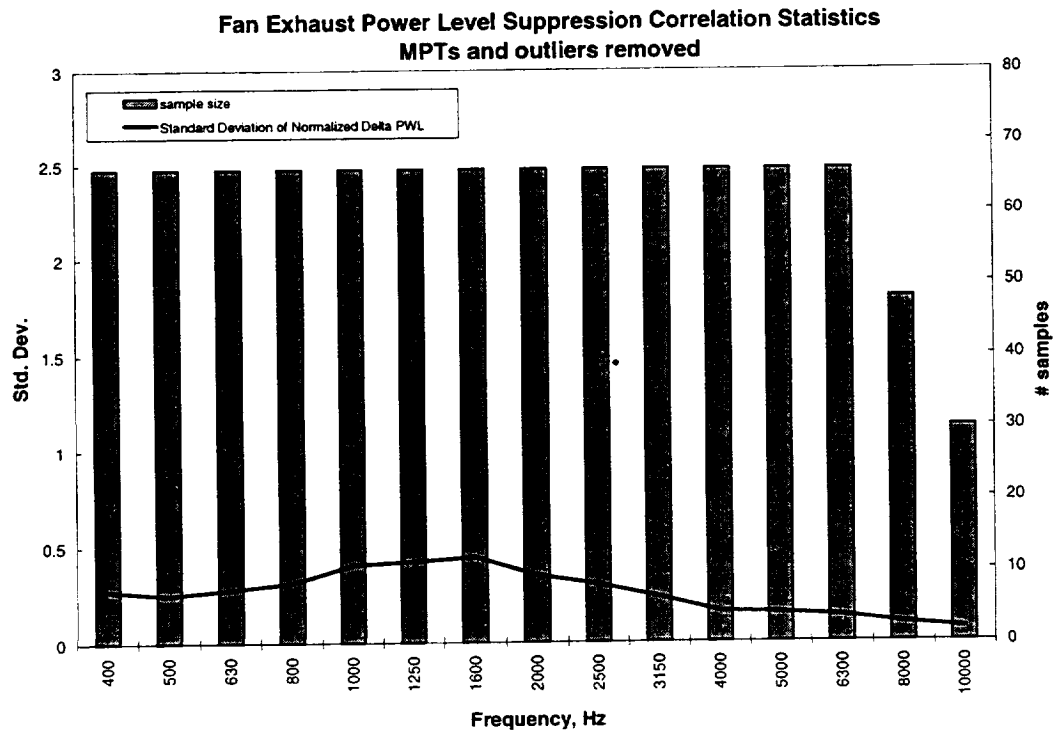


Figure 3.3.4



3.4 Fan Exhaust Sound Pressure Level Suppression Correlation

The fan exhaust sound pressure level suppressions were found to be normalized best by the same relationship that was used to correlate the exhaust sound power level suppressions as described in the previous section. Figures 3.4.1 - 3.4.8 show the entire set of normalized exhaust delta sound pressure level data, for angles relative to the engine inlet of 90°- 160°. A polynomial curve fit and corresponding equation are shown for the data at each angle. These charts represent the finalized data set. Similar charts that show the entire data set (prior to statistical data point elimination) are given in Appendix C. Charts which show the differences in sample size and standard deviation before and after the data elimination at each angle are shown in Appendix D.

Figure 3.4.1

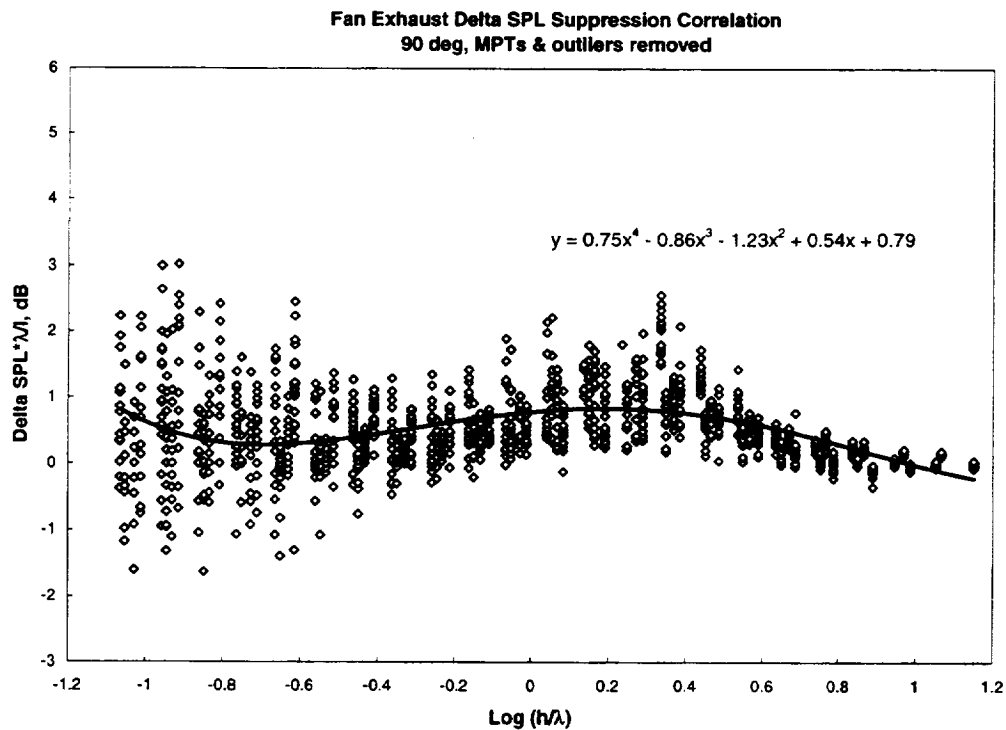


Figure 3.4.2

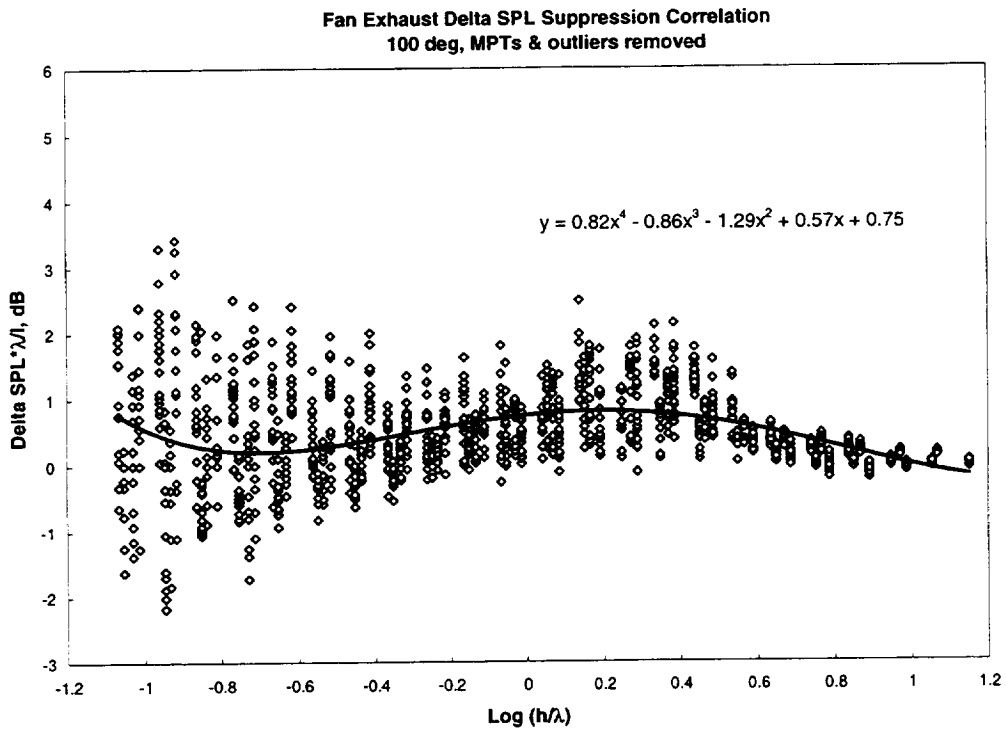


Figure 3.4.3

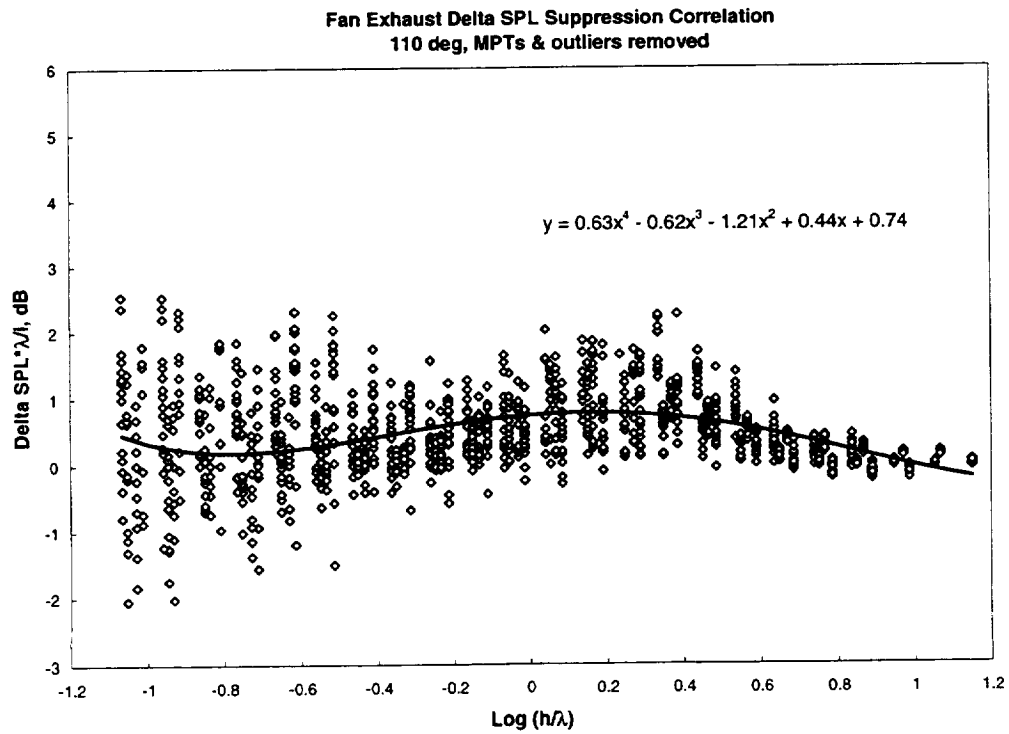


Figure 3.4.4

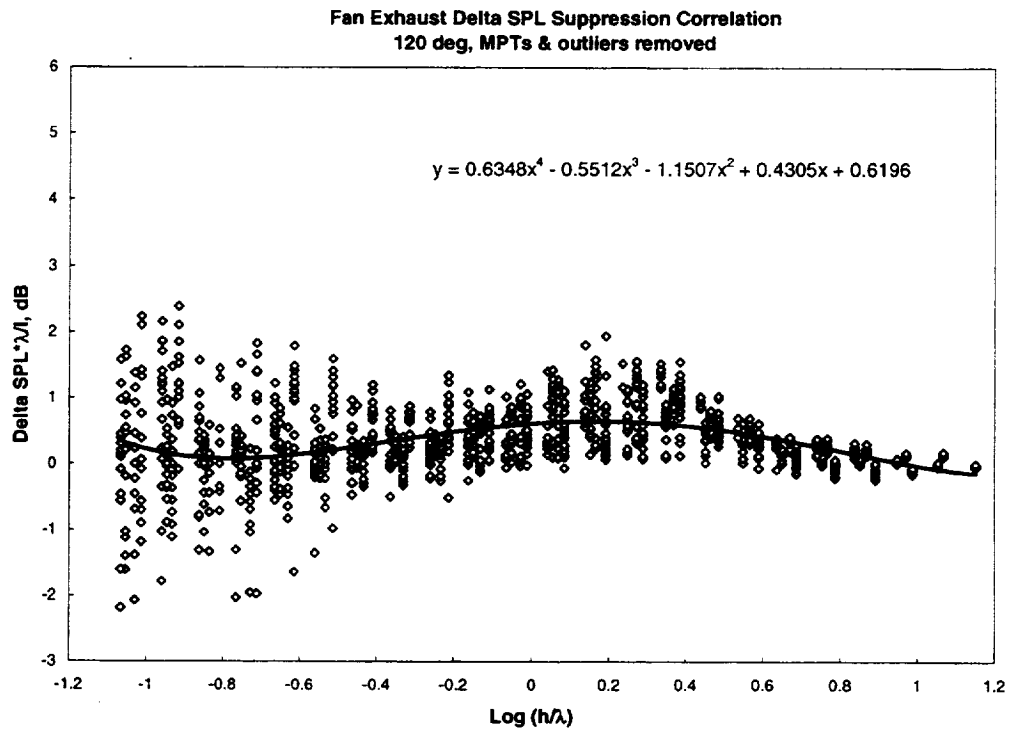


Figure 3.4.5

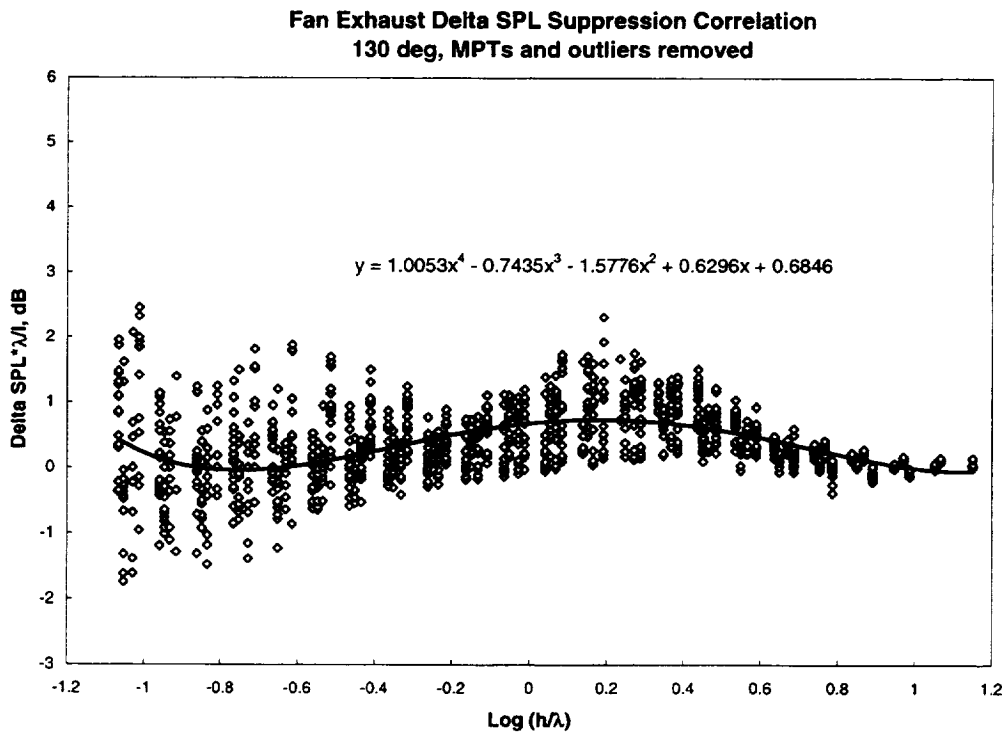


Figure 3.4.6

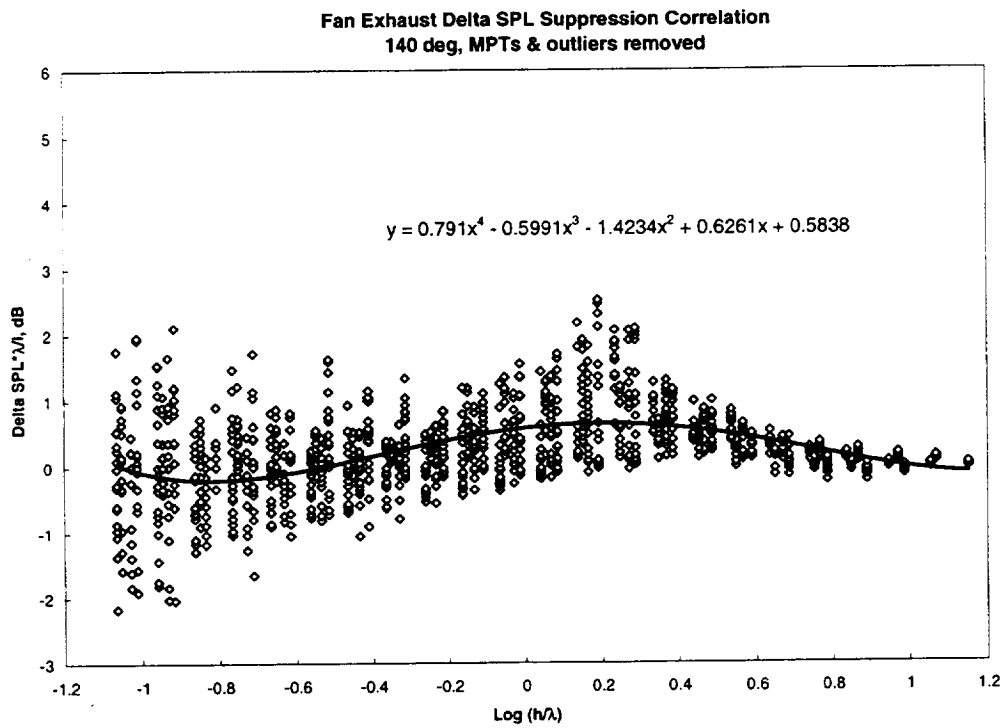


Figure 3.4.7

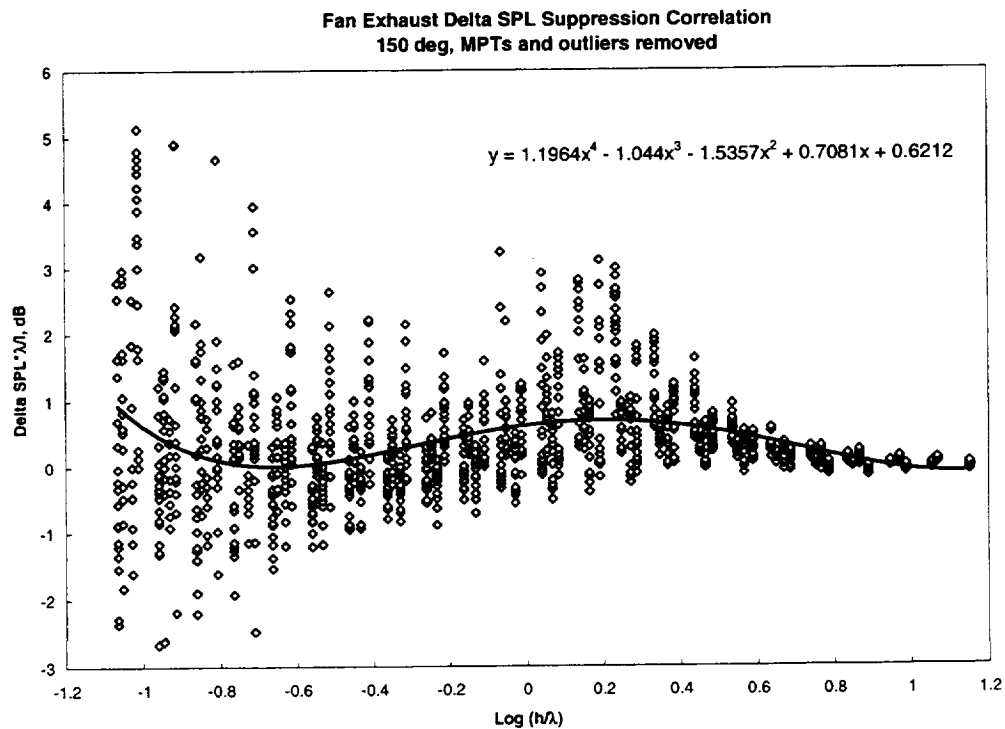
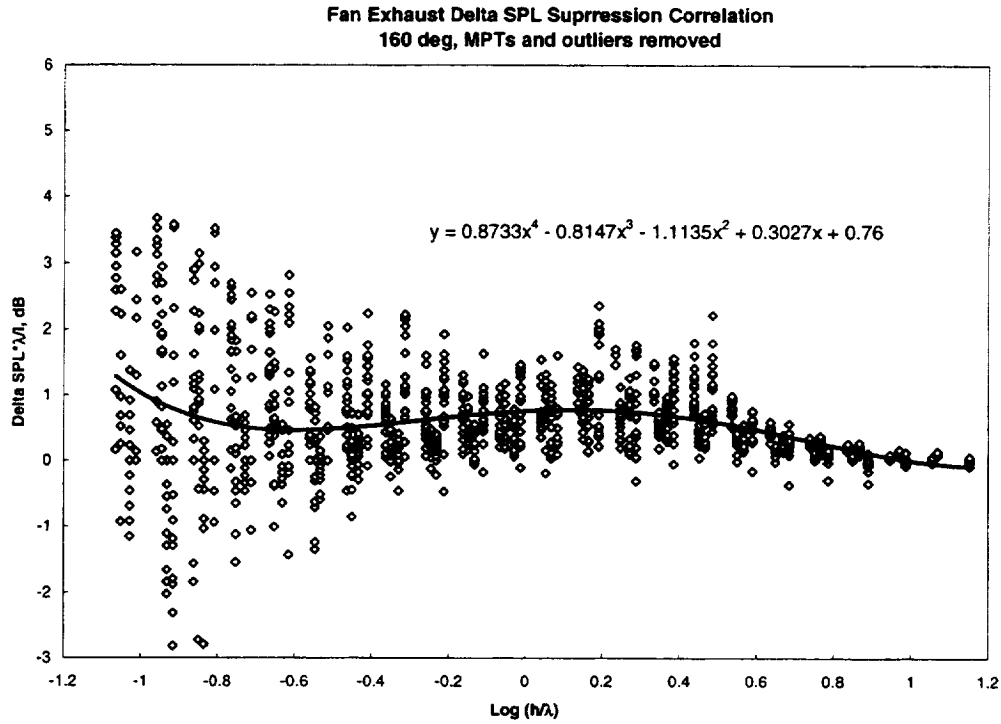


Figure 3.4.8



The polynomial curve fit for the data at each angle in Charts 3.4.1 - 3.4.8 is of the form:

$$b_1x^4 + b_2x^3 + b_3x^2 + b_4x + b_5 \quad (2)$$

A mathematical curve fit of each coefficient (for all angles) was made in order to determine the relationship between suppression and directivity. Figures 3.4.9 - 3.4.13 show plots for each of the coefficients at all angles, and the mathematical curve fits that were calculated from these points.

Figure 3.4.9

**Fan Exhaust Suppression Correlation "b₁" Coefficient
MPTs and Outliers Removed**

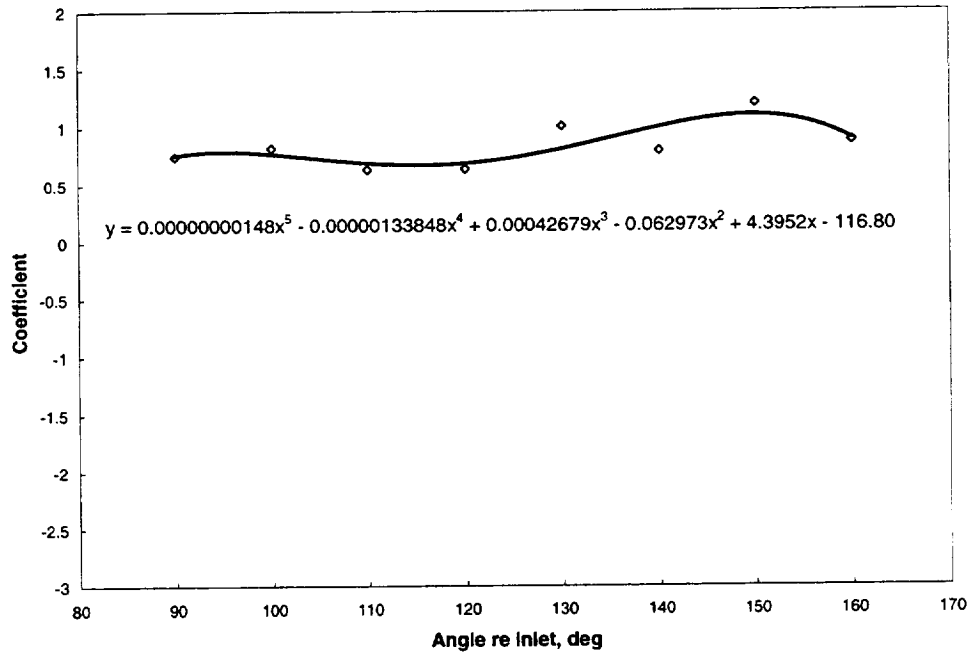


Figure 3.4.10

**Fan Exhaust Suppression Correlation "b₂" Coefficient
MPTs and Outliers Removed**

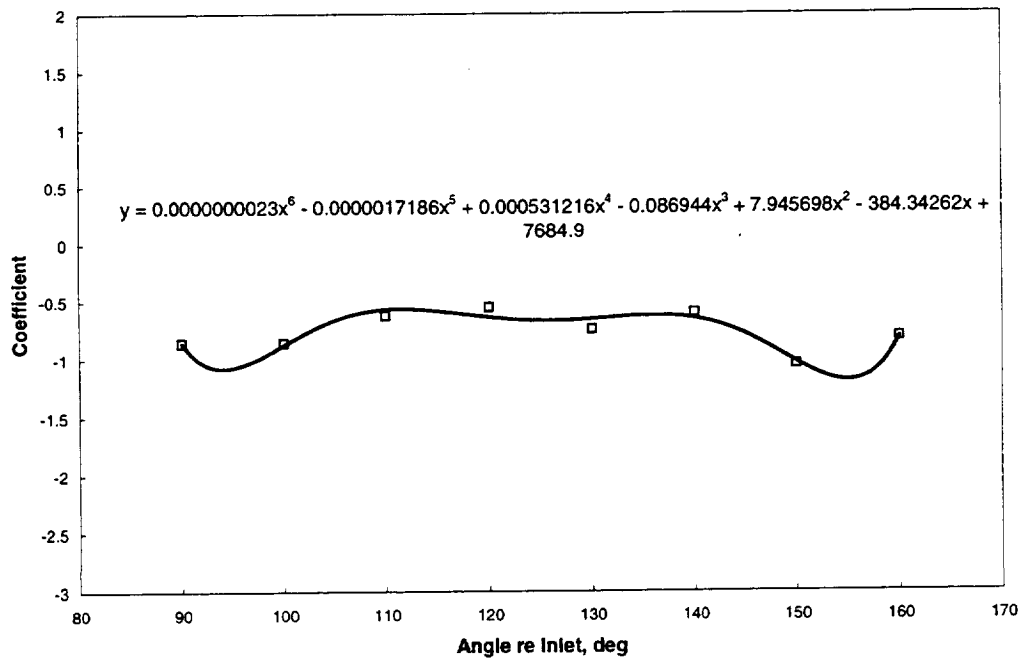


Figure 3.4.11

**Fan Exhaust Suppression Correlation "b_s" Coefficient
MPTs and Outliers Removed**

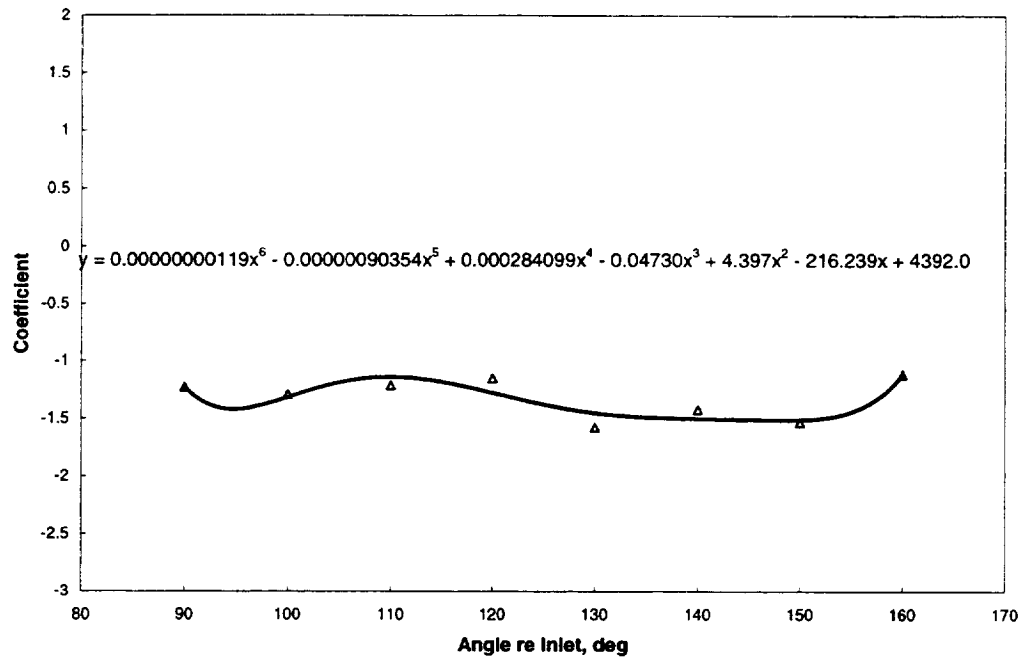


Figure 3.4.12

**Fan Exhaust Suppression Correlation "b_s" Coefficient
MPTs and Outliers Removed**

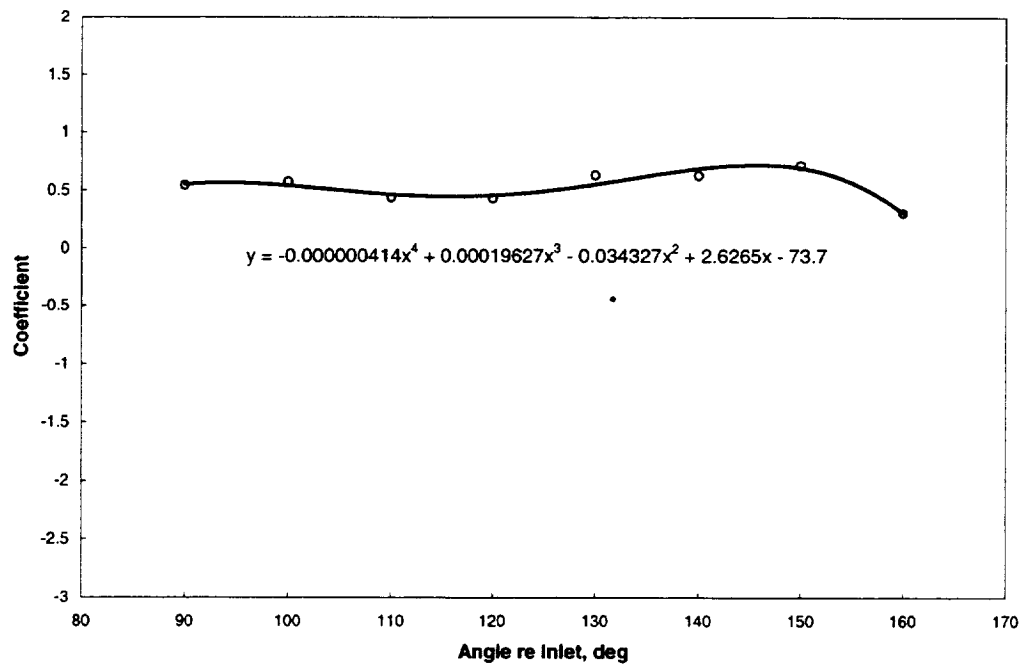
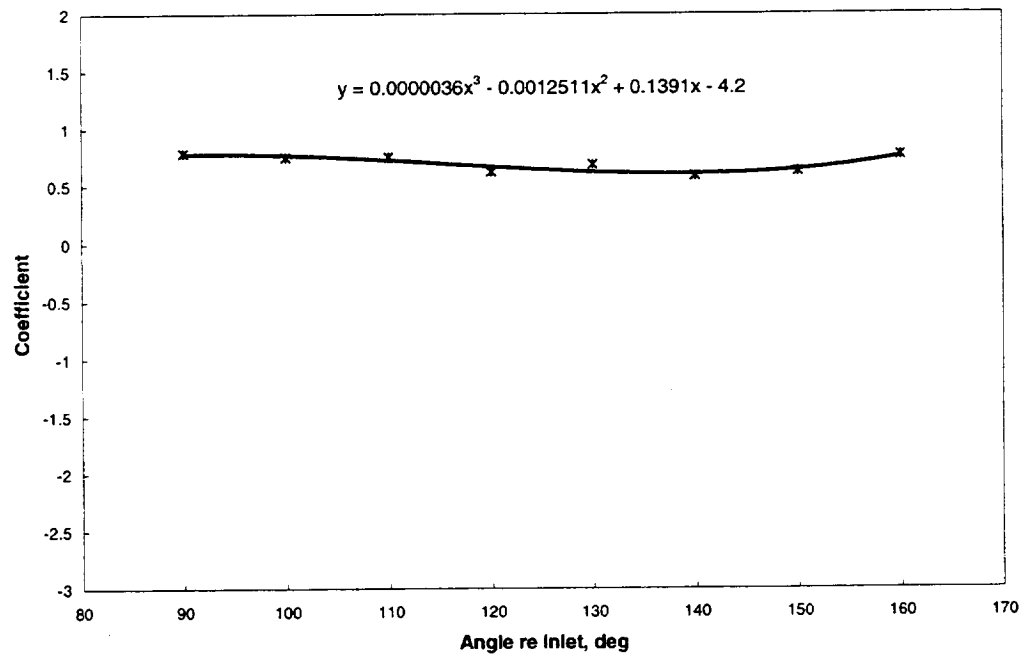


Figure 3.4.13

**Fan Exhaust Suppression Correlation "b_s" Coefficient
MPTs and Outliers Removed**



4.0 Results & Discussion

4.1 Fan Inlet Sound Power Level Suppression Model

Using the correlation developed in Section 3.1, a prediction of sound power level suppression was made for engines A, B, C, and D, and each was compared to the corresponding engine data (see Figures 4.1.1 - 4.1.4). Table 4.1.1 shows the polynomial coefficients derived from the correlation. Table 4.1.2 shows the results of the calculation (for engine A) of the normalized spectrum and the power level spectrum (using wavelength, ambient speed of sound, and engine diameter).

Table 4.1.1 Fan Inlet PWL Correlation Coefficients

	Coefficient
x^3	1.8580646
x^2	-6.7495764
x	6.2077962
constant	-0.1607321

Table 4.1.2 Fan Inlet PWL Suppression Prediction, Engine A

($c = 1116.4$ ft/s)

Freq. (Hz)	$\log(D/\lambda)$	Normalized Prediction	Δ PWL Prediction, dB
250	0.049	0.128	0.050
315	0.149	0.623	0.307
400	0.253	1.009	0.632
500	0.350	1.265	0.992
630	0.450	1.436	1.418
800	0.554	1.523	1.910
1000	0.651	1.533	2.403
1250	0.748	1.484	2.907
1600	0.855	1.374	3.446
2000	0.952	1.235	3.871
2500	1.049	1.069	4.188
3150	1.149	0.879	4.340
4000	1.253	0.676	4.236
5000	1.350	0.490	3.840
6300	1.450	0.313	3.094
8000	1.554	0.159	1.995
10000	1.651	0.052	0.816

Figure 4.1.1

**Fan Inlet PWL Suppression Prediction vs Data, Engine A
MPTs and outliers removed**

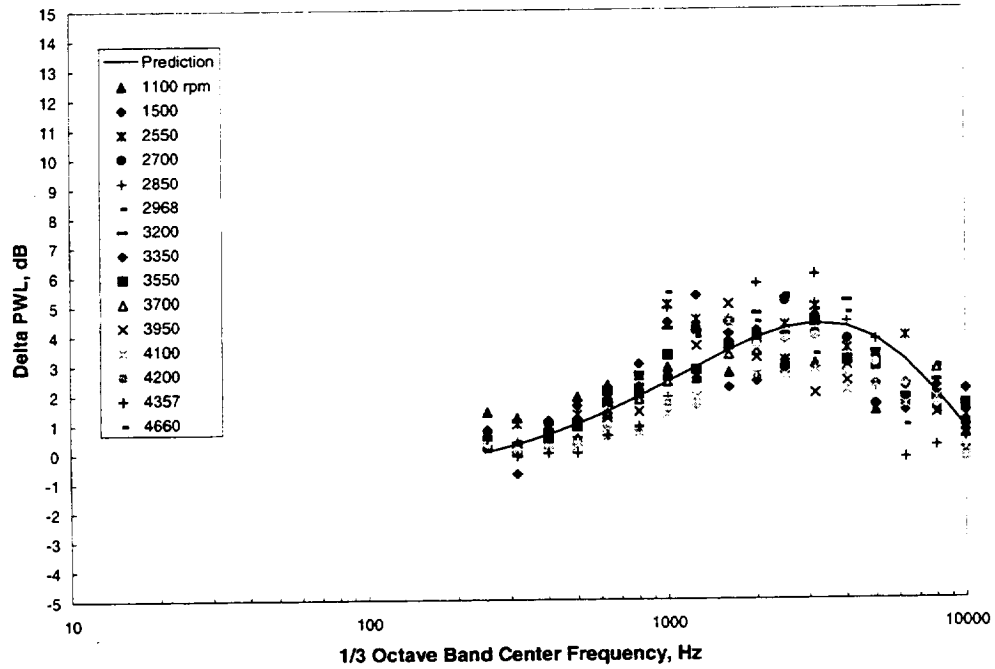


Figure 4.1.2

**Fan Inlet PWL Suppression Prediction vs Data, Engine B
MPTs and outliers removed**

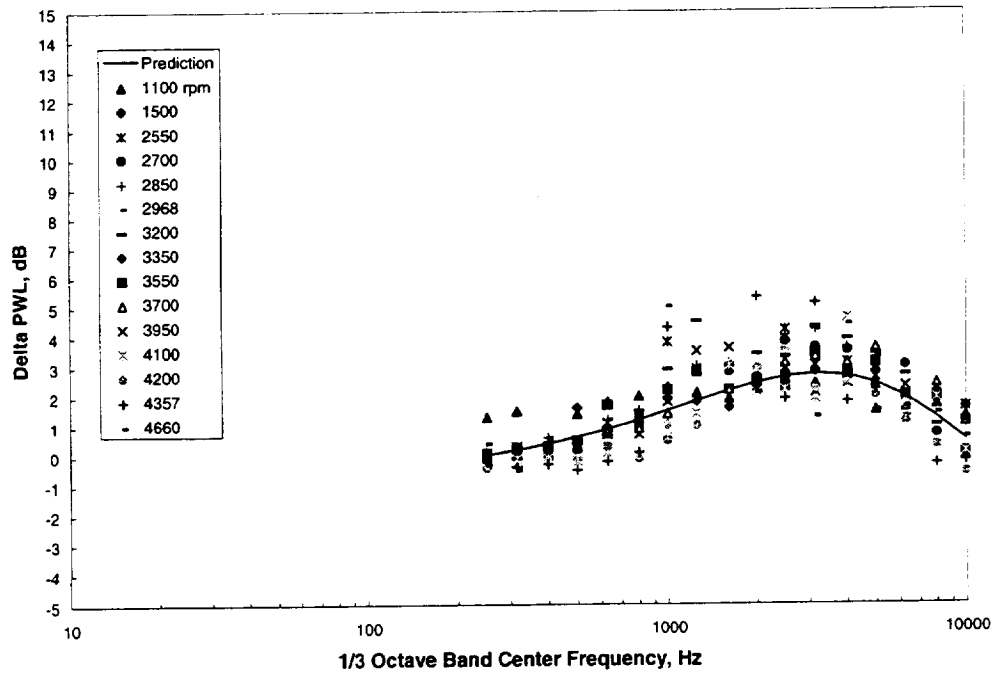


Figure 4.1.3

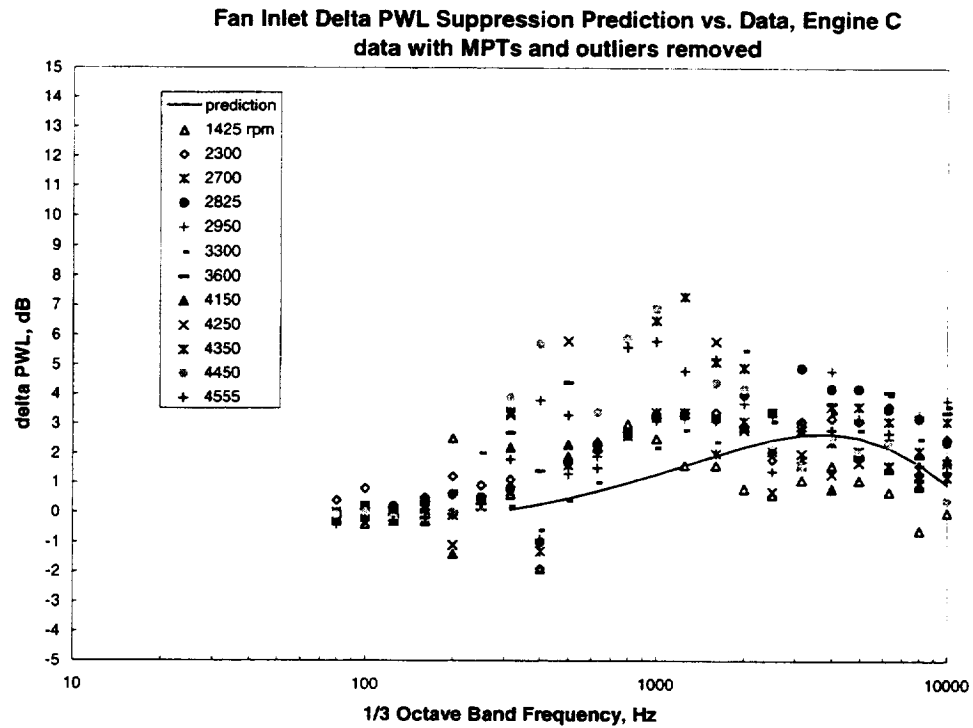
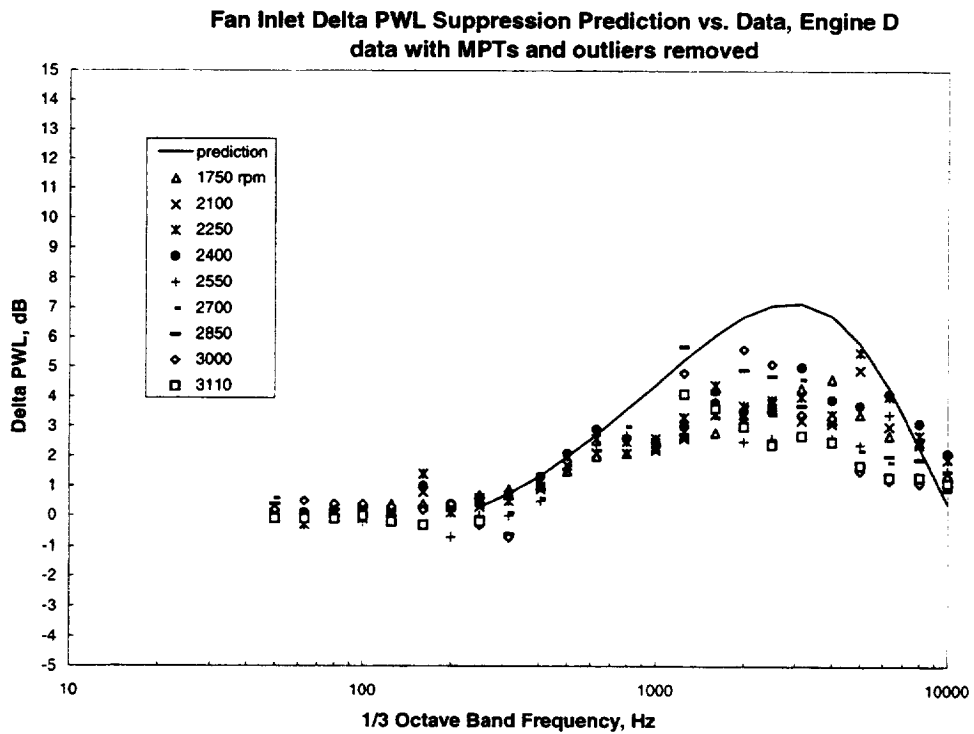


Figure 4.1.4



4.2 Fan Inlet Sound Pressure Level Suppression Model

Using the correlations shown in Section 3.2, a prediction of sound pressure level suppression was made for Engines A - D, and compared to the individual engine data set as shown in Figures 4.2.1 - 4.2.4. Table 4.2.1 shows the coefficients of the directivity correlation, and Table 4.2.2 shows the calculated coefficients of the inlet sound pressure level correlation. These coefficients are used to calculate the normalized sound pressure levels (Table 4.2.2). Then, using the wavelength, ambient speed of sound, and engine diameter (for the Engine A case), a one-third octave band sound pressure level suppression spectrum is calculated for angles 10°- 90° (Table 4.2.4). Note that the prediction model will yield negative suppression values that have been eliminated from Tables 4.2.3 and 4.2.4. In coded form, the models need to be restricted such that negative suppression values are not generated. Extrapolation beyond the ranges of angle or frequency should be made (if necessary) only from the predicted suppression values. Extrapolations derived from the high-order correlations could result in unreasonable results.

Table 4.2.1
Coefficients for Fan Inlet SPL Directivity Functions

X ⁵ Coef.	X ⁵ Coef.	X ⁴ Coef.	X ³ Coef.	X ² Coef.	X Coef.	Constant
4.9414E-09	-1.47209E-06	0.000168861	-0.00935246	0.25757607	-3.22984	13.38
-2.1059E-08	6.2678E-06	-0.000717487	0.039554327	-1.07912726	13.34955	-53.53
2.8866E-08	-8.5764E-06	0.000978356	-0.0535296	1.43762	-17.362	65.72
-1.2948E-08	3.8332E-06	-0.00043424	0.023405	-0.60847	6.9403	-22.99
5.6817E-10	-1.68137E-07	1.86625E-05	-0.0009461	0.020601	-0.1183998	-0.10

Table 4.2.2
Calculated Fan Inlet SPL Directivity Functions

X =	10°	20°	30°	40°	50°	60°	70°	80°	90°
a ₁ =	-0.968	-0.384	0.393	-0.469	-0.669	1.016	3.077	3.175	3.598
a ₂ =	5.042	2.160	-0.496	4.129	5.774	-0.989	-9.777	-10.572	-13.066
a ₃ =	-8.715	-3.771	-1.478	-9.862	-13.902	-5.709	6.087	7.726	12.497
a ₄ =	4.993	1.621	1.498	6.815	10.033	7.257	2.279	1.307	-1.640
a ₅ =	0.005	0.693	0.794	0.466	0.200	0.237	0.392	0.281	-0.030

Table 4.2.3
Normalized Inlet Sound Pressure Level Suppression Prediction, Engine A

(c = 1116.4 ft/s)

Freq.	log(D/λ)	10°	20°	30°	40°	50°	60°	70°	80°	90°
250	0.049	0.230	0.763	0.864	0.777	0.660	0.580	0.517	0.362	
315	0.149	0.573	0.858	0.983	1.278	1.408	1.192	0.837	0.615	
400	0.253	0.788	0.895	1.072	1.624	1.940	1.697	1.213	0.949	0.159
500	0.350	0.887	0.885	1.122	1.813	2.246	2.051	1.562	1.280	0.421
630	0.450	0.907	0.839	1.140	1.893	2.399	2.299	1.887	1.602	0.721
800	0.554	0.862	0.764	1.123	1.872	2.410	2.433	2.150	1.878	1.015
1000	0.651	0.779	0.677	1.077	1.778	2.312	2.452	2.311	2.060	1.240
1250	0.748	0.671	0.579	1.003	1.627	2.133	2.375	2.374	2.151	1.394
1600	0.855	0.537	0.467	0.895	1.413	1.866	2.193	2.323	2.135	1.460
2000	0.952	0.415	0.366	0.776	1.192	1.583	1.952	2.170	2.013	1.417
2500	1.049	0.300	0.272	0.643	0.961	1.281	1.656	1.921	1.794	1.276
3150	1.149	0.197	0.184	0.497	0.721	0.965	1.308	1.578	1.477	1.035
4000	1.253	0.111	0.106	0.344	0.488	0.654	0.925	1.156	1.076	0.701
5000	1.350	0.052	0.047	0.209	0.293	0.391	0.571	0.728	0.659	0.336
6300	1.450	0.013	0.002	0.085	0.126	0.163	0.232	0.290	0.222	

Table 4.2.4
Inlet Sound Pressure Level Suppression Prediction, Engine A

(c = 1116.4 ft/s)

Freq.	10°	20°	30°	40°	50°	60°	70°	80°	90°
250	0.090	0.299	0.339	0.305	0.258	0.227	0.203	0.142	
315	0.283	0.424	0.486	0.631	0.695	0.588	0.413	0.304	
400	0.494	0.561	0.672	1.018	1.216	1.064	0.761	0.595	0.099
500	0.695	0.694	0.879	1.421	1.760	1.608	1.225	1.003	0.330
630	0.896	0.829	1.126	1.869	2.369	2.271	1.863	1.582	0.712
800	1.081	0.958	1.408	2.348	3.022	3.051	2.697	2.355	1.273
1000	1.221	1.061	1.688	2.786	3.625	3.843	3.622	3.229	1.944
1250	1.314	1.135	1.966	3.187	4.180	4.654	4.651	4.214	2.731
1600	1.347	1.170	2.244	3.543	4.680	5.499	5.827	5.354	3.661
2000	1.300	1.149	2.432	3.739	4.964	6.121	6.803	6.311	4.442
2500	1.177	1.066	2.520	3.764	5.021	6.490	7.528	7.031	5.000
3150	0.972	0.907	2.453	3.561	4.767	6.456	7.791	7.295	5.108
4000	0.694	0.664	2.160	3.057	4.099	5.802	7.245	6.744	4.393
5000	0.406	0.371	1.639	2.299	3.068	4.474	5.710	5.166	2.631
6300	0.125	0.020	0.841	1.248	1.607	2.290	2.865	2.189	

Figure 4.2.1

Fan Inlet SPL Suppression Prediction vs Data, Engine A
40 degrees, MPTs and outliers removed

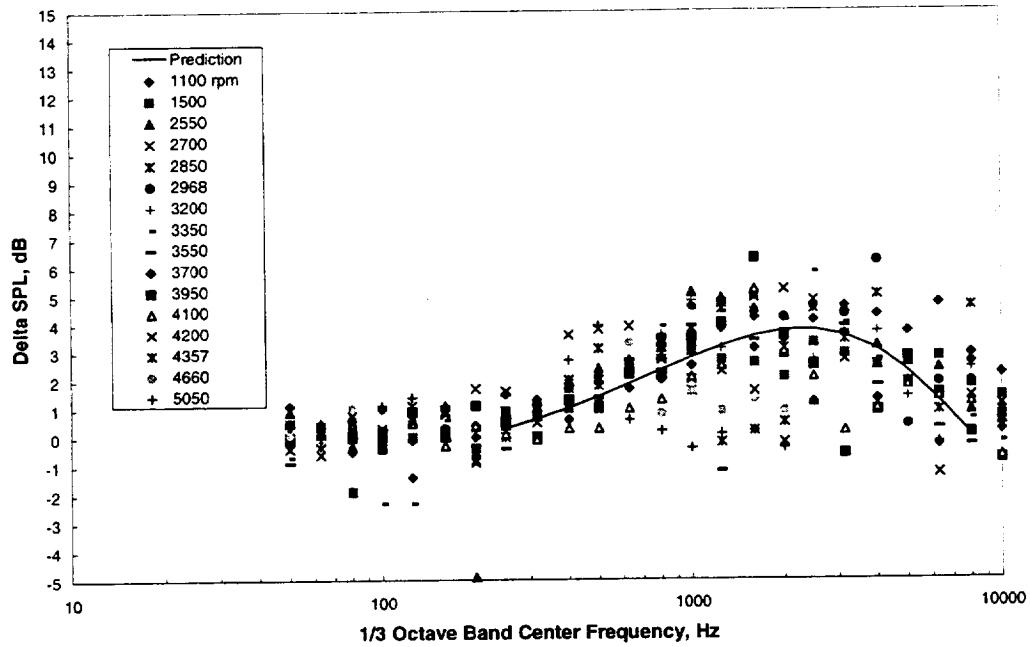


Figure 4.2.2

Fan Inlet SPL Suppression Prediction vs Data, Engine B
40 degrees, MPTs and outliers removed

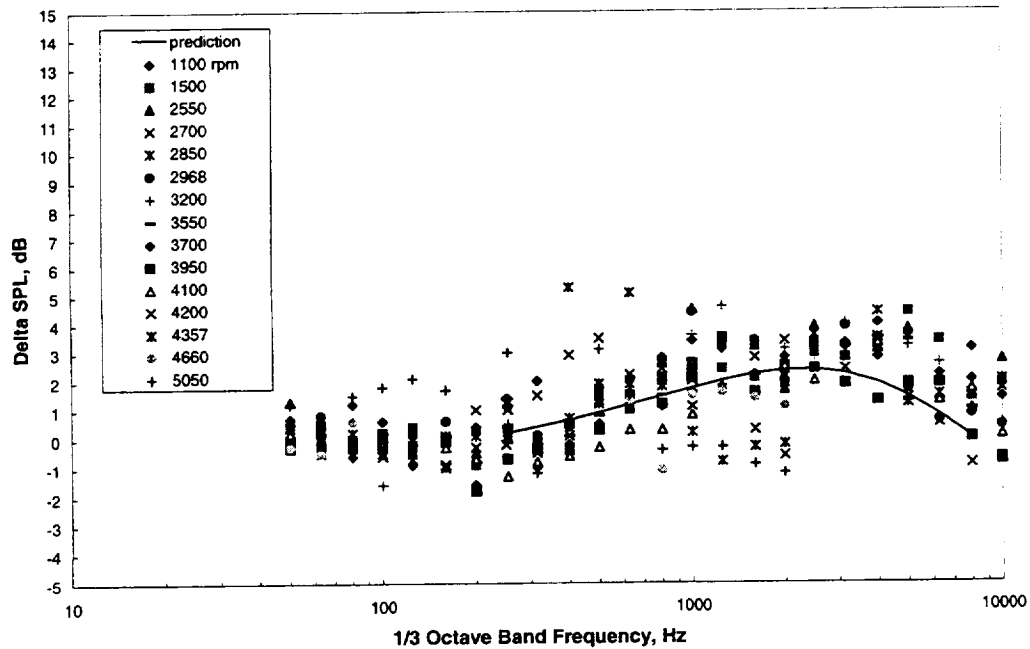


Figure 4.2.3

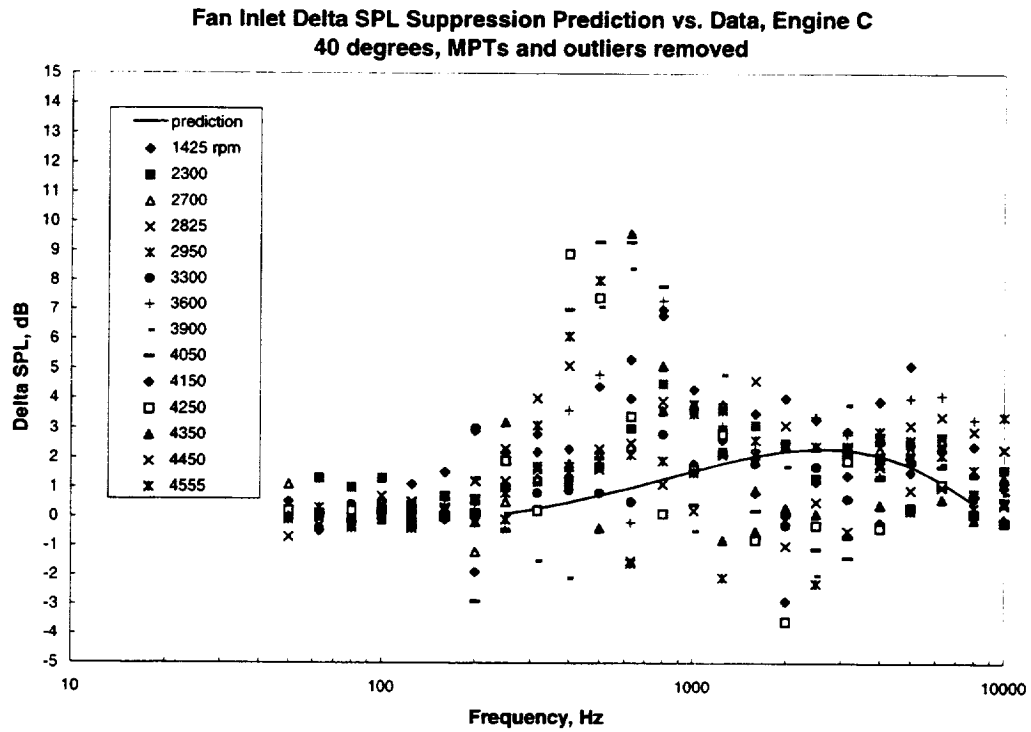
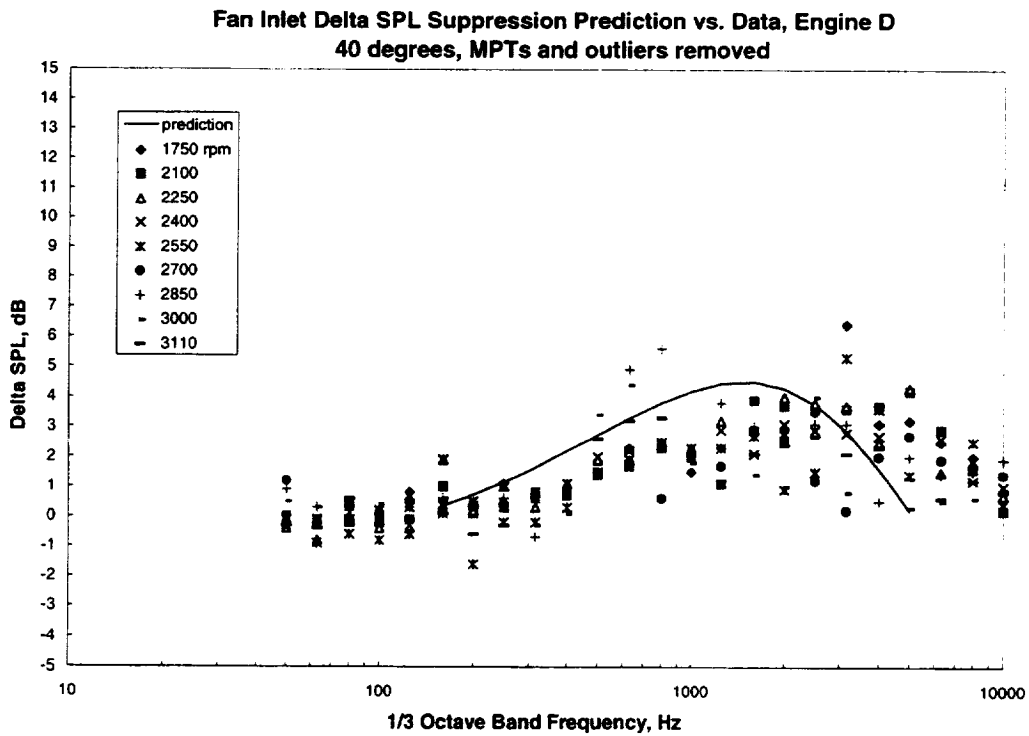


Figure 4.2.4



4.3 Fan Exhaust Sound Power Level Suppression Model

Using the correlation developed in Section 3.3, a prediction of sound power level suppression was made for each engine, and compared to the appropriate engine data set (Figures 4.3.1 - 4.3.4). The various steps in making the predictions are outlined in Tables 4.3.1 - 4.3.2 for Engine H. Table 4.3.1 shows the polynomial coefficients derived from the correlation. Table 4.3.2 shows the results of the calculation of the normalized spectrum and the power level spectrum (using wavelength, ambient speed of sound, and equivalent engine exhaust duct height..

Table 4.3.1 Fan Exhaust PWL Correlation Coefficients

	Coefficient
x^3	1.3154
x^2	-2.7136
x	0.6964
constant	0.6937

Table 4.3.2 Fan Exhaust PWL Suppression Prediction, Engine H

($c = 1116.4$ ft/s)

Freq., Hz	$\log h/\lambda$	Normalized Prediction	Δ PWL Prediction, dB
400	-0.332	0.12	0.25
500	-0.235	0.36	0.98
630	-0.135	0.55	1.87
800	-0.031	0.67	2.90
1000	0.066	0.73	3.95
1250	0.163	0.74	5.04
1600	0.270	0.71	6.20
2000	0.367	0.66	7.11
2500	0.464	0.57	7.75
3150	0.564	0.47	7.98
4000	0.668	0.35	7.55
5000	0.765	0.23	6.35
6300	0.865	0.12	4.12
8000	0.969	0.02	0.72

Figure 4.3.1

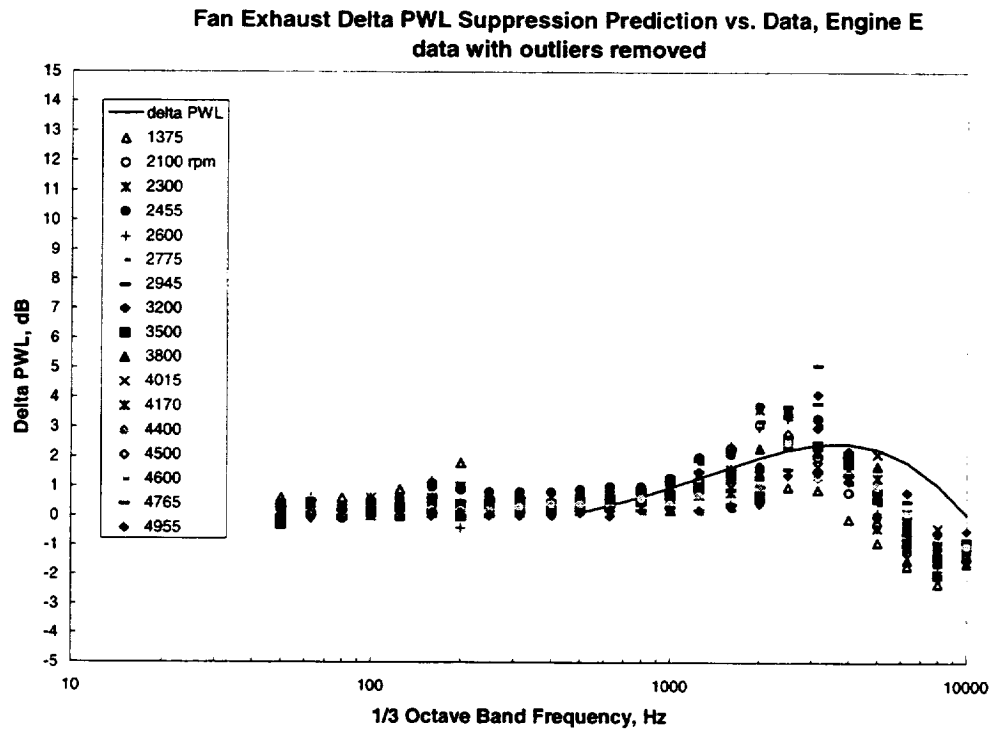


Figure 4.3.2

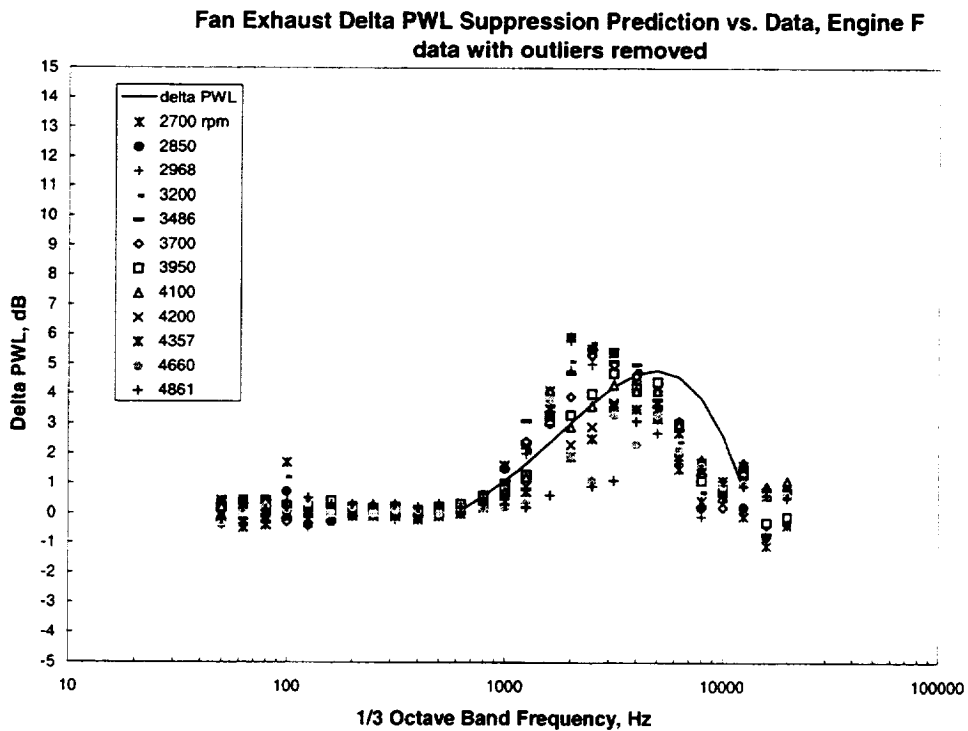


Figure 4.3.3

Fan Exhaust Delta PWL Suppression Prediction vs. Data, Engine G
data with outliers removed

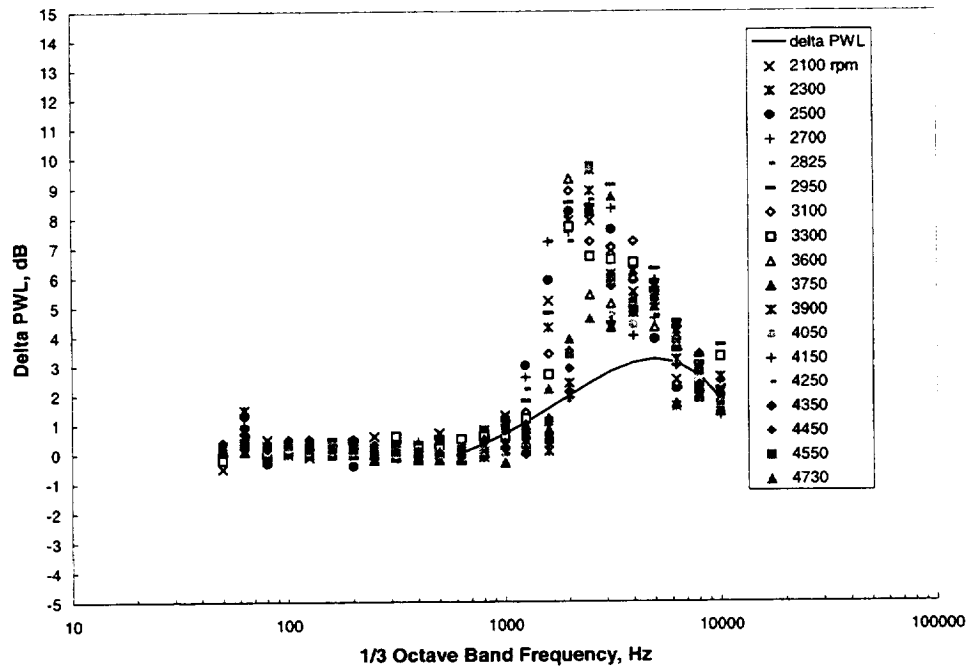
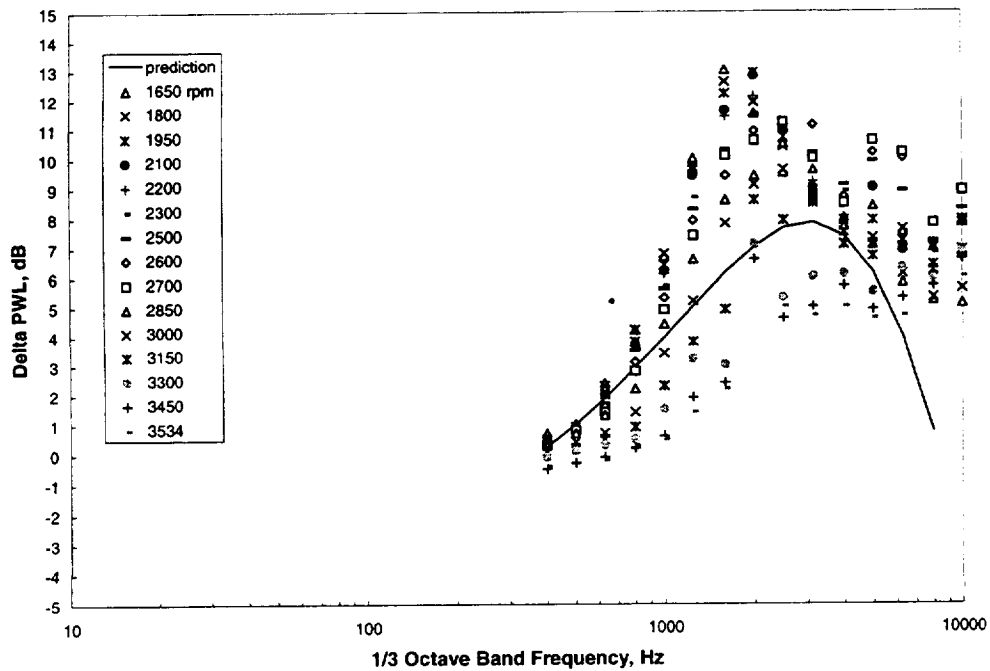


Figure 4.3.4

Fan Exhaust Delta PWL Suppression Prediction vs. Data, Engine H
data with outliers removed



4.4 Fan Exhaust Sound Pressure Level Suppression Model

Using the correlations shown in Section 3.4, a prediction of sound pressure level suppression was made for each engine, and compared to the individual engine data set. Figures 4.4.1 - 4.4.4 show these results the 120 degree position for each engine. The various steps of making the prediction are outlined in Tables 4.4.1 - 4.4.3. Table 4.4.1 shows the coefficients of the directivity correlation. Table 4.4.2 shows the functions at each angle as calculated from the previous table. These new coefficients are used to calculate the normalized sound pressure levels (shown in Table 4.4.3). Then, using the wavelength, ambient speed of sound, and equivalent exhaust duct height, a one-third octave band sound pressure level suppression spectrum is calculated for angles 90°- 160° (Table 4.4.4). Note that the prediction model will yield negative suppression values that have been eliminated from Tables 4.4.2 and 4.4.3. In coded form, the models need to be restricted such that negative suppression values are not generated. Extrapolation beyond the ranges of angle or frequency should be made (if necessary) only from the predicted suppression values. Extrapolations derived from the high-order correlations could result in unreasonable results.

Table 4.4.1
Coefficients for Fan Exhaust SPL Directivity Functions

X^6 Coef.	X^5 Coef.	X^4 Coef.	X^3 Coef.	X^2 Coef.	X Coef.	C
0	0.0000000014841	-0.00000133848	0.00042679	-0.06297	4.3952	-116.8
0.0000000023005569	-0.000001718630	0.00053121625	-0.08694440	7.945698	-384.343	7684.9
0.0000000011895006	-0.00000090354	0.00028410000	-0.04730600	4.397242	-216.239	4392
0	0	-0.00000041400	0.00019627	-0.03433	2.6265	-73.7
0	0	0	0.00000360	-0.00125	0.13913	-4.2

Table 4.4.2
Calculated Fan Exhaust SPL Directivity Functions

X=	90°	100°	110°	120°	130°	140°	150°	160°
b_1	0.75875429	0.7685	0.68546711	0.68138432	0.802646	0.988123	1.086969	0.876431
b_2	-0.858733387	-0.88072	-0.580972999	-0.65675767	-0.68427	-0.69361	-1.08727	-0.90235
b_3	-1.286757635	-1.3794	-1.195981563	-1.32396841	-1.47672	-1.48691	-1.44348	-0.97221
b_4	0.531019	0.521	0.444961	0.437248	0.532847	0.667384	0.677125	0.298976
b_5	0.81219	0.802	0.75759	0.70056	0.65251	0.63504	0.66975	0.77824

Table 4.4.3**Normalized Exhaust Sound Pressure Level Suppression Prediction, Engine H**

(c = 1116.4 ft/s)

Freq.	90°	100°	110°	120°	130°	140°	150°	160°
400	0.534885037	0.518740775	0.5077991	0.441956	0.347842	0.287198	0.339037	0.615584
500	0.629887164	0.617253263	0.59668827	0.535378	0.457168	0.408218	0.44844	0.668727
630	0.719798328	0.709336157	0.67771888	0.619593	0.556024	0.520353	0.555529	0.722905
800	0.79464793	0.784679223	0.74277522	0.685864	0.634727	0.613105	0.647568	0.768141
1000	0.841442965	0.830179241	0.78162831	0.723507	0.681105	0.672487	0.707919	0.793514
1250	0.861376774	0.847002521	0.79631113	0.73429	0.697733	0.702017	0.737833	0.797851
1600	0.848819204	0.828773864	0.78268318	0.712704	0.679437	0.698386	0.731658	0.7749
2000	0.804984849	0.777716901	0.74344056	0.662501	0.629801	0.663262	0.689715	0.728221
2500	0.730875807	0.694340039	0.68024853	0.584313	0.550606	0.601045	0.61487	0.658082
3150	0.624565666	0.576241568	0.59282021	0.47662	0.441224	0.513594	0.506882	0.563955
4000	0.487576342	0.424713387	0.48425626	0.341508	0.3051	0.407166	0.370039	0.449462
5000	0.340640398	0.26204751	0.37262126	0.199431	0.164334	0.303211	0.22836	0.334073
6300	0.176964275	0.079926249	0.25482081	0.043831	0.014299	0.203648	0.07958	0.215545
8000	0.005818948		0.14130096			0.125564		0.106583
10000			0.05414549			0.092573		0.030776

Table 4.4.4**Exhaust Sound Pressure Level Suppression Prediction, Engine H**

(c = 1116.4 ft/s)

Freq., Hz	90°	100°	110°	120°	130°	140°	150°	160°
400	1.159460579	1.124464956	1.10074689	0.95802	0.75401	0.622554	0.734925	1.334389
500	1.706743704	1.672510857	1.61678791	1.45066	1.238743	1.106108	1.215093	1.811983
630	2.457462672	2.421743784	2.31379927	2.115352	1.89832	1.776536	1.896632	2.468068
800	3.445087765	3.401869794	3.22020071	2.973468	2.75177	2.658035	2.807444	3.330172
1000	4.559951576	4.498911151	4.23580373	3.920831	3.691045	3.644344	3.836358	4.300217
1250	5.834971205	5.737599934	5.39421617	4.974088	4.726445	4.755464	4.998084	5.404646
1600	7.359879874	7.186072195	6.78643248	6.179664	5.891215	6.055516	6.344007	6.718948
2000	8.724755168	8.429213995	8.05771294	7.180455	6.826039	7.188705	7.475418	7.89276
2500	9.901913815	9.406926813	9.21601495	7.916285	7.45961	8.142966	8.330271	8.915704
3150	10.66164473	9.836728485	10.1197341	8.136137	7.531918	8.767302	8.652723	9.626995
4000	10.5691038	9.206434933	10.497135	7.402811	6.613593	8.826059	8.021269	9.742911
5000	9.230000031	7.100445346	10.0965542	5.403778	4.452808	8.215809	6.187639	9.052056
6300	6.041735352	2.728761191	8.69983456	1.49644	0.488174	6.952732	2.716952	7.358922
8000	0.252272537		6.1259103			5.443645		4.620744
10000			2.93425469			5.016697		1.66783

Figure 4.4.1

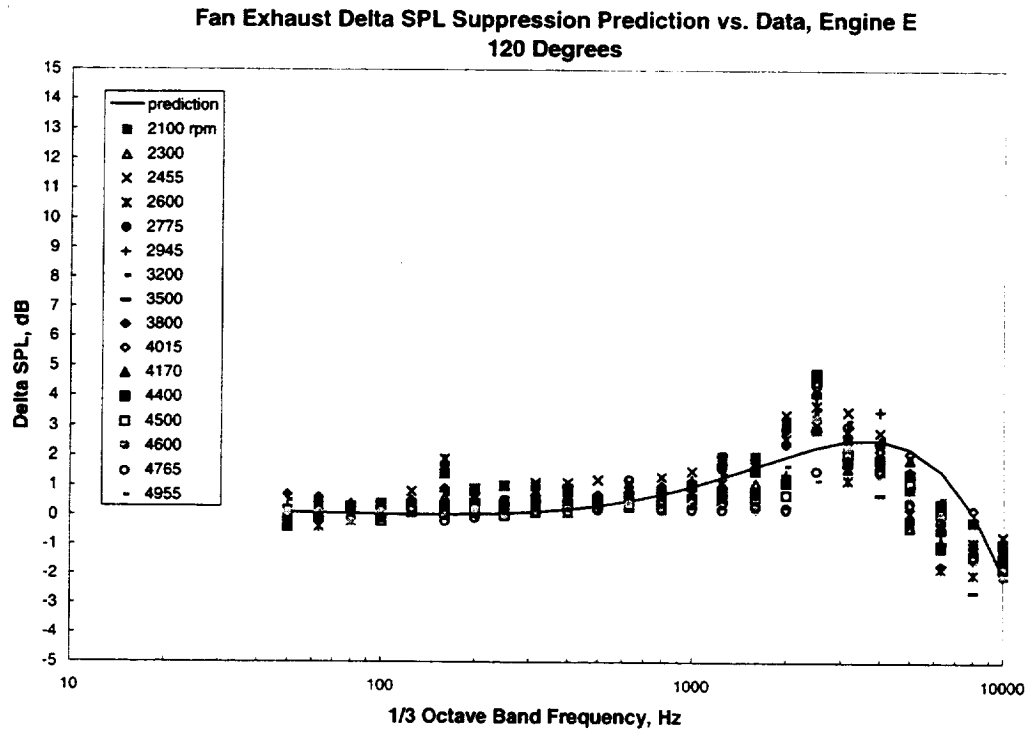


Figure 4.4.2

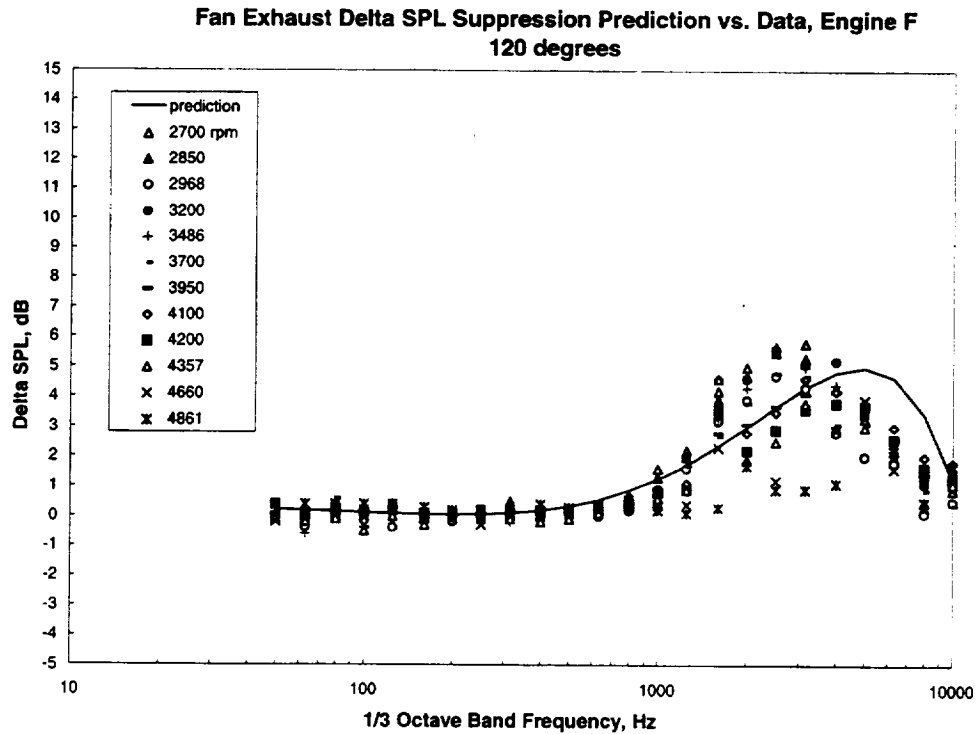


Figure 4.4.3

Fan Exhaust Delta SPL Suppression Prediction vs. Data, Engine G
120 degrees

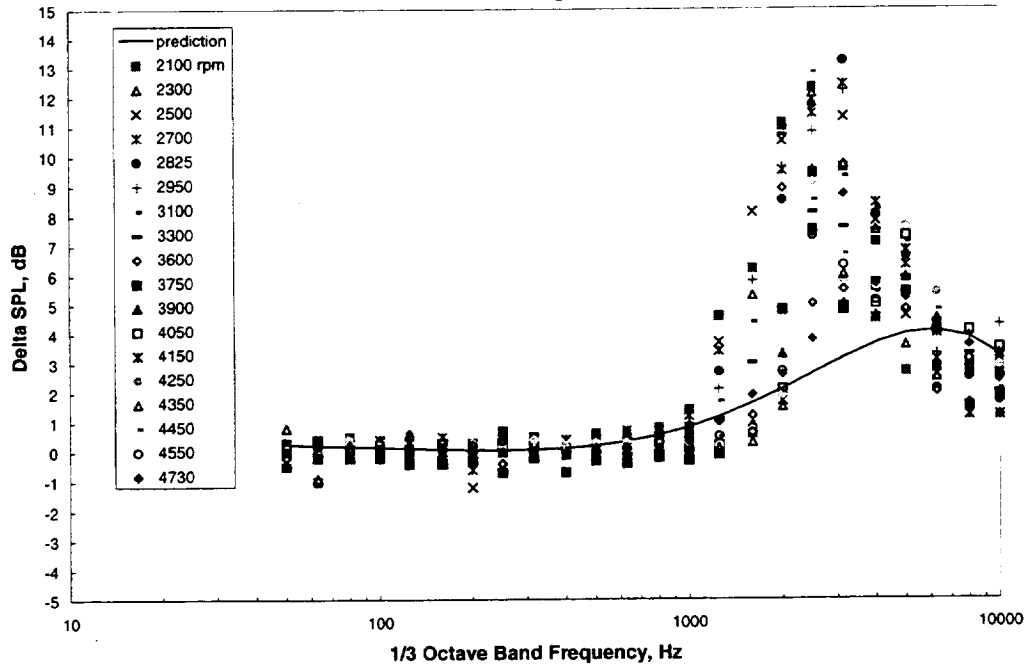
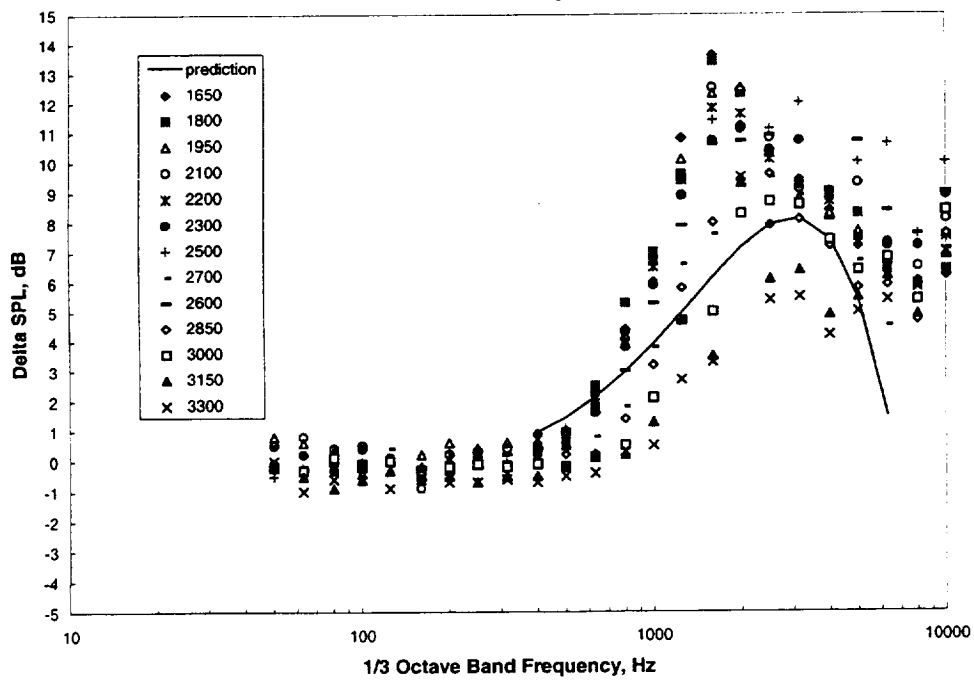


Figure 4.4.4

Fan Exhaust Delta SPL Suppression Prediction vs. Data, Engine H
120 degrees



Concluding Remarks

A fan inlet and fan exhaust suppression estimation model has been developed that is based on correlations of current commercial engine data with simple nacelle and treatment geometry information. Each database is for similar types of treatment -- i.e. the fan inlet treatment for all four engines is a 2DOF design, with similar tuning frequencies.

Correlations with additional parameters (other than the ones used) were attempted, but with no positive results. An example of this was an attempt to correlate suppression with fan blade tip speed. In some instances, a trend of decreased suppression with increased fan tip speed is generally indicated (Figures 4.3.1 - 4.4.4). However, a consistent trend was not always demonstrated (Figures 4.1.1 - 4.2.4). The fact that the treatment designs are inherently similar may be one reason why there are relatively few correlating parameters.

A common suppression correlation is the ratio of treatment length to duct height. At first glance, it may appear that this parameter was not used. In essence, it was where the correlation started. Further collapse of the data was attained when the data (already normalized by L/D or l/h) was normalized by a ratio of the duct height to the wavelength of interest. Mathematically, the "D" or "h" is eliminated, simplifying the normalization to be the factor λ/L (fan inlet) or λ/l (fan exhaust).

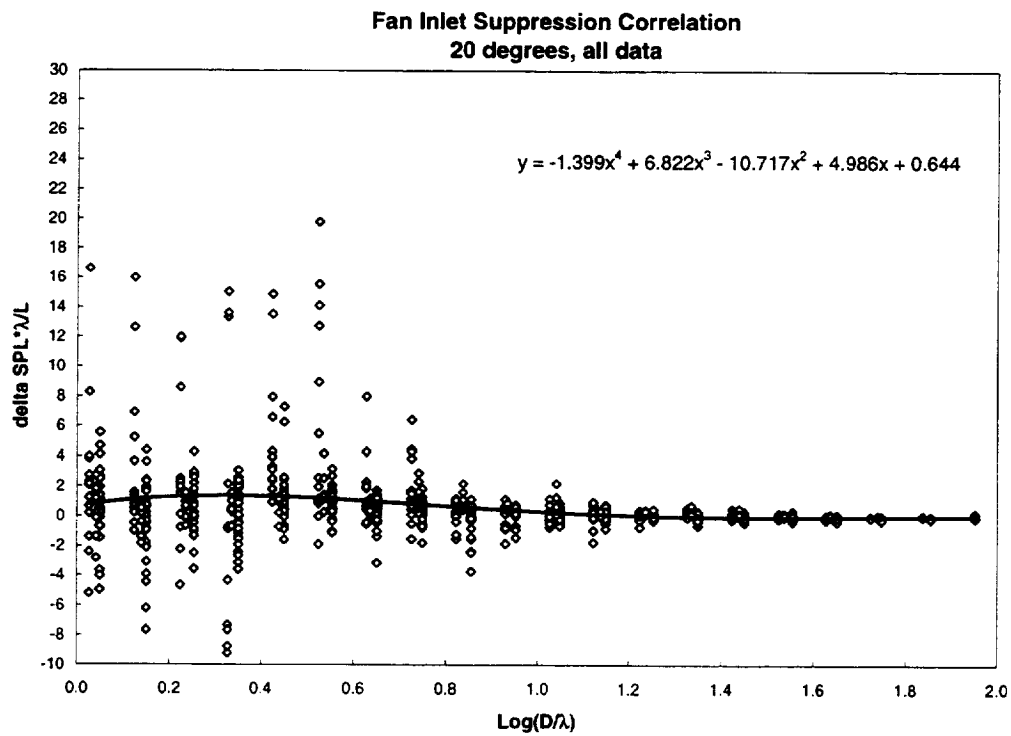
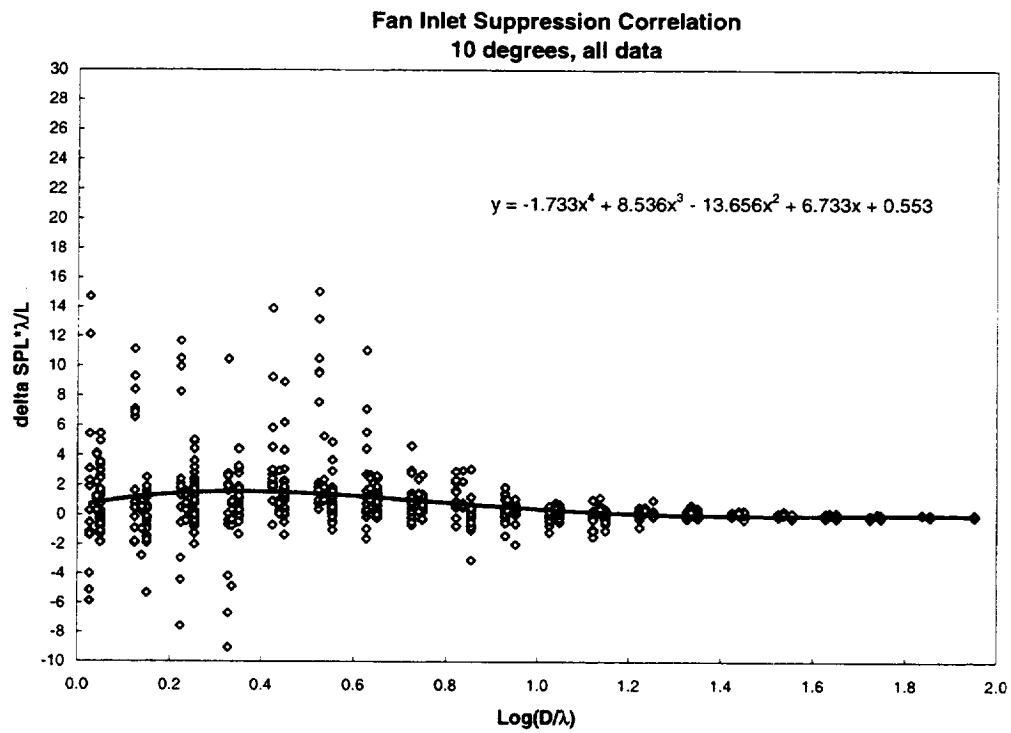
Investigation into the large data scatter at low frequencies showed that large suppressions were measured when a strong MPT source existed. This occurred (for the most part) only in one of the databases used. It was decided that the MPT data should be removed since 1) incorporation of the entire data set would substantially reduce the quality of the correlation, 2) a model of MPT suppression would be beyond the scope of developing a tool for use in ANOPP, and 3) the large amount of MPT content in the one database is not representative of the majority of fan noise sources and would therefore be of little value to model in ANOPP.

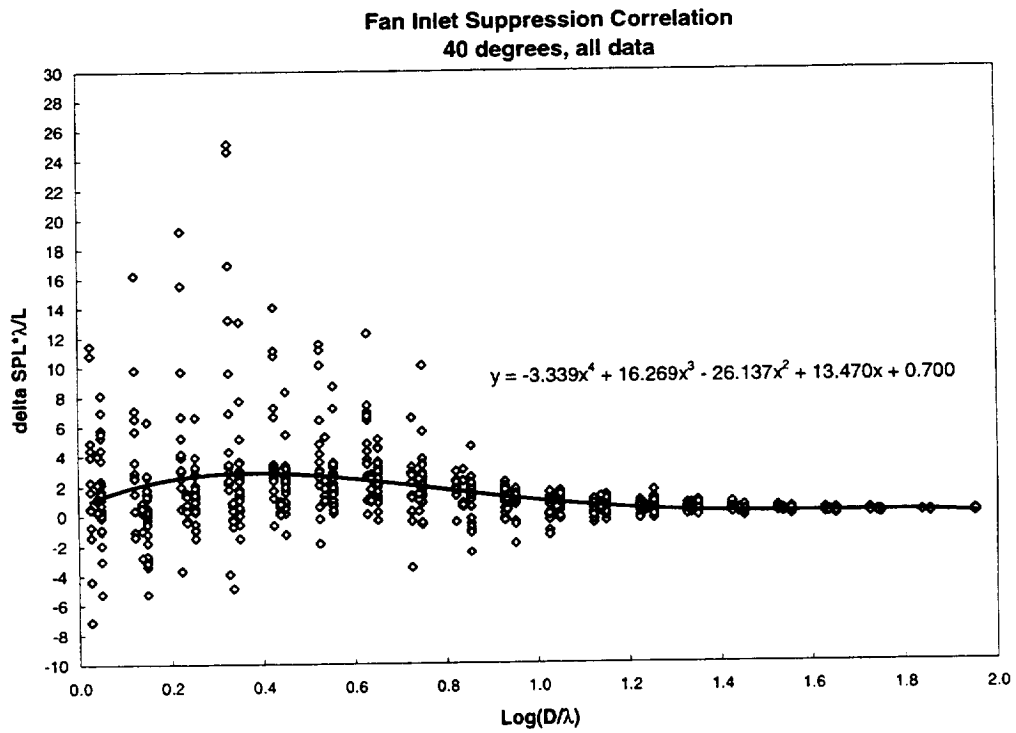
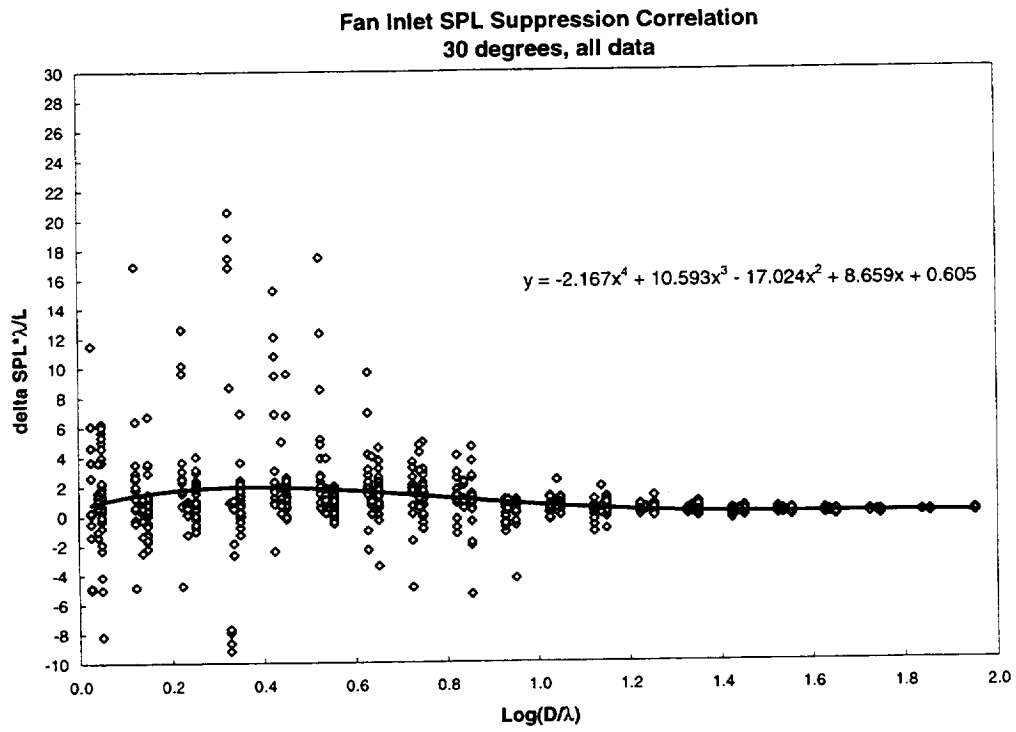
It should be mentioned that the correlations are limited to the ranges for which they have been developed: 10° - 90° for fan inlet suppression and 90° - 160° for fan exhaust suppression. Additionally, the correlations must be restricted such that only positive suppression values are used -- negative values can be generated but must be discarded. Extrapolation beyond the ranges of angle or frequency should be made (if desired) only from the predicted suppression values that are within the specified range. Blind extrapolations of the high-order correlations could yield unreasonable results.

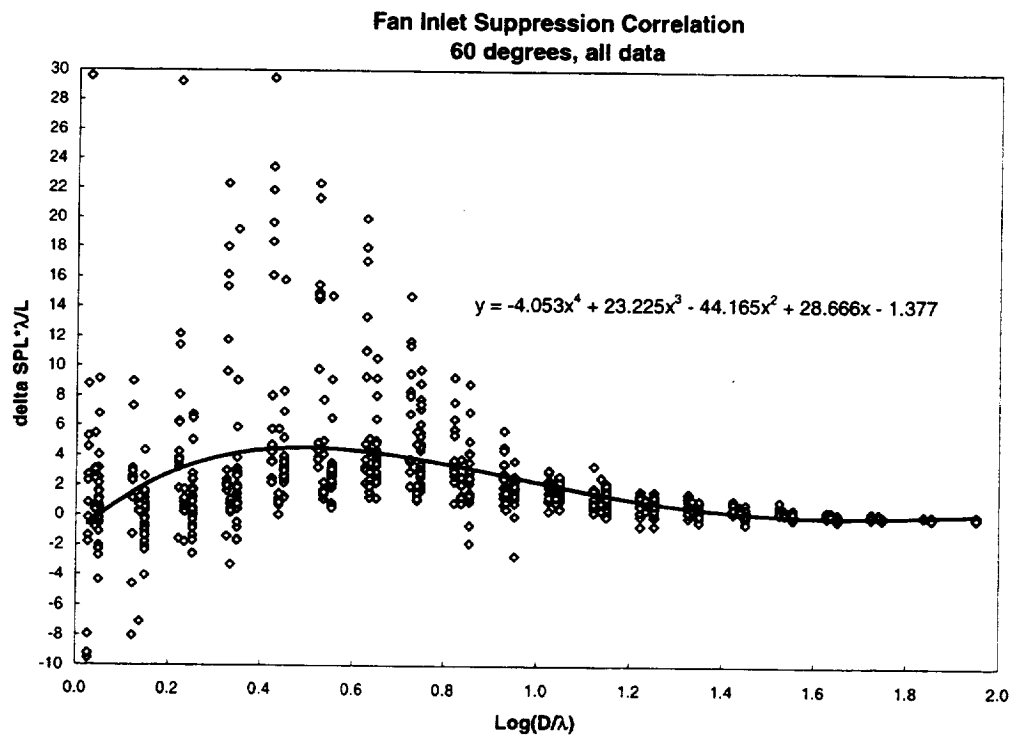
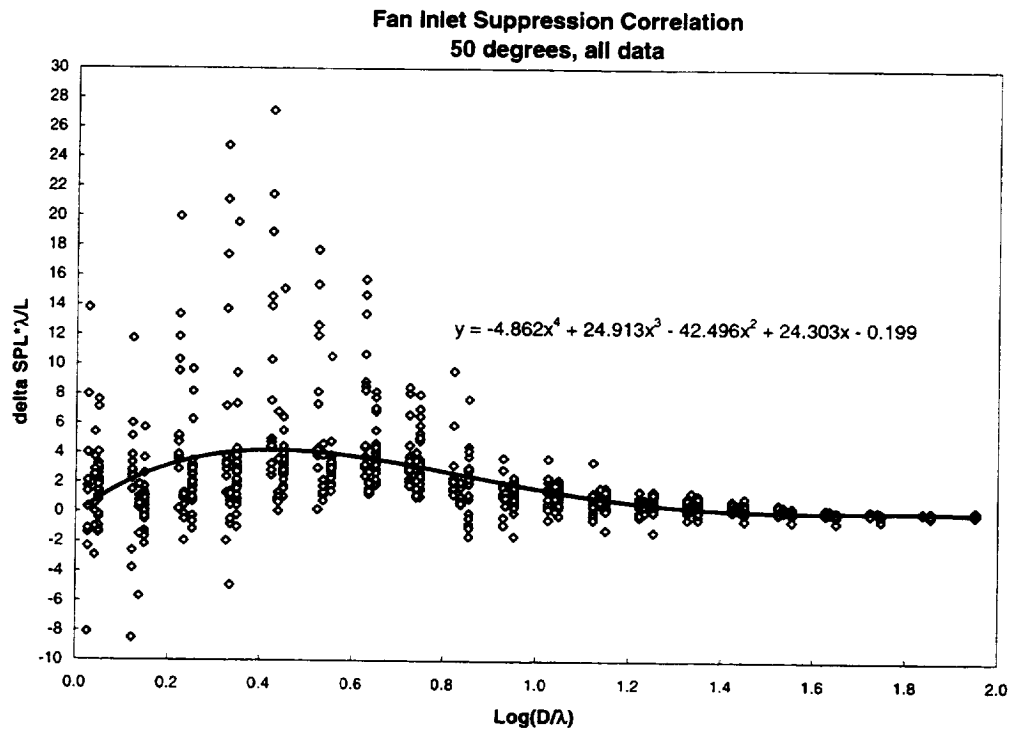
These models are not a treatment design tool, but should be useful as a simple means of modifying treatment areas, engine size, etc. for system noise evaluation. These models are representative of current engines and conventional treatment designs, and would not be applicable to treatment designs that differ significantly from those currently in use.

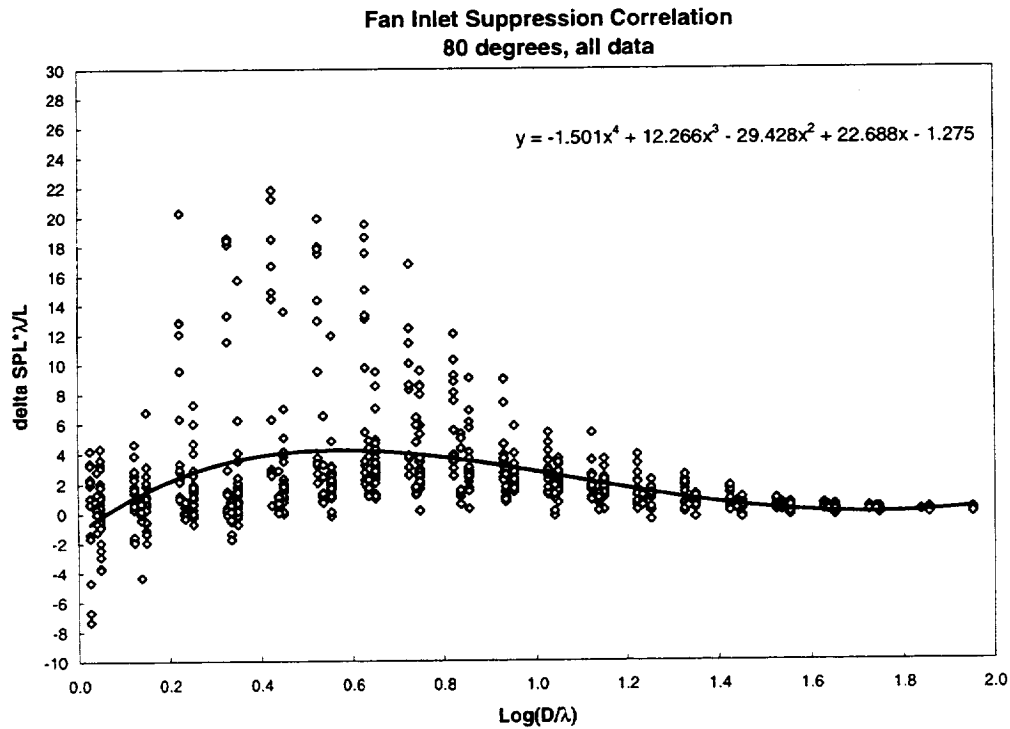
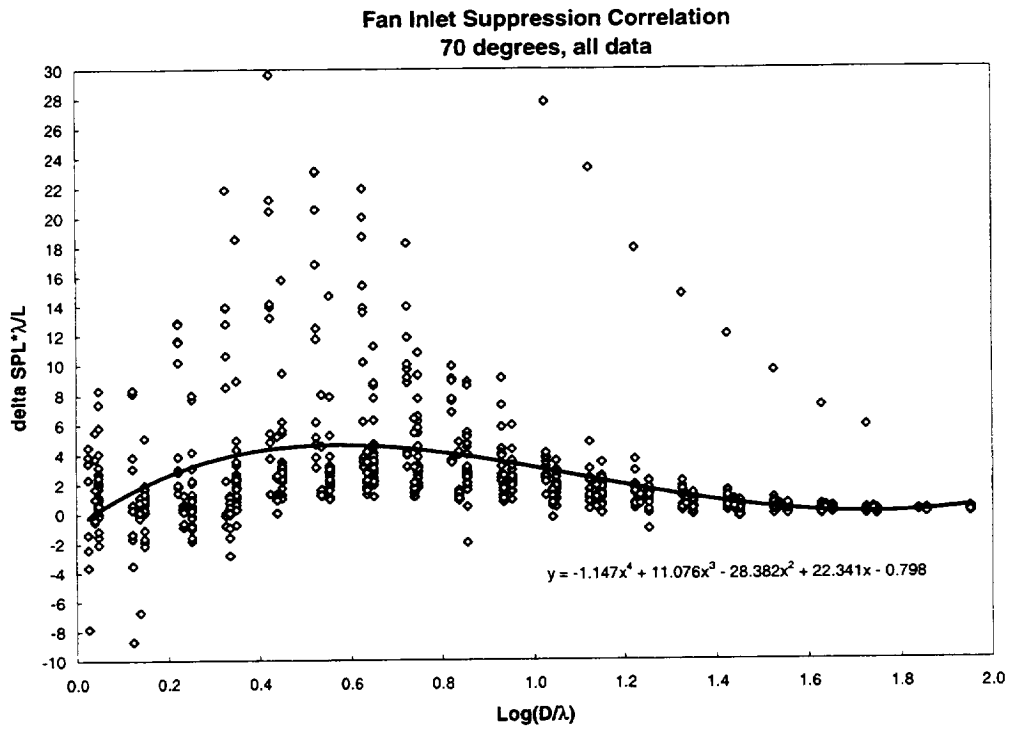
Appendix A. Fan Inlet SPL Suppression Correlation, all data

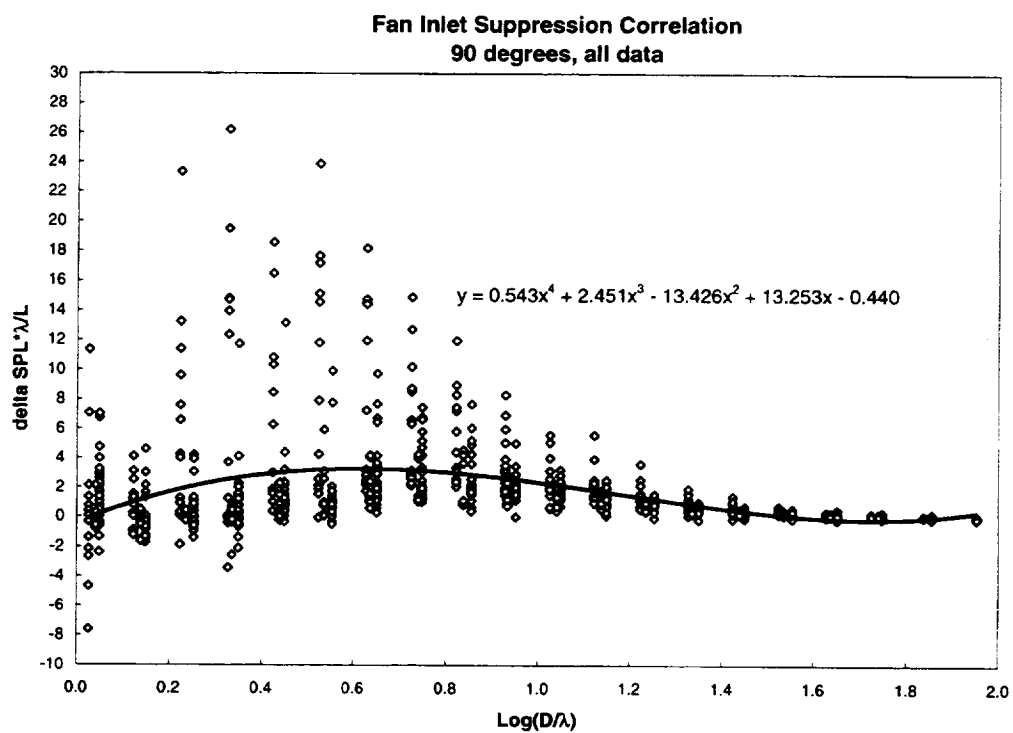
Angle, °	Page
10	42
20	42
30	43
40	43
50	44
60	44
70	45
80	45
90	46







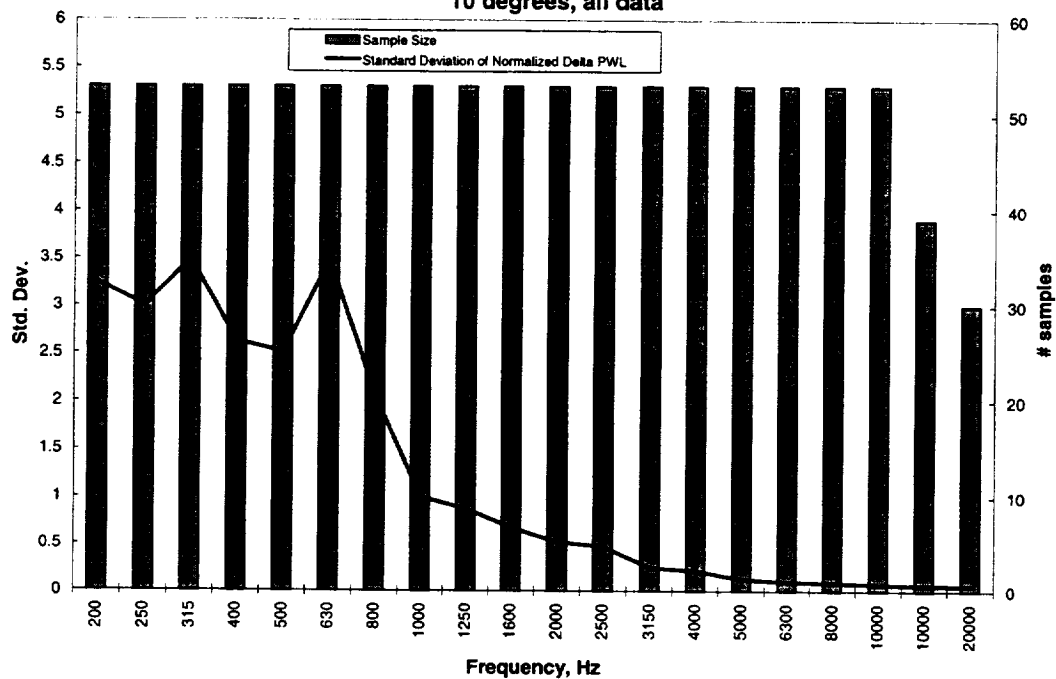




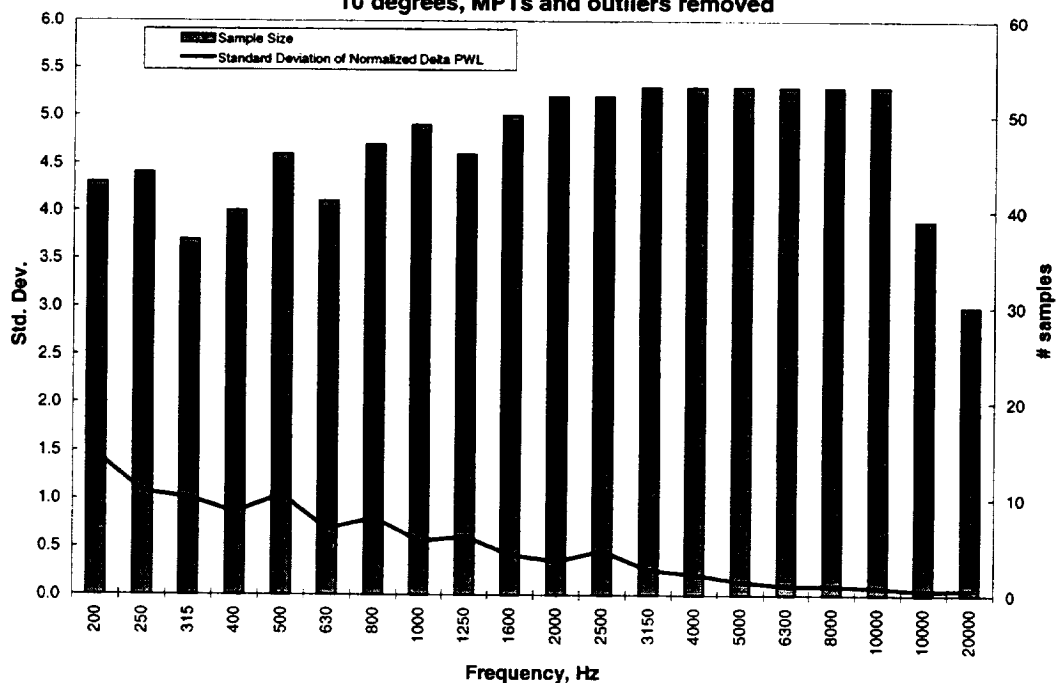
Appendix B. Fan Inlet SPL Correlation Statistics

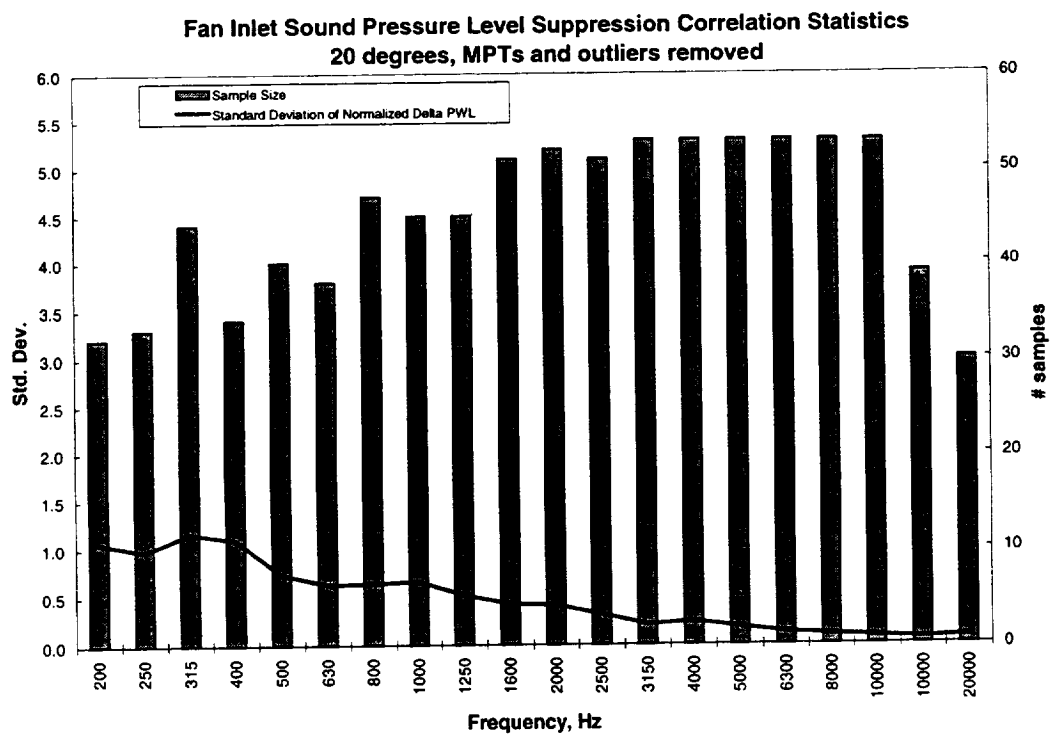
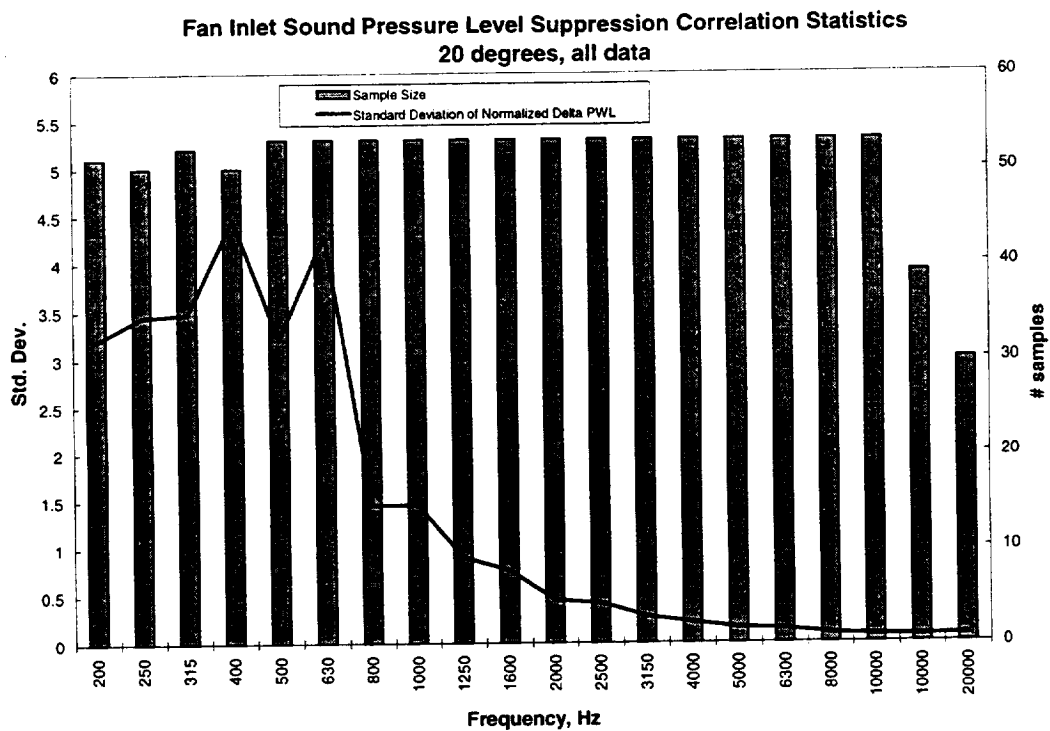
Angle, °	Page
10	48
20	49
30	50
40	51
50	52
60	53
70	54
80	55
90	56

Fan Inlet Sound Pressure Level Suppression Correlation Statistics
10 degrees, all data

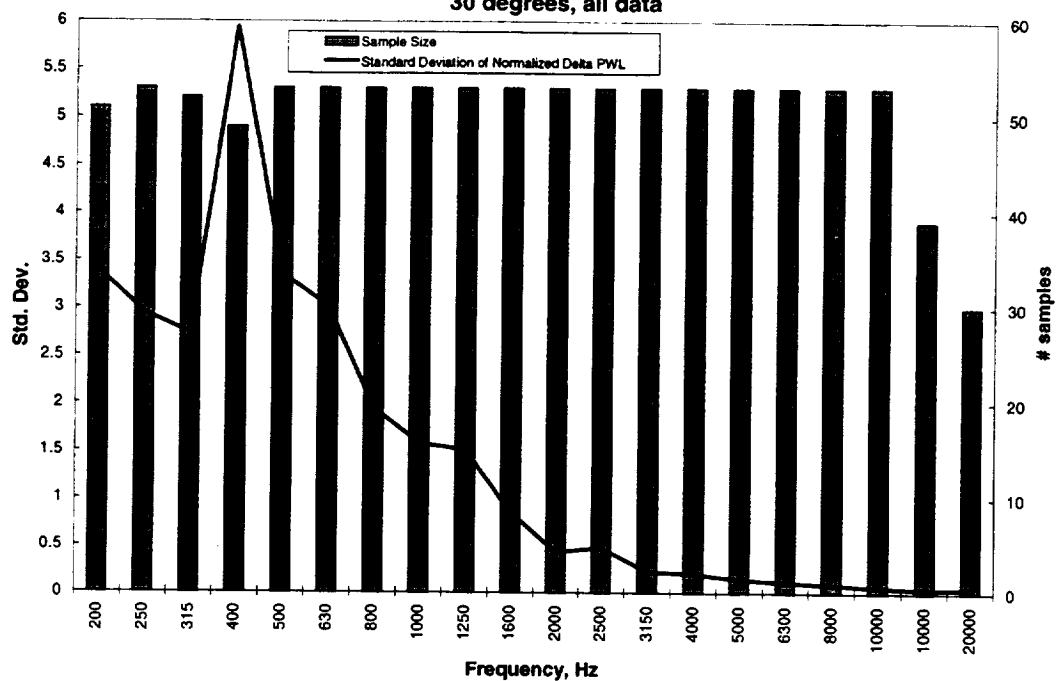


Fan Inlet Sound Pressure Level Suppression Correlation Statistics
10 degrees, MPTs and outliers removed

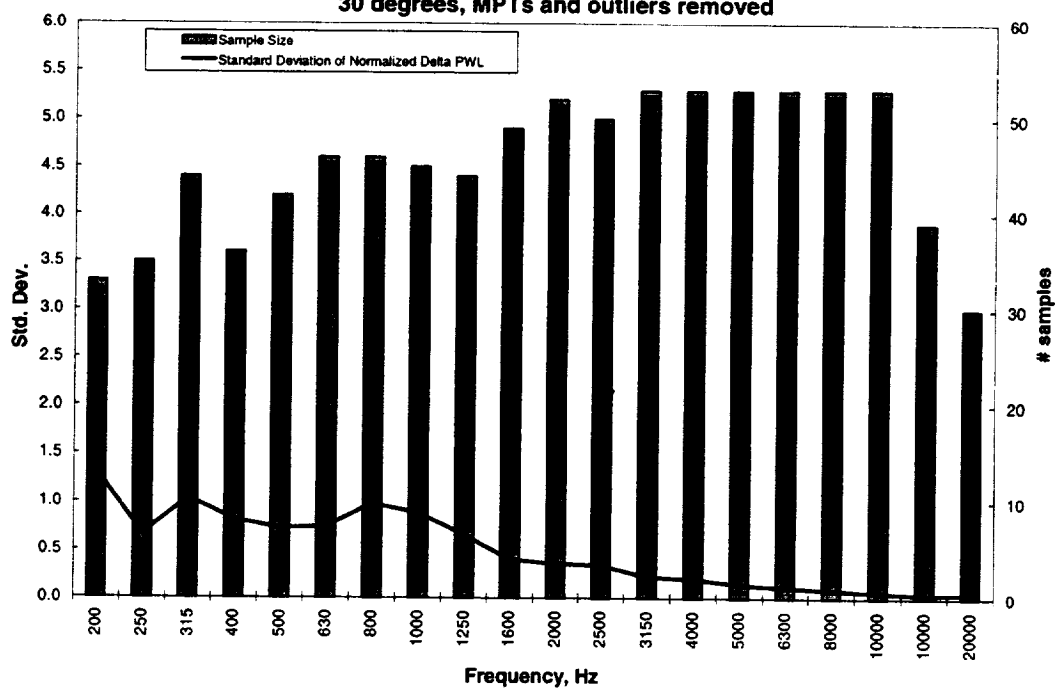


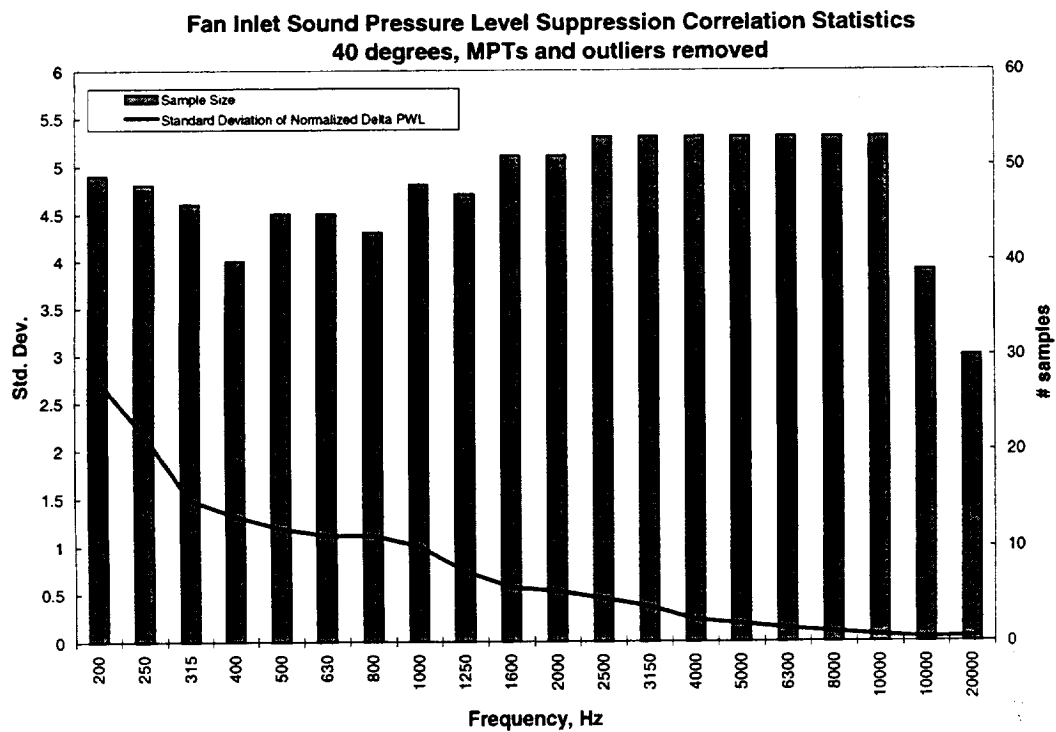
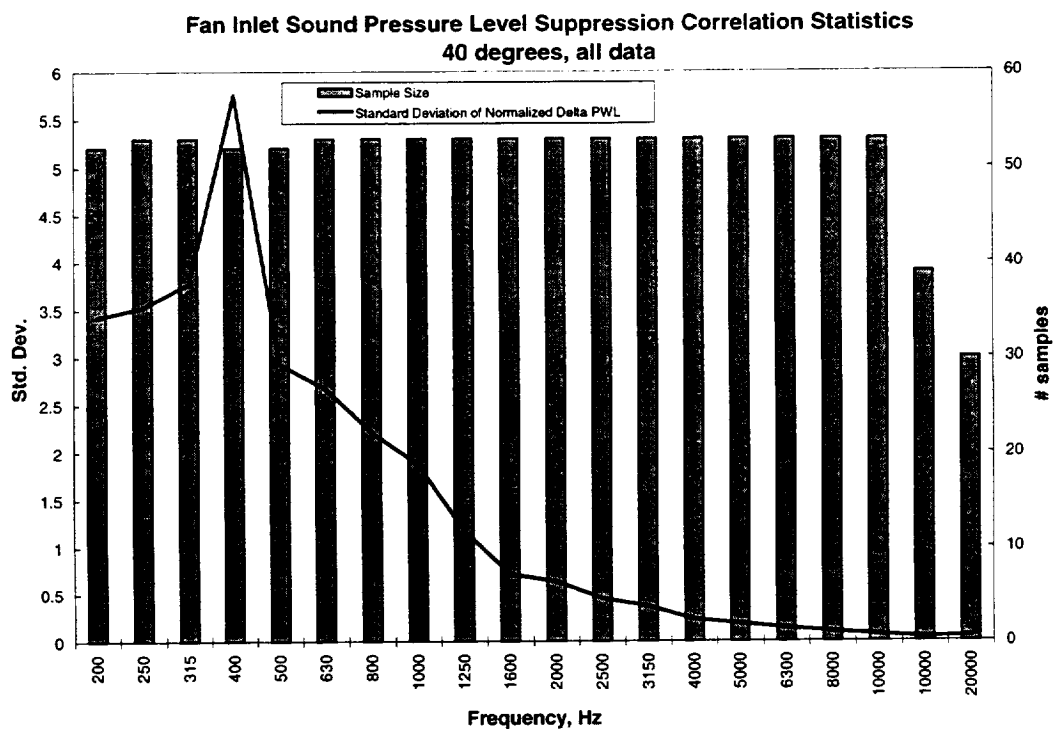


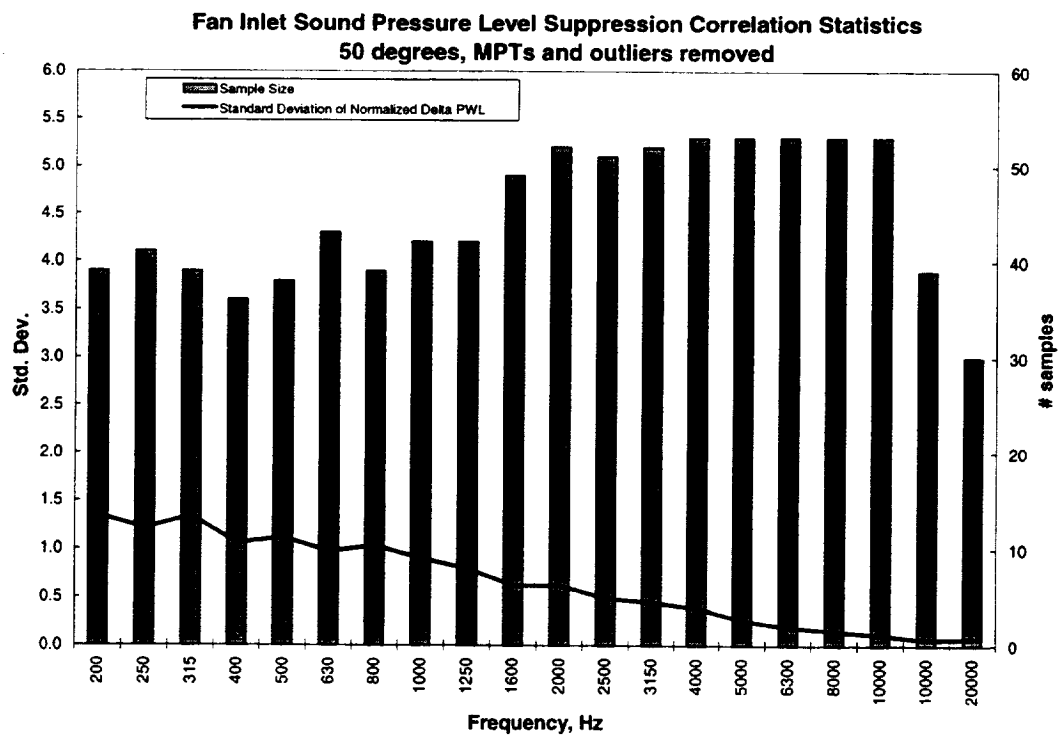
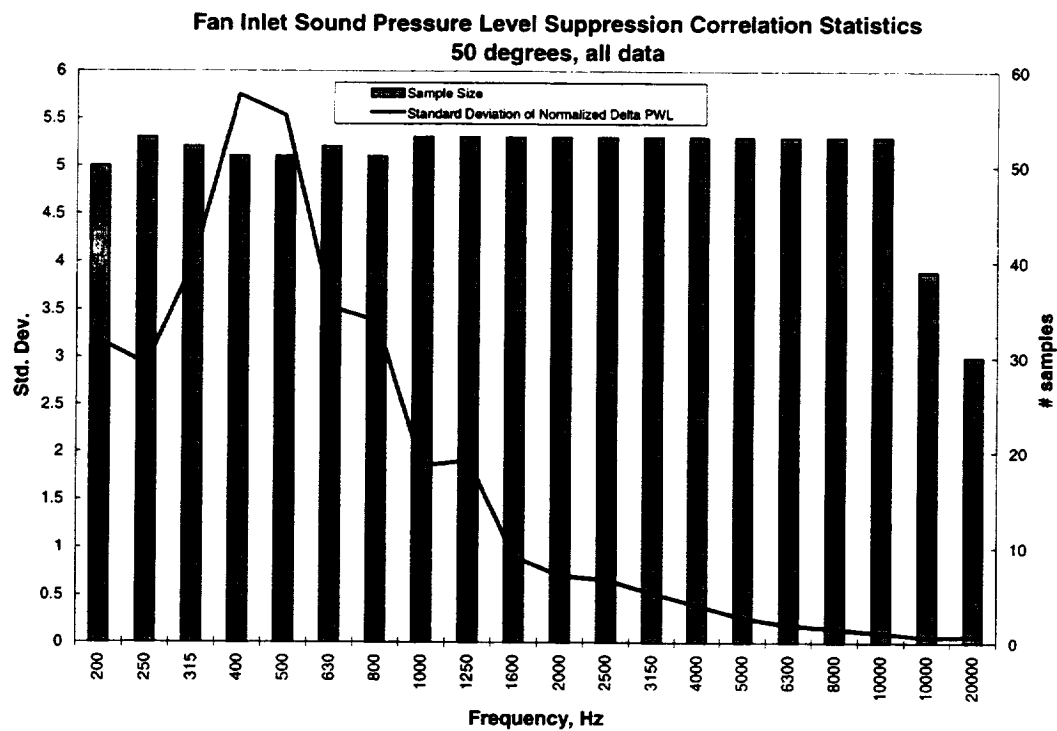
Fan Inlet Sound Pressure Level Suppression Correlation Statistics
30 degrees, all data

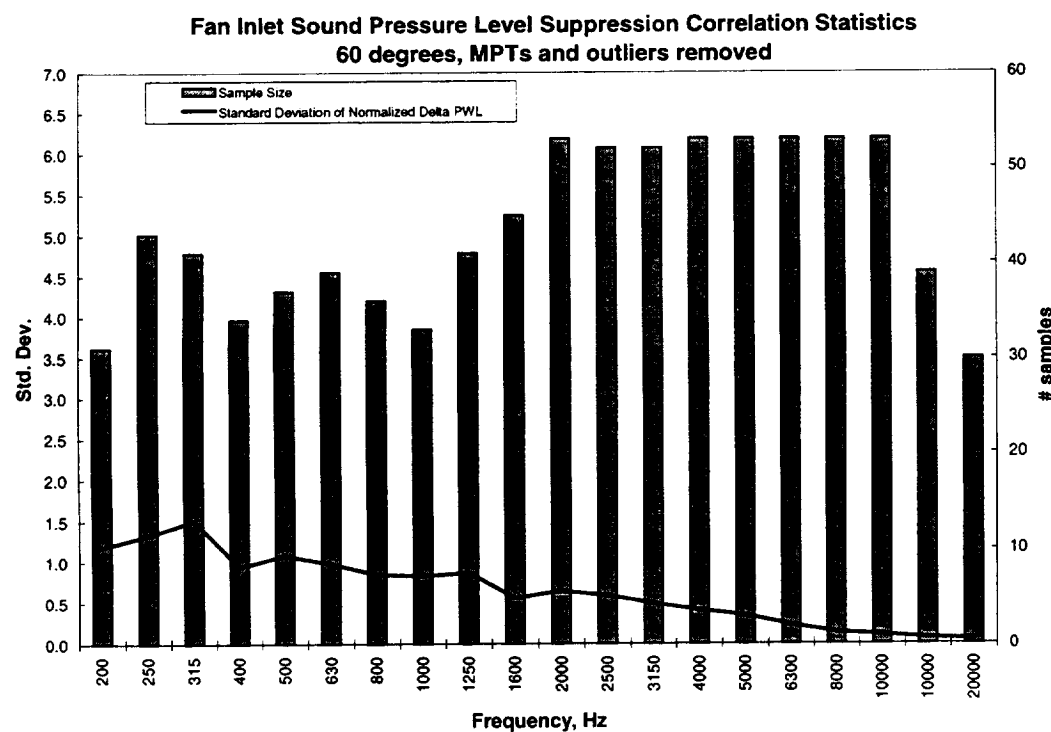
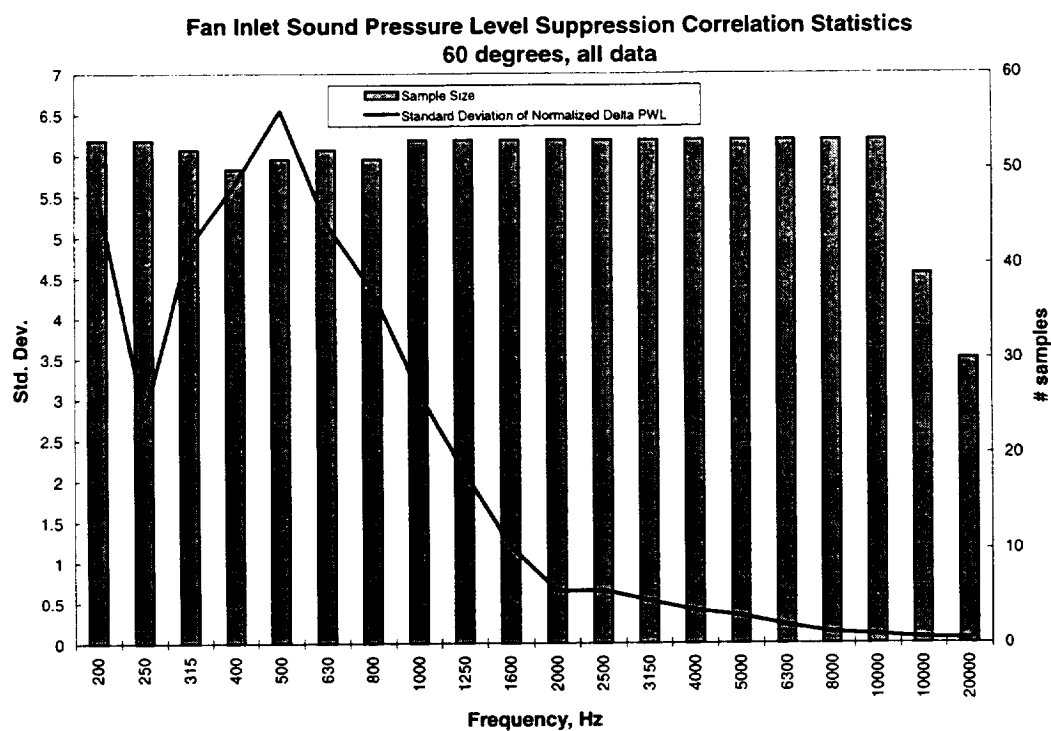


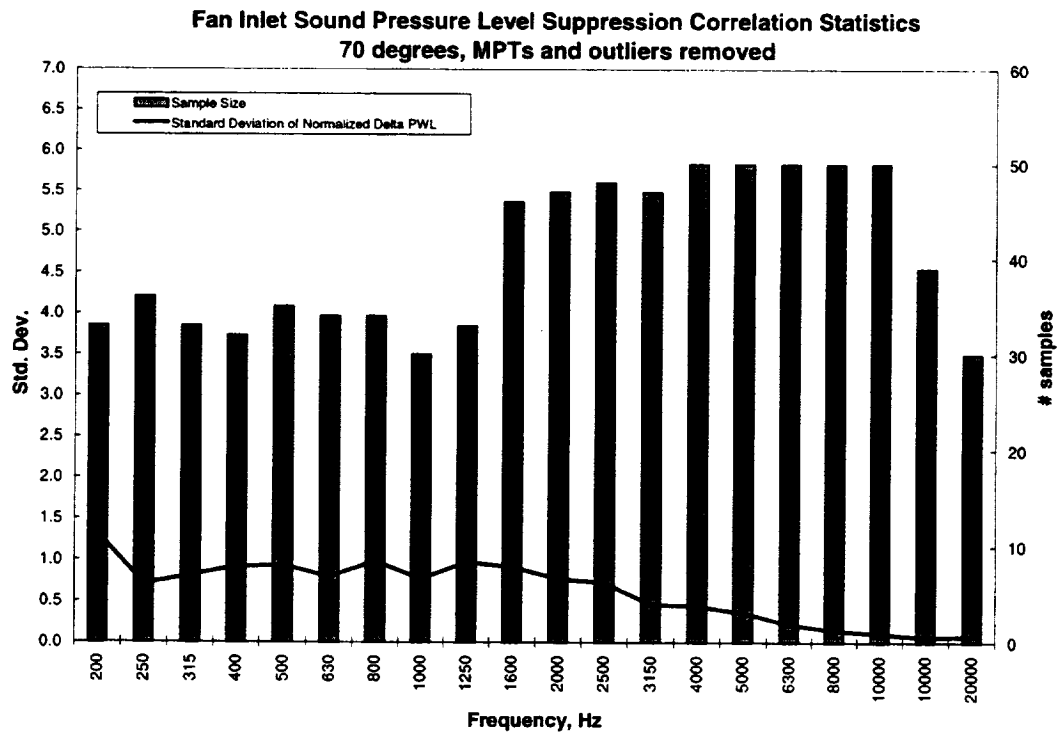
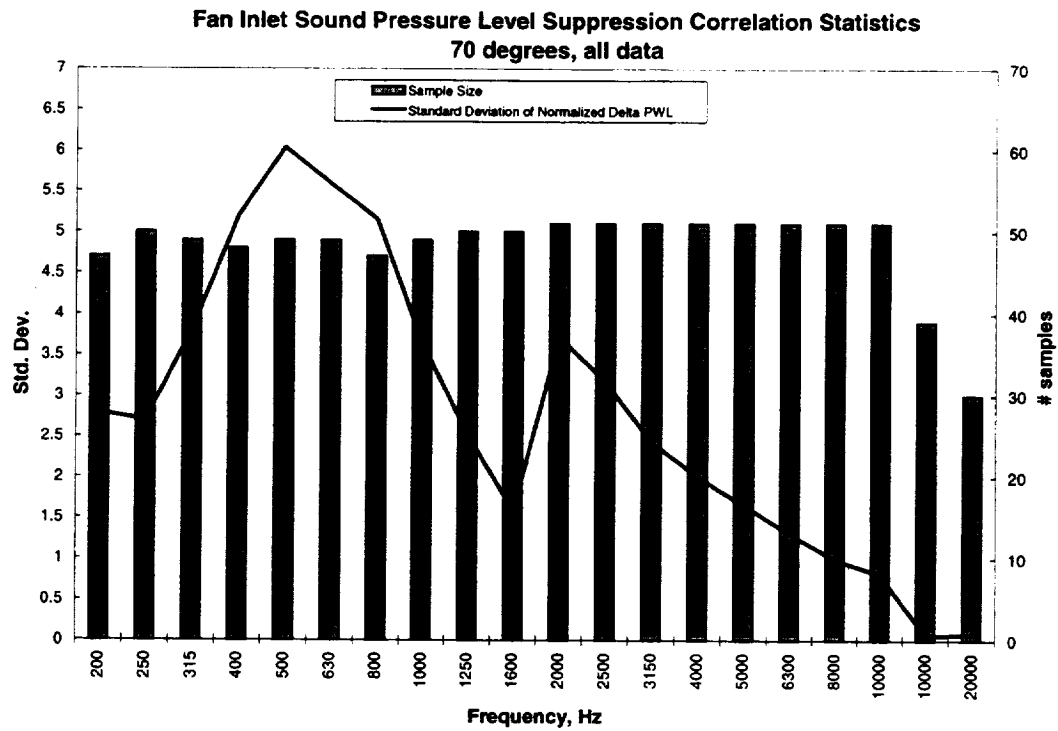
Fan Inlet Sound Pressure Level Suppression Correlation Statistics
30 degrees, MPTs and outliers removed



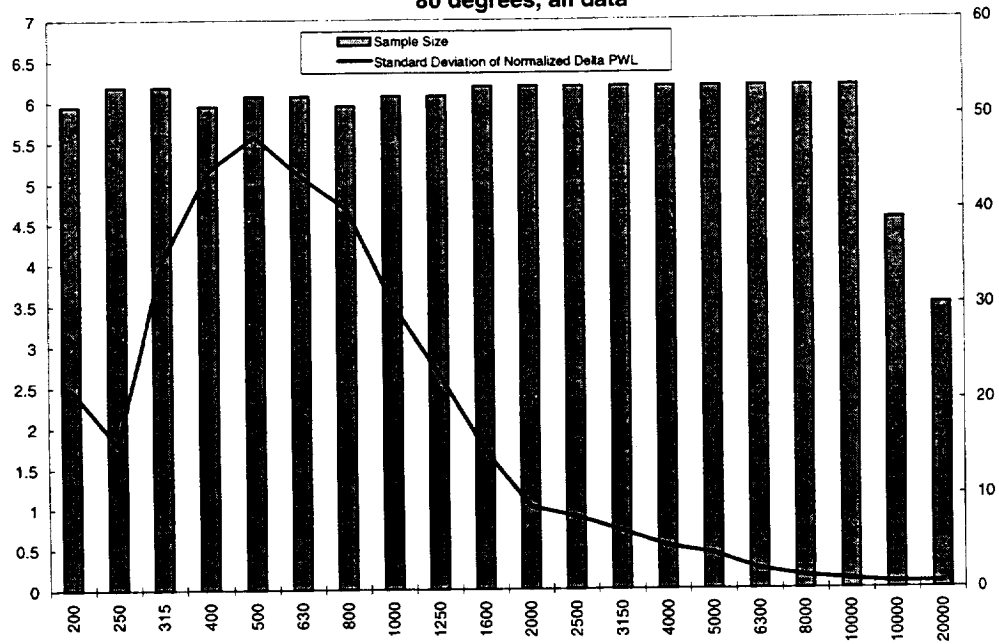




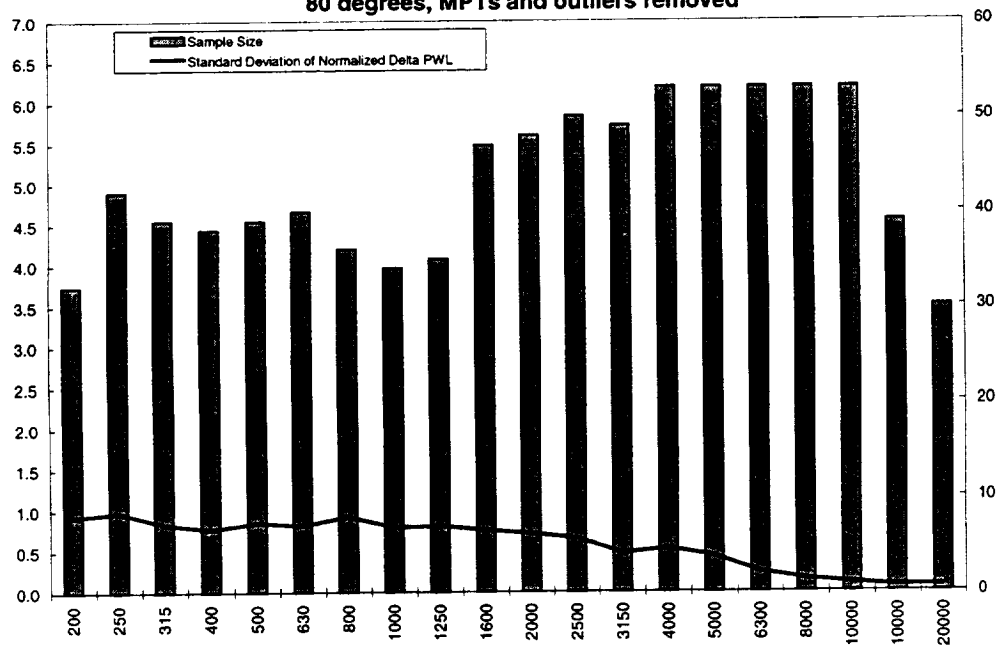


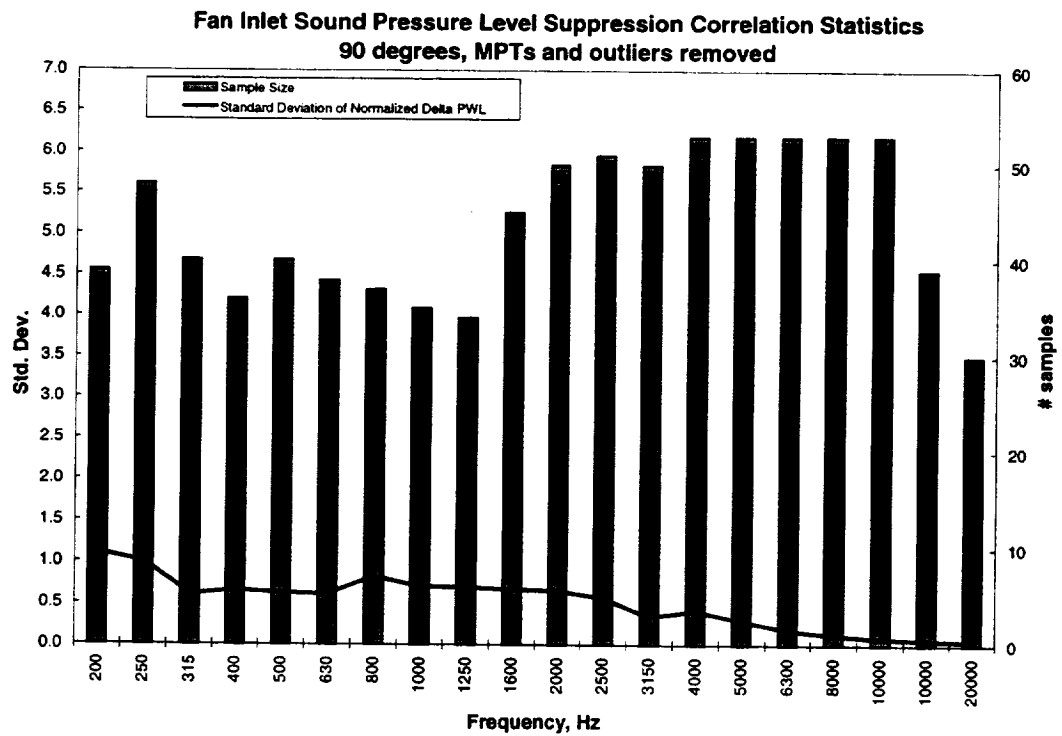
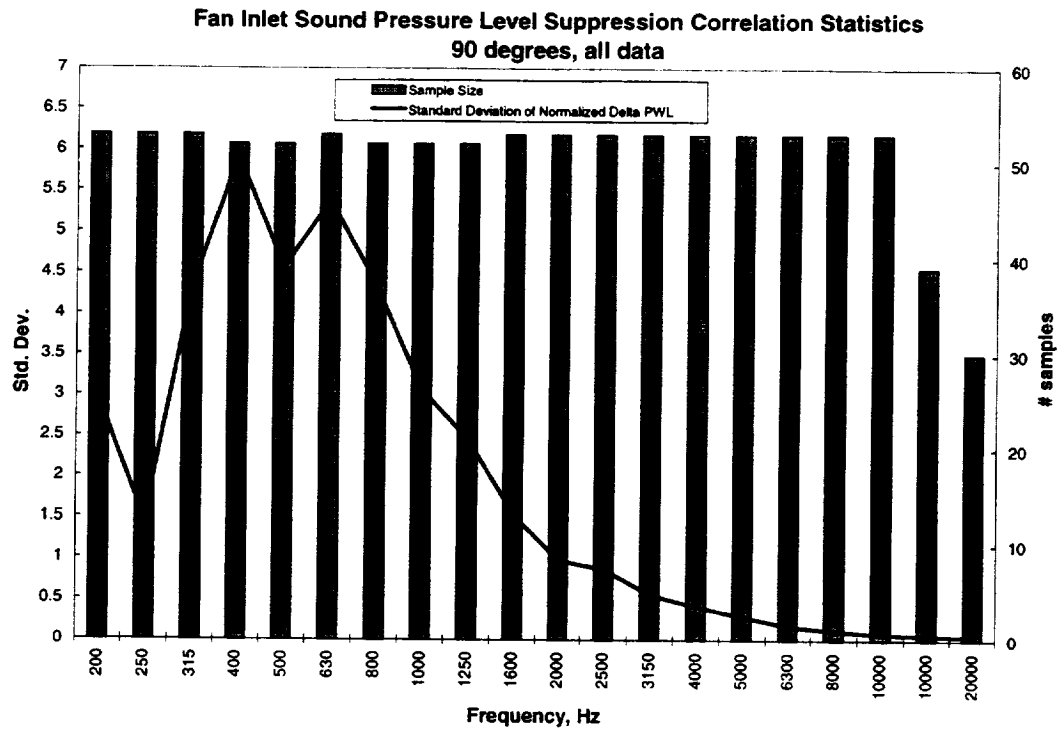


**Fan Inlet Sound Pressure Level Suppression Correlation Statistics
80 degrees, all data**



**Fan Inlet Sound Pressure Level Suppression Correlation Statistics
80 degrees, MPTs and outliers removed**

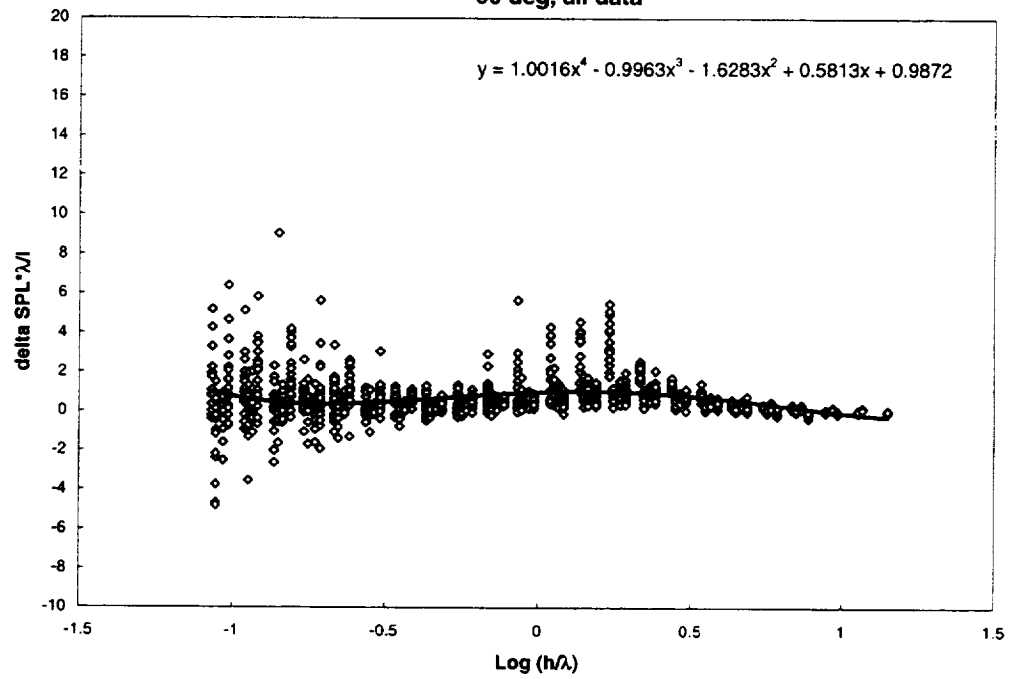




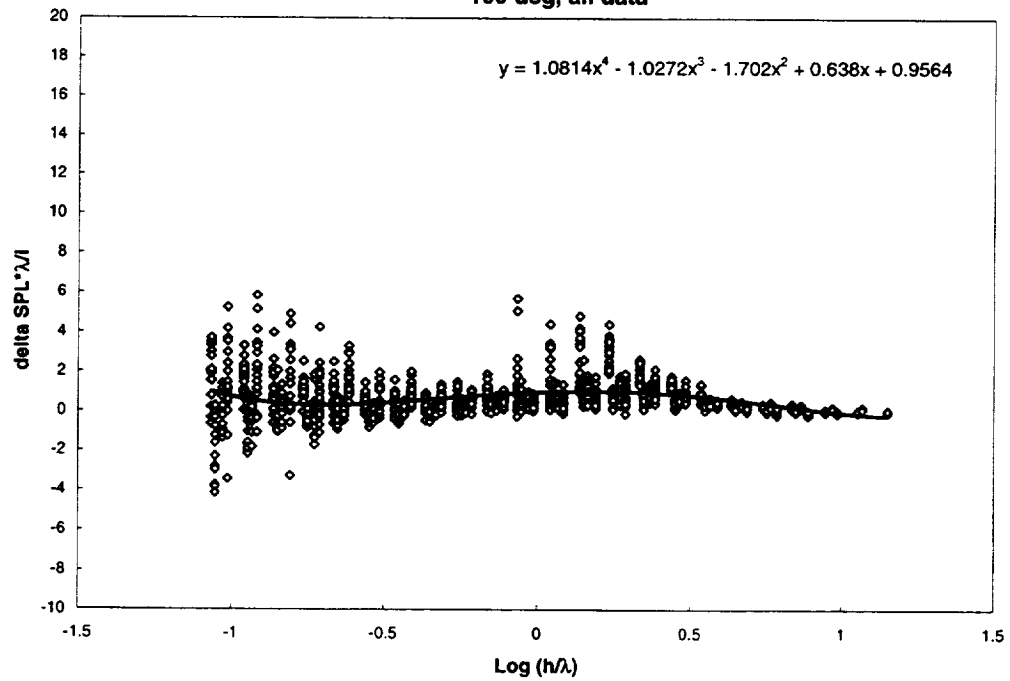
Appendix C. Fan Exhaust SPL Suppression Correlation, all data

Angle, °	Page
90	58
100	58
110	59
120	59
130	60
140	60
150	61
160	61

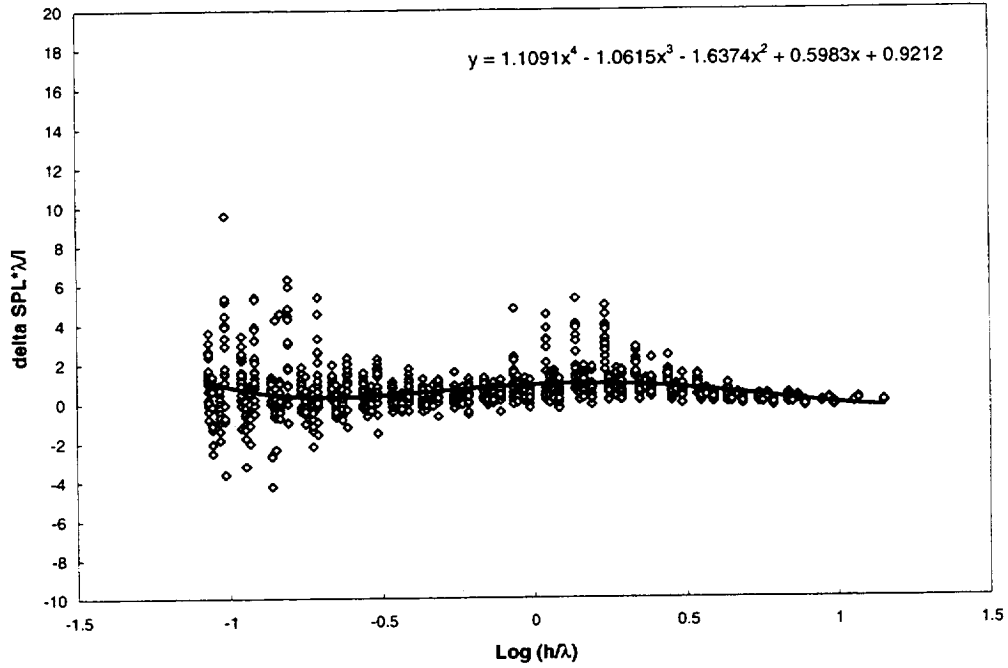
Fan Exhaust Suppression SPL Correlation
90 deg, all data



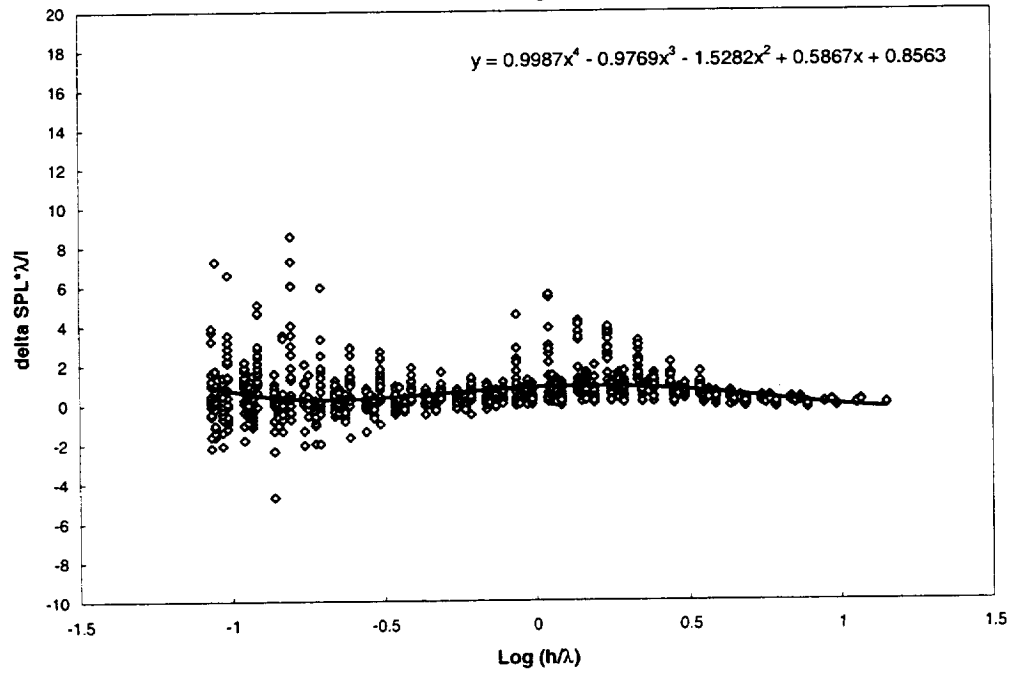
Fan Exhaust Suppression SPL Correlation
100 deg, all data



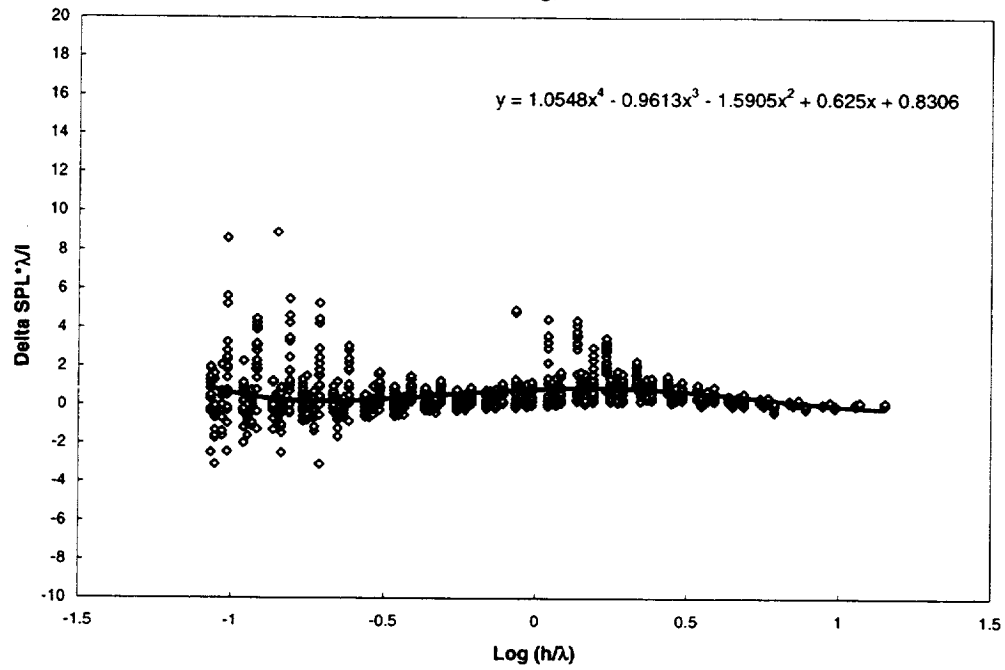
Fan Exhaust Suppression SPL Correlation
110 deg, all data



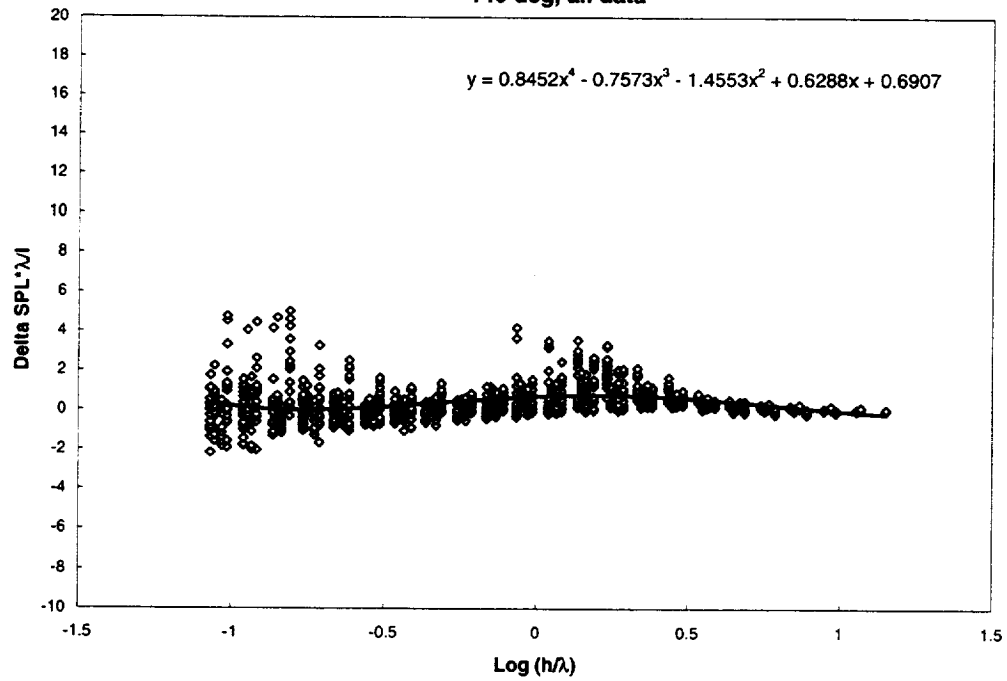
Fan Exhaust Suppression SPL Correlation
120 deg, all data



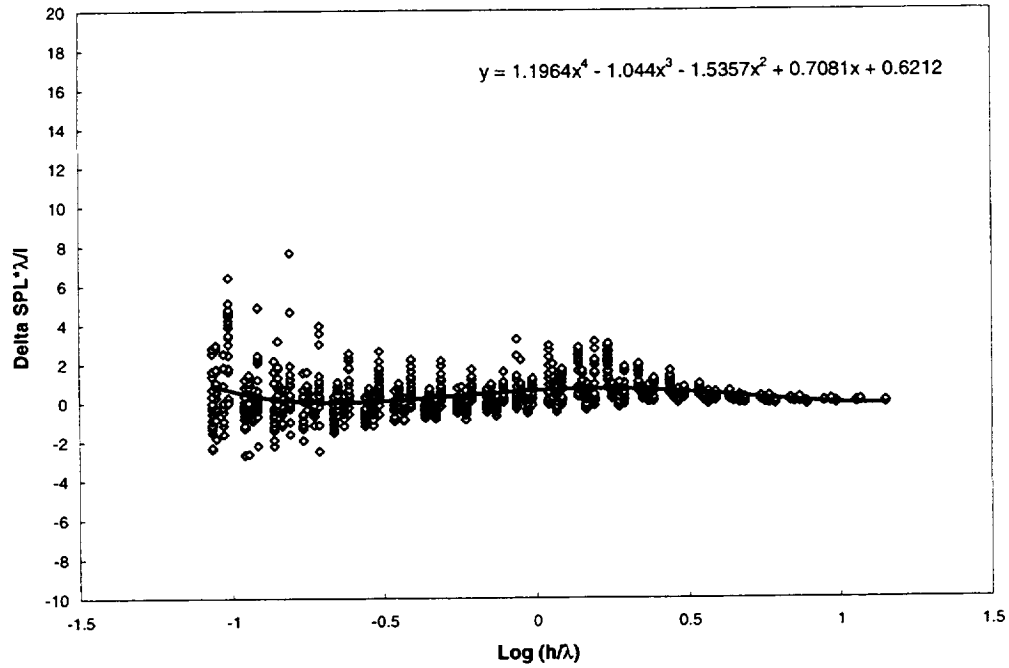
Fan Exhaust Suppression SPL Correlation
130 deg, all data



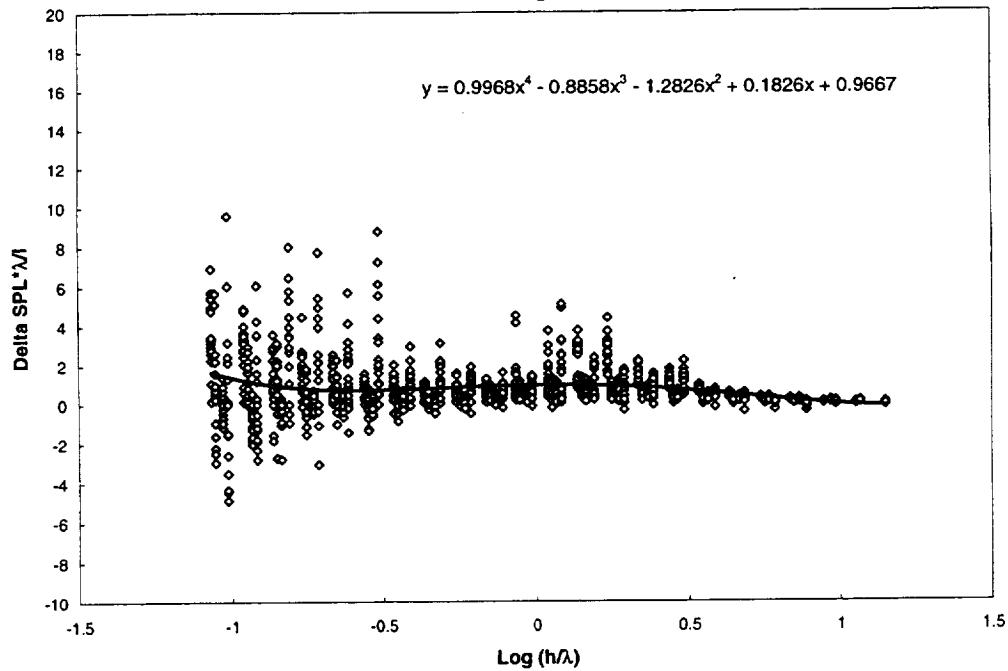
Fan Exhaust Suppression SPL Correlation
140 deg, all data



Fan Exhaust Suppression SPL Correlation
150 deg, all data



Fan Exhaust Suppression SPL Correlation
160 deg, all data

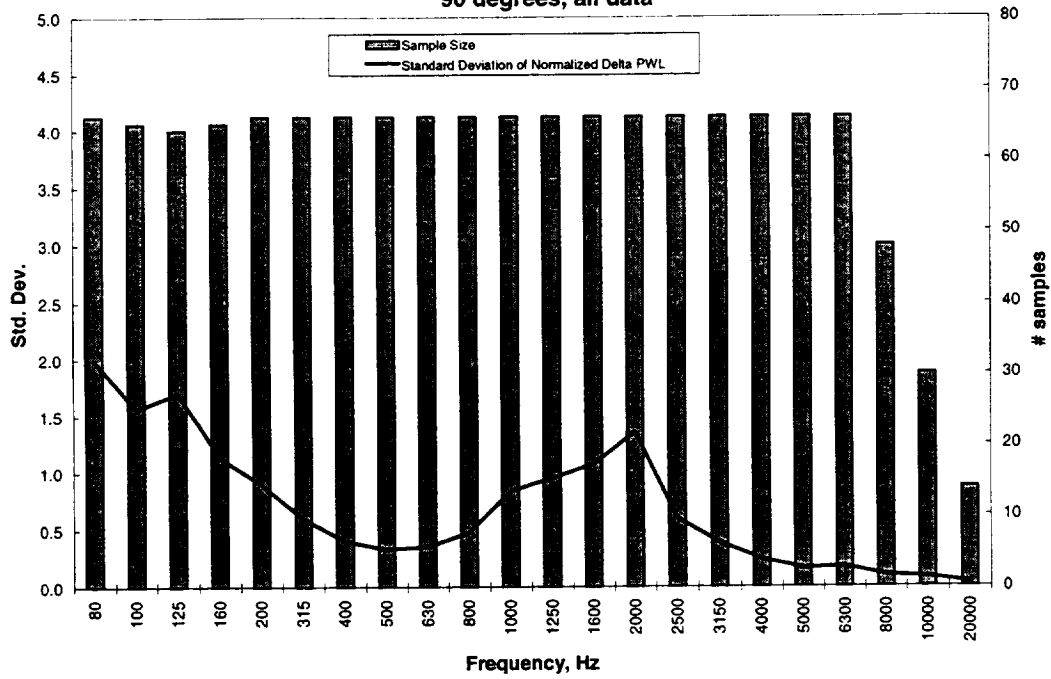


Appendix D. Fan Exhaust SPL Correlation Statistics

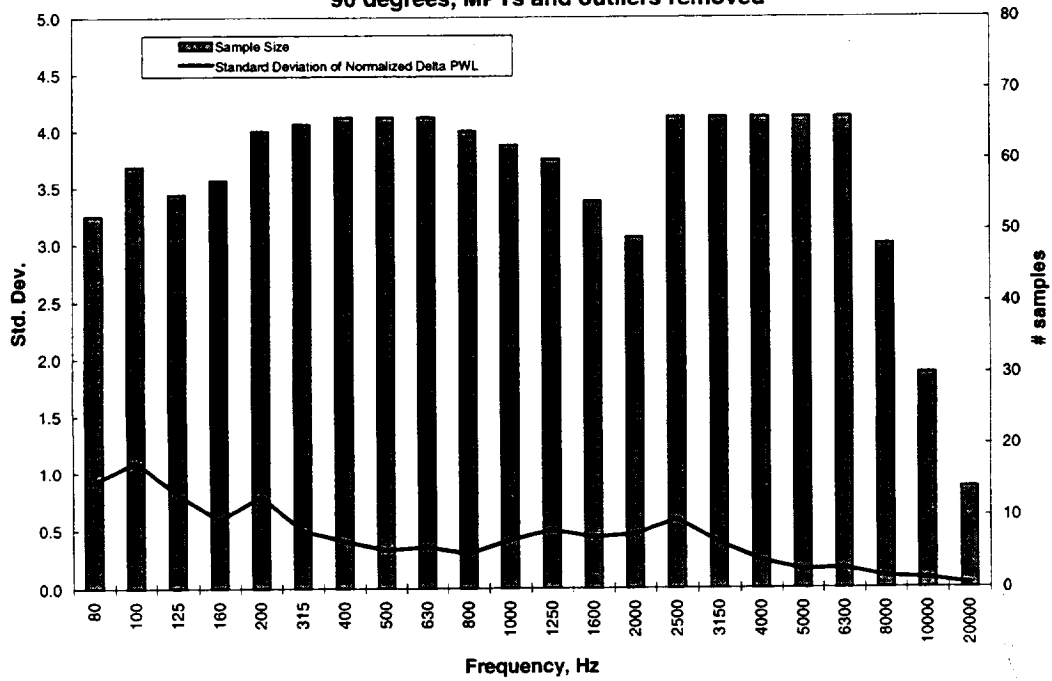
Angle, °	Page
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100	64
110	65
120	66
130	67
140	68
150	69
160	70

.

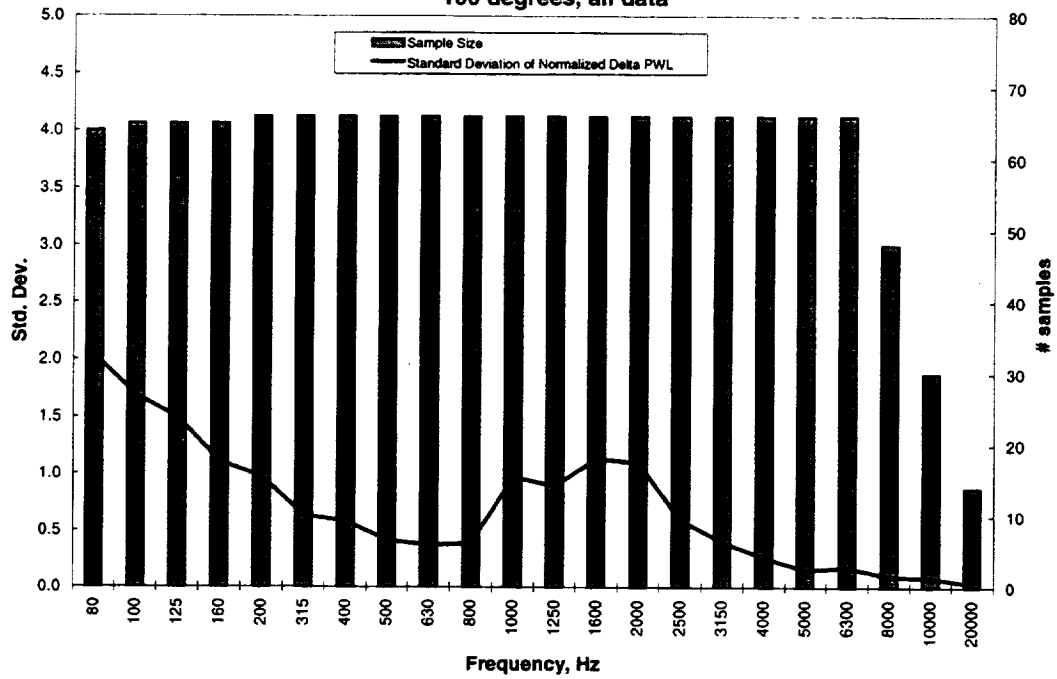
Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
90 degrees, all data



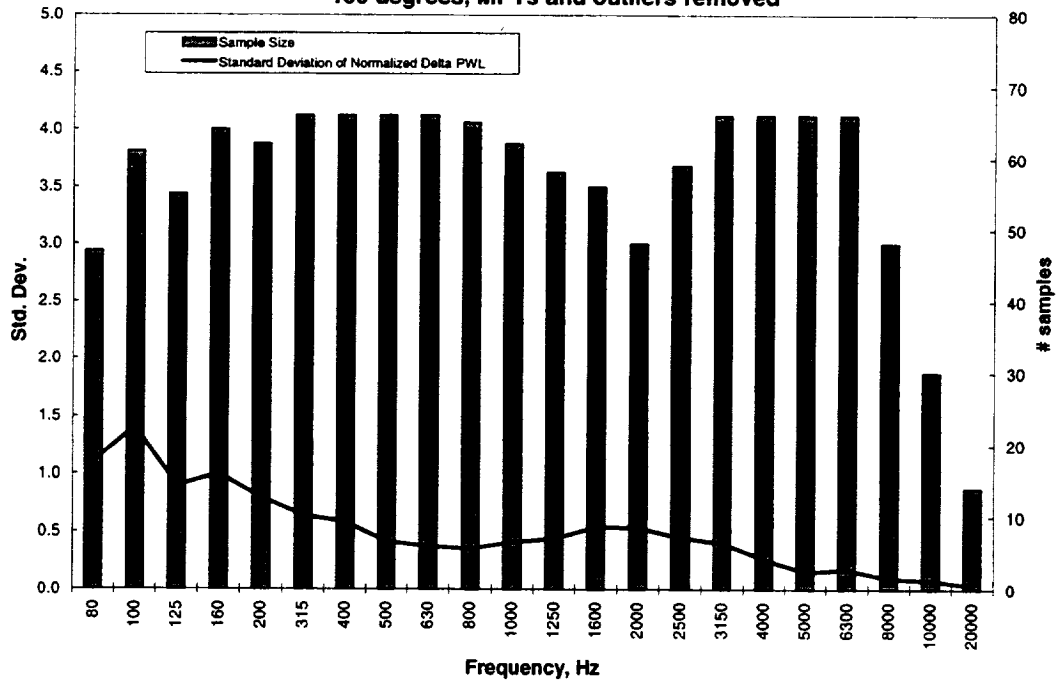
Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
90 degrees, MPTs and outliers removed



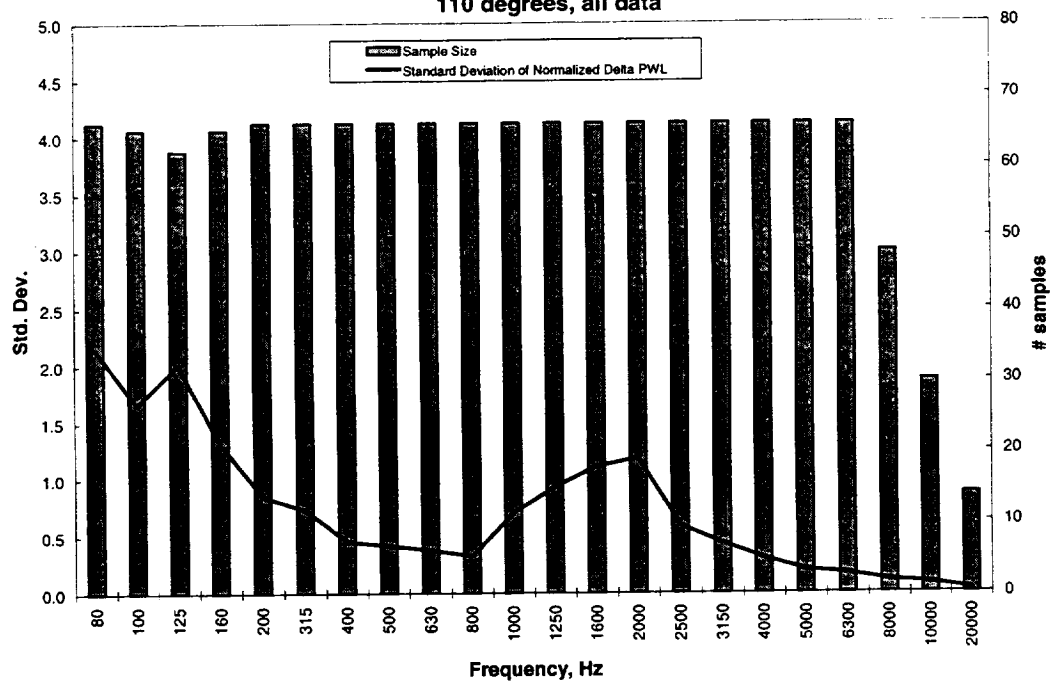
Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
100 degrees, all data



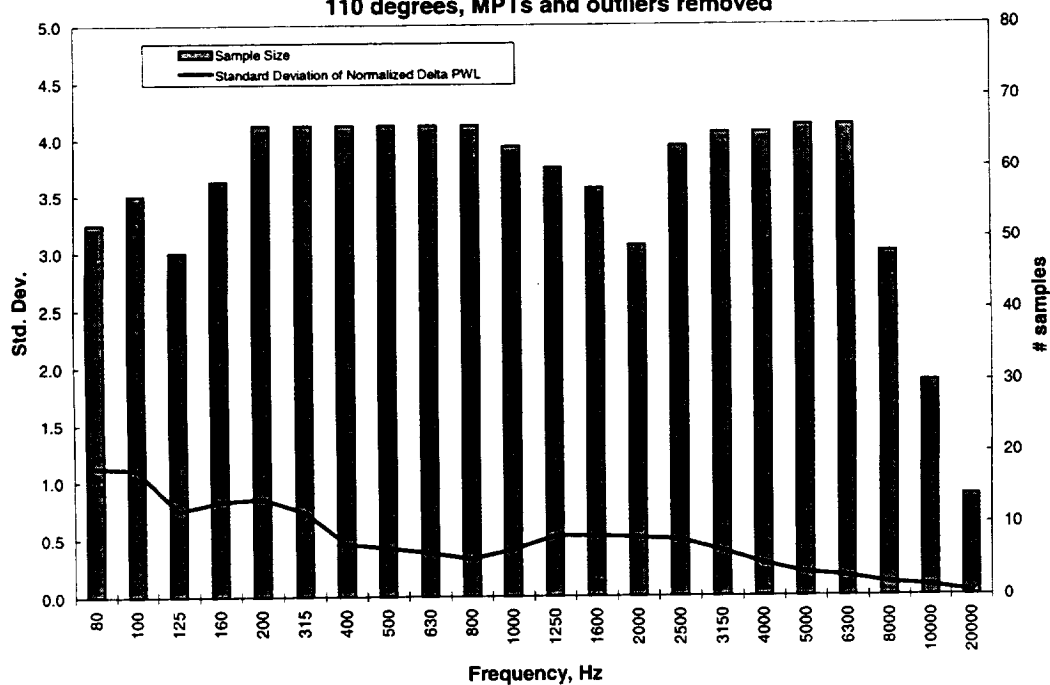
Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
100 degrees, MPTs and outliers removed



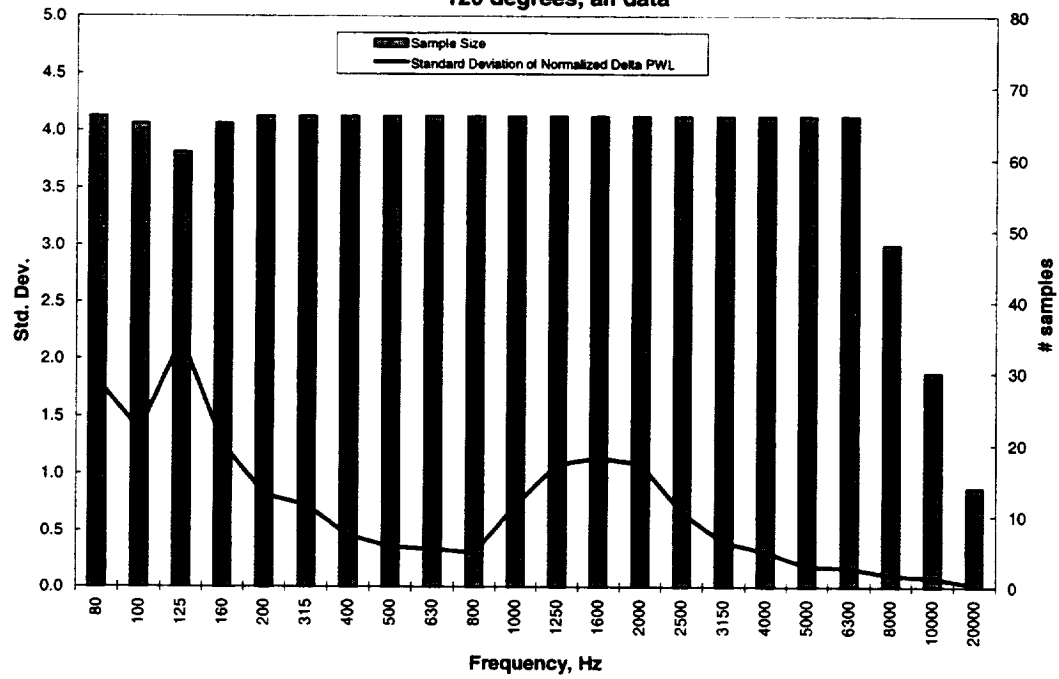
Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
110 degrees, all data



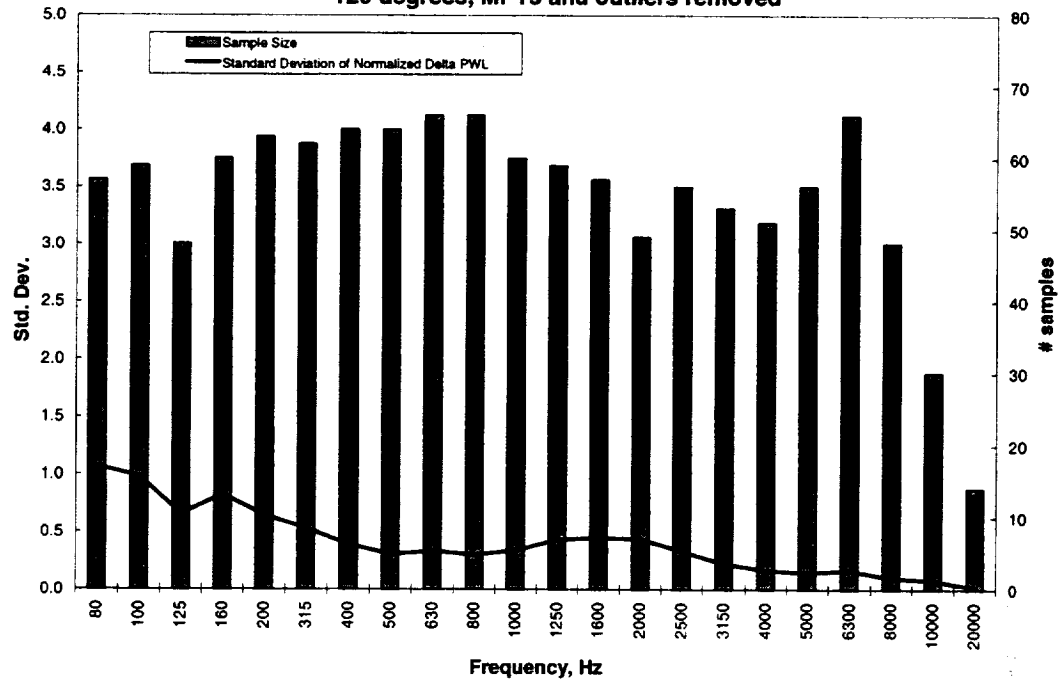
Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
110 degrees, MPTs and outliers removed



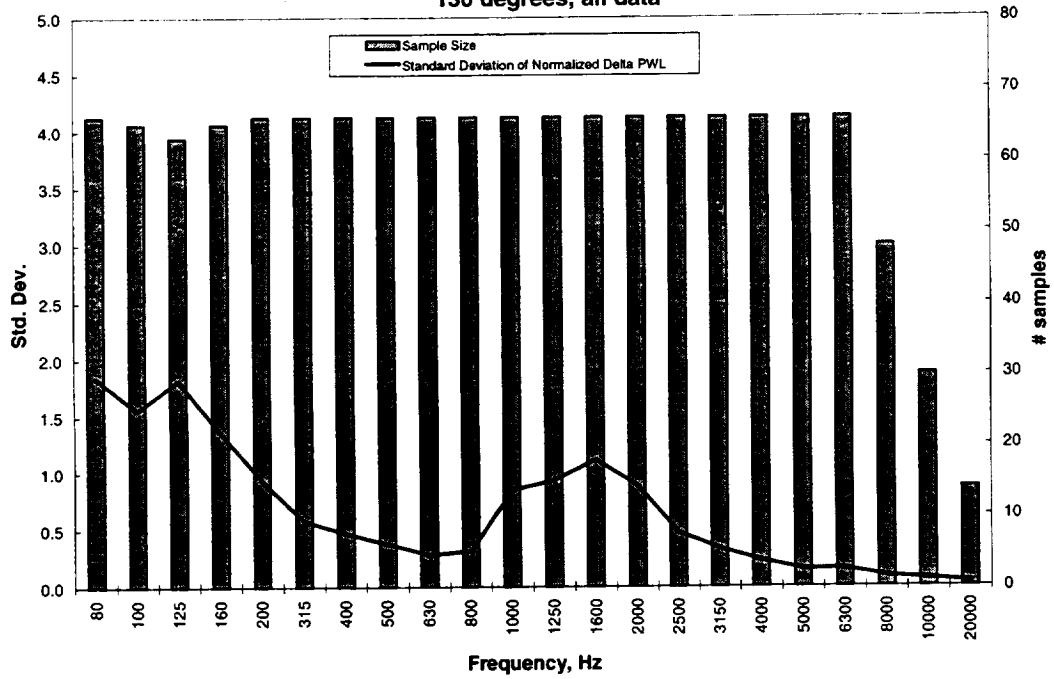
Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
120 degrees, all data



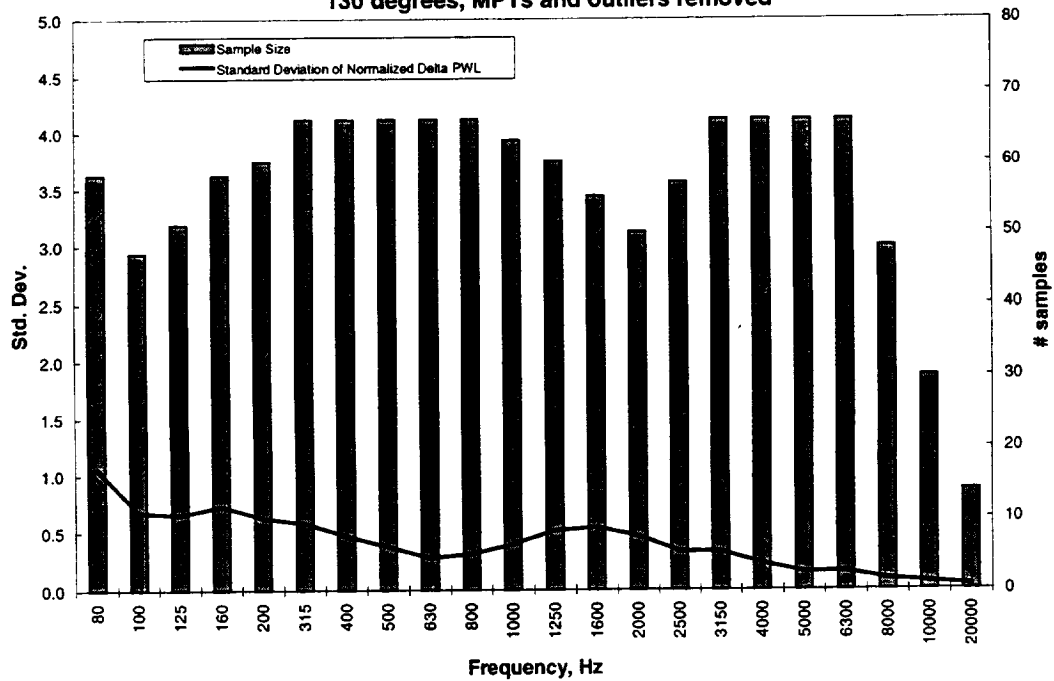
Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
120 degrees, MPTs and outliers removed



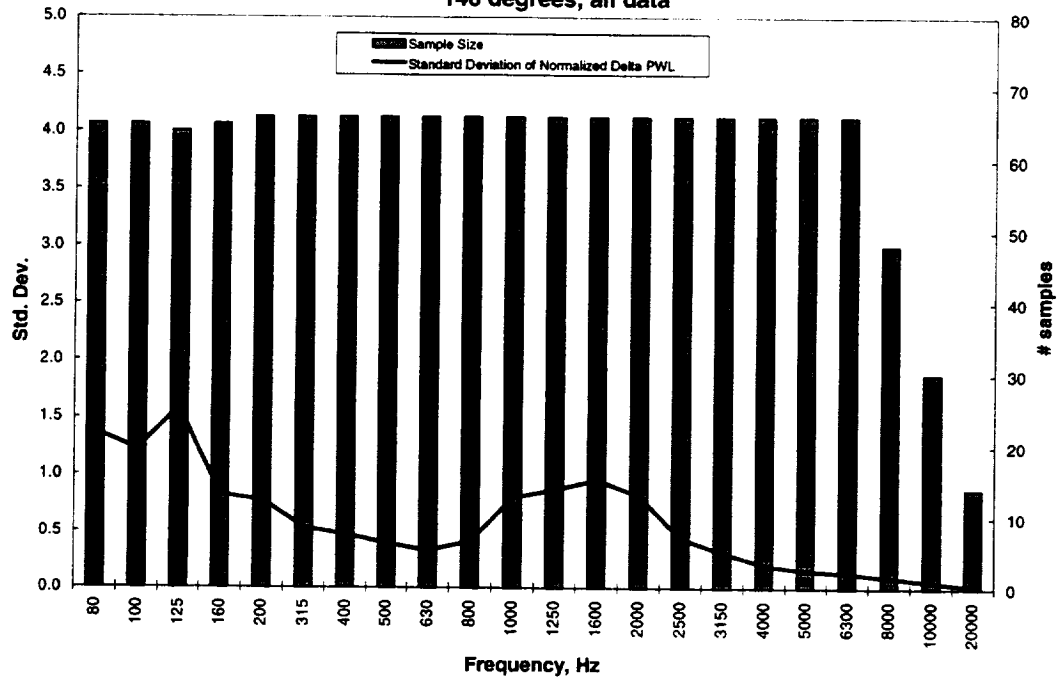
**Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
130 degrees, all data**



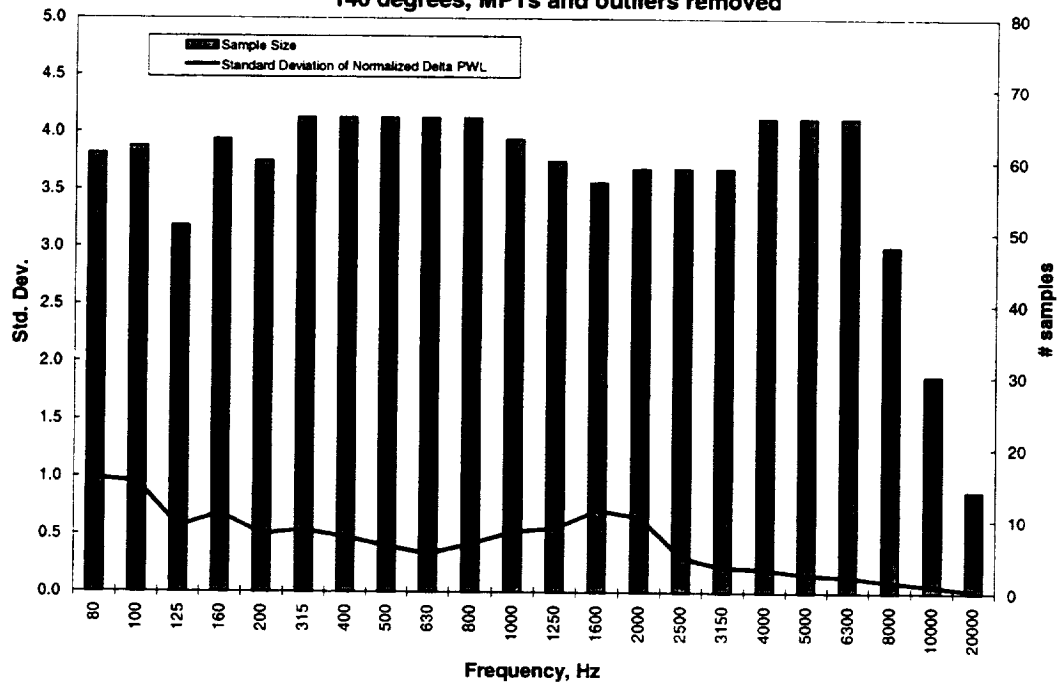
**Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
130 degrees, MPTs and outliers removed**



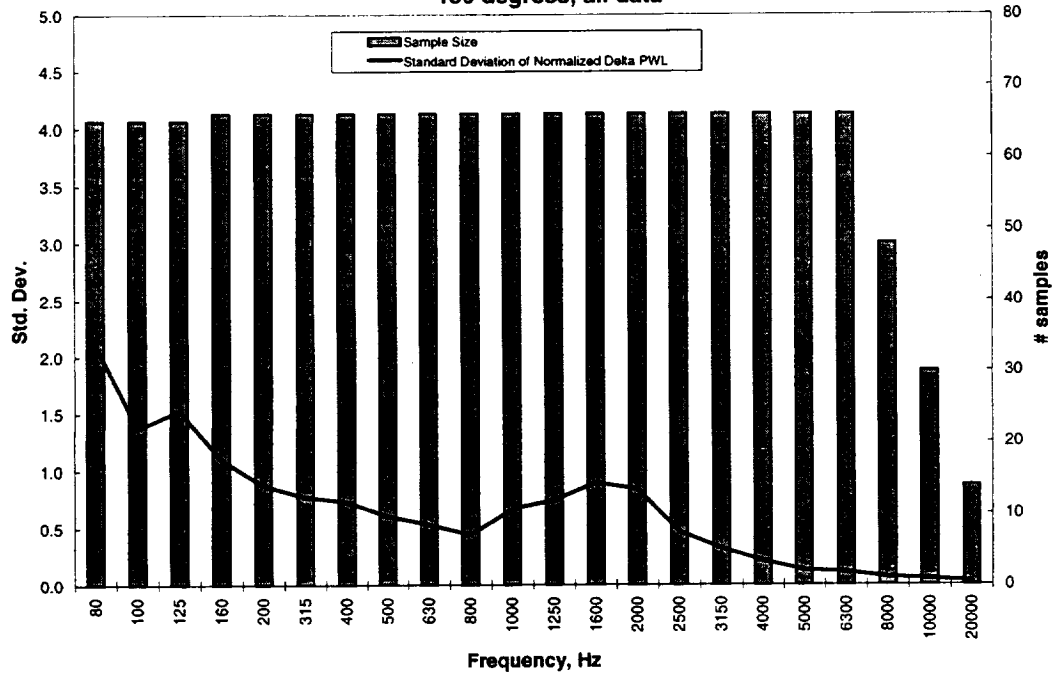
**Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
140 degrees, all data**



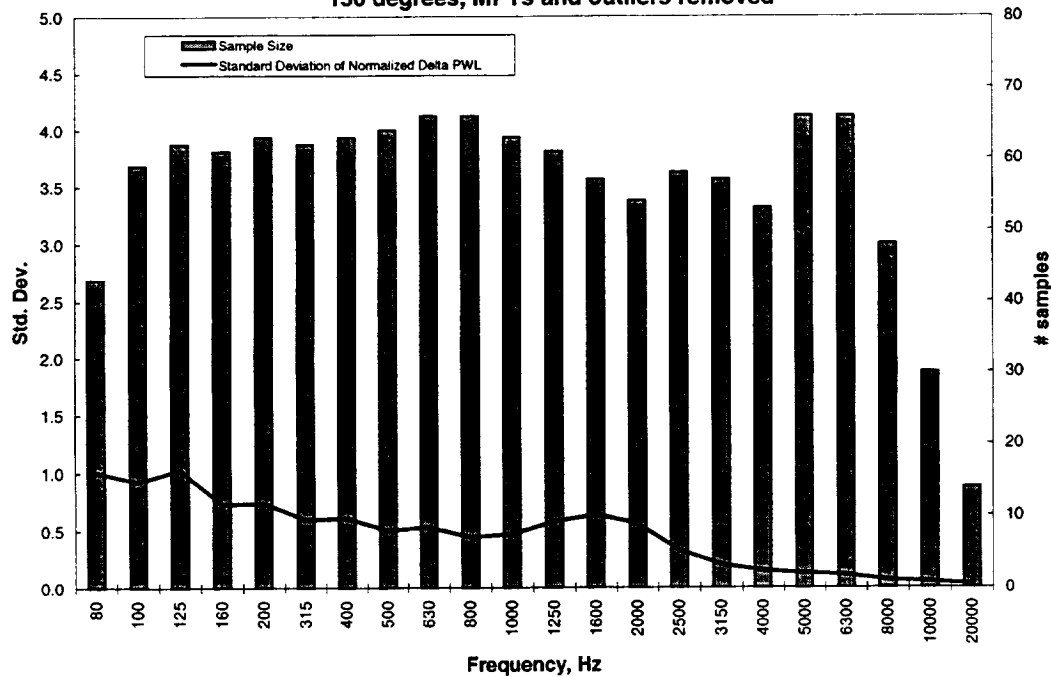
**Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
140 degrees, MPTs and outliers removed**



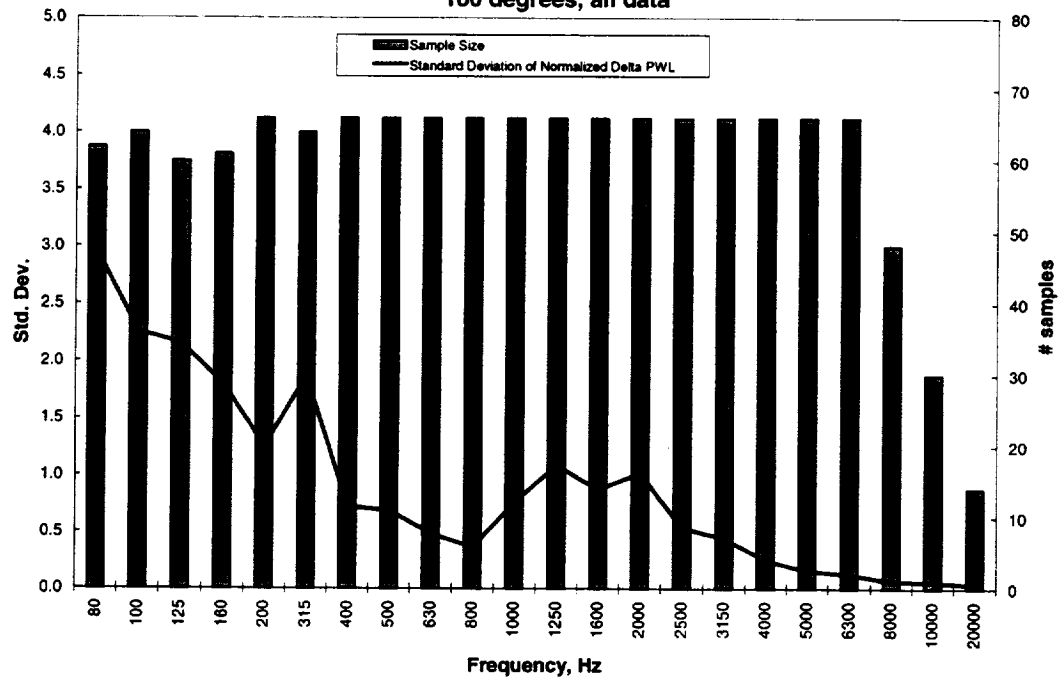
Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
150 degrees, all data



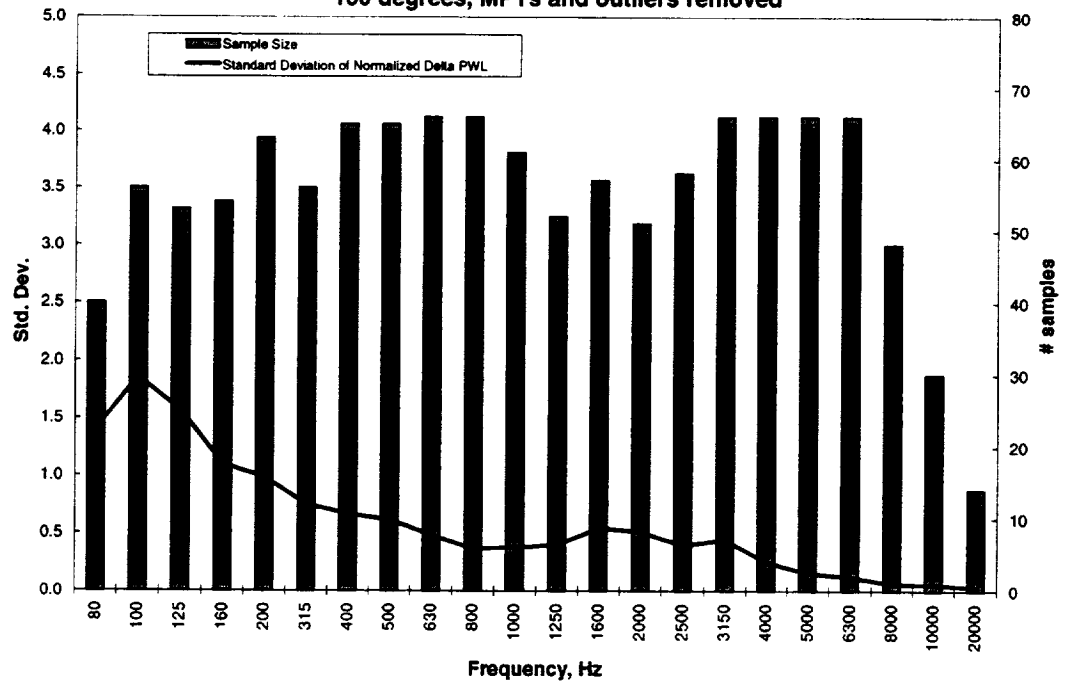
Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
150 degrees, MPTs and outliers removed



Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
160 degrees, all data



Fan Exhaust Sound Pressure Level Suppression Correlation Statistics
160 degrees, MPTs and outliers removed



6.0 References

Heidmann, Marcus F.: Interim Prediction Method for Fan and Compressor Source Noise, NASA TM X-71763, 1979.

Kontos, K. B., Janardan, B. A., and Gliebe, P. R.: Improved NASA-ANOPP Noise Prediction Computer Code for Advanced Subsonic Propulsion Systems, Volume 1 -- ANOPP Evaluation and Fan Noise Model Improvement, NASA CR 195480, 1996.

Meyer, Stuart L.: Data Analysis for Scientists and Engineers, John Wiley & Sons, New York, 1975.

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) General Electric Aircraft Engines P.O. Box 156301 Cincinnati, Ohio 45215-6301		8. PERFORMING ORGANIZATION REPORT NUMBER E-10595		
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13. ABSTRACT (Maximum 200 words) ANOPP (Aircraft Noise Predication Program) is an industry-wide tool used to predict turbofan engine flyover noise in system noise optimization studies. Its goal is to provide the best currently available methods for source noise prediction. As part of a program to improve the Heidmann fan noise model, models for fan inlet and fan exhaust noise suppression estimation that are based on simple engine and acoustic geometry inputs have been developed. The models can be used to predict sound power level suppression and sound pressure level suppression at a position specified relative to the engine inlet.				
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