Enclosure 1

Exelon Report AM-2005-12, "An Assessment of the Uncertainty in the Application of the Modified 930 MWe Acoustic Circuit Model Predictions for the Replacement Quad Cities Units 1 and 2 Steam Dryers," Revision 1

An Assessment of the Uncertainty in the Application of the Modified 930 MWe Acoustic Circuit Model Predictions for the Replacement Quad Cities Units 1 and 2 Steam Dryers

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Revision 1

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Abstract

This report documents the evaluation of uncertainties associated with the use of the Modified 930 MWe Acoustic Circuit Model (ACM) to predict time histories for the application of unsteady loads to the Quad Cities Units 1 and 2 Steam Dryers.

Revision 1 to this report was prepared to document uncertainty calculations for alternate cases requested. Specifically, an uncertainty based on filtering the data to exclude all frequency content except between 135 Hz and 160 Hz for the whole dryer and a specific case using only the hood mounted sensors are included. These cases supplement but do not supercede the work presented in the main body of this report. The changes associated with Revision 1 of this report are contained in their entirety in Appendix B of this report.

1. Introduction

This report documents the evaluation of the uncertainty associated with the methodology used for the prediction of time history information for application of unsteady pressure loads on the Quad Cities (QC) Units 1 and 2 steam dryers. The Continuum Dynamics, Inc. (CDI) Modified 930 MWe Acoustic Circuit Model (ACM) takes inputs from Main Steam Line (MSL) mounted strain gages and provides a detailed pressure time history for the steam volume of the reactor pressure vessel, with emphasis on the surfaces of the steam dryer. This methodology has been validated against in-plant measurements taken on the QC2 instrumented steam dryer during power ascension testing. The output of the ACM is used as input to the General Electric (GE) Finite Element Model (FEM), which is used to compute the stresses in the dryer for comparison against code allowable fatigue and stress limits.

A description of the QC2 Power Ascension Test and the associated instrumentation placement is provided in the Appendix.

Due to the complicated nature of the issue, this process has the possibility to be affected by uncertainties in a number of ways:

1) Measurement accuracy of the MSL strain gages
2) Limitations of the ACM
3) Measurement accuracy of the in-situ QC2 pressure measurements used for validation of the ACM
4) Accuracy of the ACM itself

This report examines the individual components of uncertainty, then develops a recommendation for the treatment of uncertainty in the integrated application, exclusive of the structural analysis model uncertainty (FEM). The intent is to form a basis for the QC1 and QC2 applications, as well as for future applications of this methodology for the Dresden Unit 2 and Unit 3 steam dryers.

2. Description of Uncertainties

The individual parts of the application will be discussed.

2.1 MSL Strain Gage Measurements

There are two key elements that apply to the results obtained from strain gages to determine breathing mode unsteady pressures for use in the ACM. The first concerns the ability of the strain gage to read the strain measurement correctly and the process of converting the strain measurement into a pressure term. The second involves the potential for strain gage measurements to include local pipe structural response, e.g., axial direction or pipe shell modes not related to fluctuating pressure, in addition to the breathing mode response. The second item was discussed in detail in Reference 6, with the conclusion being that strain gage failures lead to increased conservatism in the load predictions, both in frequency content and amplitude.

2.1.1 Strain Gage Measurement Accuracy

The MSL pipe strain gage measurement uncertainty is composed of two major components. These are the instrumentation, cabling and data acquisition response and the conversion of hoop strain to pressure, i.e., the wall thickness of the pipe. To minimize uncertainty and yield the most accurate predictions possible, ultrasonic wall thickness measurements were made of the QC1 and QC2 MSLs at the strain gage locations. Reference 1 provides an assessment of the strain gage measurement accuracy. A value of +/-5.03% was determined to be the accuracy of the strain gage measurements.

In Reference 2, the error in strain gage readings was applied to the eight sets of strain gage data used to develop the unsteady pressure input into the ACM. The changes in pressure in the four dryer pressure transducers closest to the steam line nozzles was then computed to determine the uncertainty in the minimum error ACM predictions due to strain gage uncertainty. The pressure predictions were determined to be accurate to within +/-3.6%. This work was not repeated for the Modified 930 MWe ACM. While it can be expected that the model uncertainty would be comparable, it is conservative to apply a +/-5.03% strain gage uncertainty term directly.

2.2 Limitations of the ACM

It has been noted that the ACM underpredicts loads below approximately 18 Hz. This is largely a function of the spacing of the MSL strain gage pairs and the ability to discriminate long wavelength low frequency acoustic waves.

The strain gages are located at 651' and 621' elevation on the QC2 MSLs. If a quarter wave spans both detection points, it can be expected that signal discrimination will be affected. With a spacing of 30 feet and nominal acoustic speed of 1600 fps, a quarter wavelength associated with this distance yields a frequency of approximately 13.3 Hz. Review of ACM prediction data suggests a loss of low frequency signal prediction at 18 Hz or less, which is consistent with expectations. It should be noted that the phenomena described here is dependent primarily on the strain gage placement, and is not a function of any particular version of the ACM being used.

A reasonable way to determine the effect of omission of the low frequency load content is to separate out the low frequency signal content from the measured pressure data on the QC2 dryer and compare the effects on the RMS and peak pressures observed. This can be accomplished using a digital filtering operation on the FFT of the pressure time history and then recreating the time history minus the selected frequency components. The QC2 dryer pressure sensors are charge sensitive piezoelectric pressure transducers that have a flat frequency response between 2 Hz and 1000 Hz, which is consistent with the application under consideration.

This approach was applied for QC2 TC-41 data (at a 930MWe/2884 MWt condition) for the 4 pressure sensor locations nearest the steam line nozzles (P-3, P-12, P-20, and P-21). The digital filter was set to remove frequency components from 0 to 20 Hz. The RMS and peak pressures were then computed for comparison, and are presented in the included table. As a check of the fidelity of the FFT process, an unfiltered transform was inverted back to the time domain and its statistics compared to the actual time history. Agreement in RMS and peak pressures was achieved out to 6 significant figures. Similar response is expected from the other dryer pressure sensor locations.

The results of this comparison support a conclusion that the loads omitted by the ACM in the 0-20 Hz range are negligible. The change in RMS pressure is less than 0.4% with the average of the change for the four sensors being 0.254%. The change in peak pressures is less than 3% at most. Therefore, use of a bias term in the uncertainty analysis of 3% would conservatively bound the loss of 0-20 Hz loading components.

Table 1 Contribution of 0-20 Hz Components to Total Load, QC2 TC-41

Sensor	*RMS pressure psi/ (% of total)*	*Min pressure psi/ (% of total)*	*Max pressure psi/ (% of total)*
P-3 Base	0.6503	-1.9535	1.8748
P-3 minus 0-20Hz components	0.6488 (0.2307%)	-1.9346 (0.9675%)	1.8767 (0.1013%)
P-12 Base	0.7143	-2.1562	1.936
P-12 minus 0-20Hz components	0.7128 (0.21%)	-2.1934 (-1.696%)	1.9655 (-1.524%)
P-20 Base	0.5029	-1.707	1.7529
P-20 minus 0-20Hz components	0.5009 (0.397%)	-1.6964 (0.621%)	1.7101 (2.442%)
P-21 Base	0.8883	-2.3669	2.26
P-21 minus 0-20Hz components	0.8867 (0.18%)	-2.3618 (0.2155%)	2.1965 (2.8097%)

2.3 QC2 Steam Dryer Pressure Measurement Uncertainty

The uncertainty in dryer pressure measurements consists of two components. The first is the instrument accuracy and calibration results. The second is due to phenomenological effects that may induce error into the steam dryer-mounted pressure instruments.

2.3.1 Instrument Accuracy

Reference 3 provides a detailed discussion of the expected instrument accuracy based on vendor supplied data and calibration results. The testing used two pressure instrument types with differing ranges for each. Two of the instruments used a larger range and had a slightly higher absolute error. The remaining 25 were of a smaller range and had a lower absolute error. The instrument accuracy is developed for both and yields a 3.9% absolute measurement uncertainty and a 2.9% relative measurement uncertainty for the limiting sensor. The relative measurement uncertainty is the most appropriate value to apply for this assessment, since variations from the mean are of interest, rather than the absolute maximum values.

2.3.2 Phenomenological Considerations

There are phenomenological considerations that are salient to the unsteady pressure measurements taken on the QC2 steam dryer. These include:

1) The effects of dome-mounted versus flush-mounted pressure transducers, with respect to measurement of incident acoustic pressure oscillations.
2) The potential for the nozzle entry vortices to induce unsteady velocity fields on the sensors nearest the nozzles.

Item 1 was the subject of considerable analytical work, as well as confirmatory testing in a wind tunnel. The results of this work are contained in Reference 4. There were two important conclusions of this work:

a) The dome-mounted sensors will tend to overpredict the pressures by 3-8%. No correction was recommended in the test data reduction since the overprediction is conservative in application to structural analysis considerations. This will yield a 3% conservative bias.
b) The sensor domes had an extremely low sound signature as determined by wind tunnel testing. Therefore, the sensor domes could reasonably be expected to yield appropriate frequency content, unaltered by bluff body acoustic noise from the housing. It was also determined that downstream

sensors would not be affected by vortex shedding from upstream sensor mounts.

For item 2, following review of the data collected on QC2, it was determined that there was no evidence of vortex–induced unsteady components in the dryer pressure sensor responses opposite the MS nozzles, and therefore no additional factors were warranted. (Reference 6)

2.4 Uncertainty Associated with the ACM

The validation of the ACM has been performed against QC2 in-vessel measurements. The initial efforts were directed at comparison predictions to measurements at six dryer pressure sensor locations. Two blind benchmark tests were performed and subsequent model adjustments were made. The resultant model, typically referred to as the "modified 930 MWe model," was then applied to develop dryer loads that were used to qualify the QC2 steam dryer. In this work, it was noted that the model generally overpredicted the loads, particularly in the steam dryer skirt region. The frequency content was found to be accurate, particularly at the dominant acoustic load frequencies (135-160 Hz). This validation is provided in Reference 5.

This validation work was limited to comparisons with 6 dryer pressure sensors. The criterion applied to the Modified 930 MWe ACM was that it be capable of predicting the 6 sensor responses to within 90% or greater. This criterion was met on 5 of 6. The sixth sensor measured very low pressures and was discarded.

An additional review of the Modified 930 MWe predictions of the QC2 TC-41 data has been performed and is included in this report. This review includes 22 of the 26 sensors and develops a basis to assess the uncertainty of the load prediction capabilities of this ACM. It should be noted that the ACM model is limited to frequency content from 0-200 Hz. The QC2 TC-41 data was sampled at a 2048 Hz rate. For this comparison, no filtering of the test data was performed, which is conservative.

3. Calculations/Data Considerations

3.1 Software Applications

The Mathcad-11 software package was used to support this evaluation. The statistical analysis features were used to calculate standard deviation (RMS pressure) along with minimum, maximum, and mean values. The spectral analyses presented were performed using complex Fast Fourier Transforms, to allow characterization of the frequency content and power spectral density (PSD) of the measured data. The data sets were reviewed to determine the data trigger point. All data after the trigger point was used from each data set. The PSDs were generated using sample groups of 2048 samples per group, based on the data time step. Intermediate computational results are reported to 4 significant figures to allow comparison. The final recommended results were rounded to 2 significant figures.

3.2 Comparison of Modified 930 MWe ACM to QC2 TC-41 Data

The Modified 930 MWe model was used to develop a full set of pressures for comparison to the QC2 plant test data. For this comparison, the same data interval was employed in the prediction and the test data. This interval is approximately 65 seconds of plant data. The following tables provide a summary of the comparison of RMS and peak pressures.

Table 2 Statistical Comparison Sensors P-1 to P-5 Same Data Interval

Sensor	*RMS pressure psi*	*Min pressure psi*	*Max pressure psi*
P-1 CDI	0.415	-1.264	1.306
P-1 Measured	0.431	-1.299	1.407
P-2 CDI	0.255	-0.861	0.896
P-2 Measured	0.546	-1.533	1.417
P-3 CDI	0.682	-2.262	2.193
P-3 Measured	0.631	-1.887	1.817
P-4 CDI	0.201	-0.76	0.657
P-4 Measured	0.313	-1.041	0.936
P-5 CDI	0.185	-0.714	0.785
P-5 Measured	0.314	-1.127	1.184

Based on CDI dataset: 930modbenchmark1.txt time/dated 9/06/2005,1:18:58PM.
Based on plant data set:
P01_05_TC41_repeat.txt time/dated 5/23/2005 10:32AM

Table 3 Statistical Comparison Sensors P-6 to P-10 Same Data Interval

Sensor	*RMS pressure psi*	*Min pressure psi*	*Max pressure psi*
P-6 CDI	0.465	-1.503	1.655
P-6 Measured	0.43	-1.408	1.395
P-7 CDI	0.247	-0.713	0.791
P-7 Measured	0.38	-1.217	1.081
P-8 CDI	0.23	-0.815	0.805
P-8 Measured	0.44	-1.268	1.178
P-9 CDI	0.581	-1.794	1.826
P-9 Measured	0.579	-1.593	1.578
P-10 CDI	0.434	-1.335	1.322
P-10 Measured	0.356	-1.079	1.071

Based on CDI dataset: 930modbenchmark1.txt time/dated 9/06/2005,1:18:58PM.
Based on plant data set:
P06_10_TC41_repeat.txt time/dated 5/23/2005 10:33AM

Table 4 Statistical Comparison Sensors P-11 to P-15 Same Data Interval

Sensor	*RMS pressure psi*	*Min pressure psi*	*Max pressure psi*
P-11 CDI	0.211	-0.808	0.802
P-11 Measured	0.446	-1.37	1.38
P-12 CDI	0.659	-1.751	1.848
P-12 Measured	0.69	-2.069	1.907
P-13 CDI	0.064	-0.246	0.24
P-13 Measured	0.17	-0.624	0.657
P-14 CDI	0.075	-0.247	0.243
P-14 Measured	0.294	-0.934	0.97
P-15 CDI	0.286	-1.064	1.132
P-15 Measured	0.547	-1.676	1.516

Based on CDI dataset: 930modbenchmark1.txt time/dated 9/06/2005,1:18:58PM.
Based on plant data set:
P11_15_TC41_repeat.txt time/dated 5/23/2005 10:34AM

Table 5 Statistical Comparison Sensors P-16 to P-20 Same Data Interval

Sensor	*RMS pressure psi*	*Min pressure psi*	*Max pressure psi*
P-16 CDI	0.04	-0.158	0.164
P-16 Measured	0.167	-0.585	0.571
P-17 CDI	0.251	-0.879	0.864
P-17 Measured	0.232	-0.808	0.742
P-18 CDI	0.449	-1.36	1.301
P-18 Measured	0.398	-1.212	1.143
P-20 CDI	0.605	-1.977	1.994
P-20 Measured	0.499	-1.613	1.588

Based on CDI dataset: 930modbenchmark1.txt time/dated 9/06/2005,1:18:58PM
Based on plant data set:
P16_20_TC41_repeat.txt time/dated 5/23/2005 10:35AM

Table 6 Statistical Comparison Sensors P-21 to P-27 Same Data Interval

Sensor	*RMS pressure psi*	*Min pressure psi*	*Max pressure psi*
P-21 CDI	0.804	-2.289	2.337
P-21 Measured	0.883	-2.261	2.099
P-22 CDI	0.702	-2.515	2.589
P-22 Measured	0.422	-1.379	1.243
P-23 CDI	0.03	-0.109	0.125
P-23 Measured	0.105	-0.456	0.378
P-24 CDI	0.251	-1.034	0.986
P-24 Measured	0.225	-0.764	0.831
P-25 CDI	0.772	-2.25	2.293
P-25 Measured	0.344	-1.27	1.166
P-26 CDI	0.044	-0.177	0.171
P-26 Measured	0.104	-0.334	0.337
P-27 CDI	0.033	-0.13	0.124
P-27 Measured	0.218	-0.559	0.543

Based on CDI dataset 930modbenchmark1.txt time/dated 9/06/2005, 1:18:58 PM
Based on plant data set:
P21_25_TC41_repeat.txt time/dated 5/23/2005 10:37AM
P26_27_TC41_repeat.txt time/dated 5/23/2005 10:37AM

Figures 1, 2, and 3 provide a graphical display of prediction vs measurement for RMS, peak positive, and peak negative pressures. These were generated by sorting the predictions and measurements, and then plotting the sorted files. The sensor locations P-13, P-14, P-19, P-23, P-26 were not included in these plots. The P-13, P-14, and P-23 sensors are internally mounted to the dryer and measure the internal dryer pressure. P-19 had been determined to be malfunctioning during the power ascension testing. P-26 is on the mast in a non-meaningful location for structural load considerations.

A perfect match would lie exactly on the reference line. For pressure transducers on the outer dryer surface, values above the line are conservative, while values below the line are non-conservative.

Figure 1 RMS Comparison

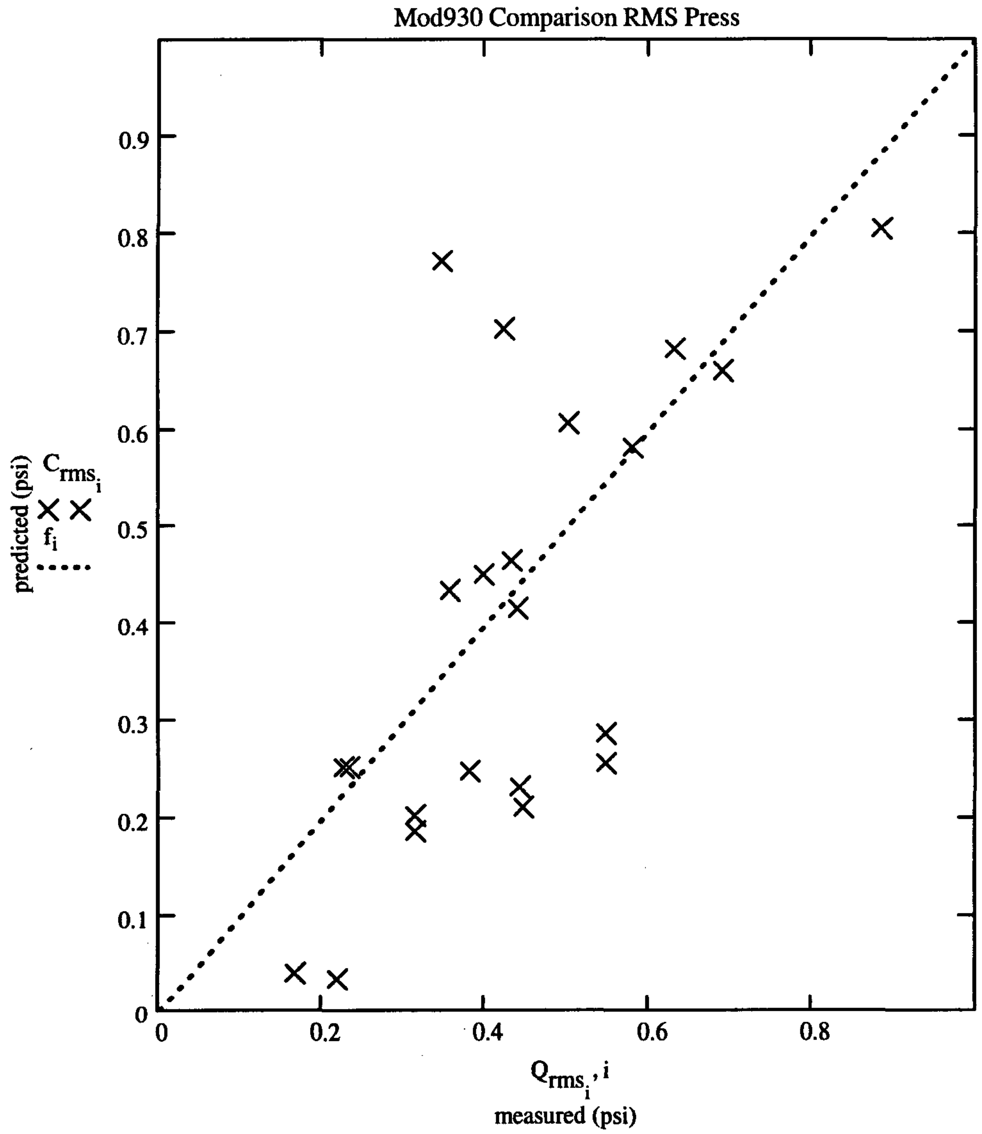


Figure 2 Peak Pressure Comparison

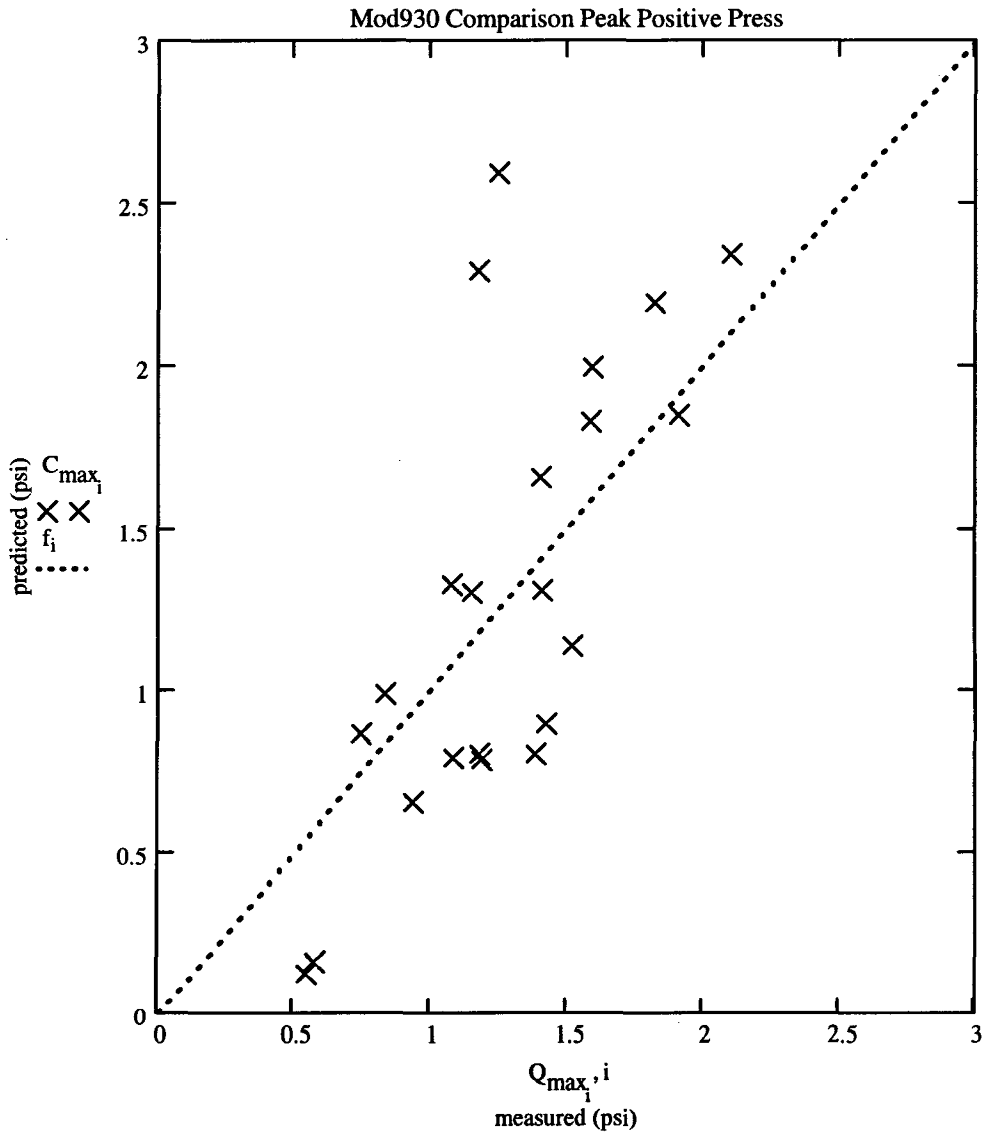
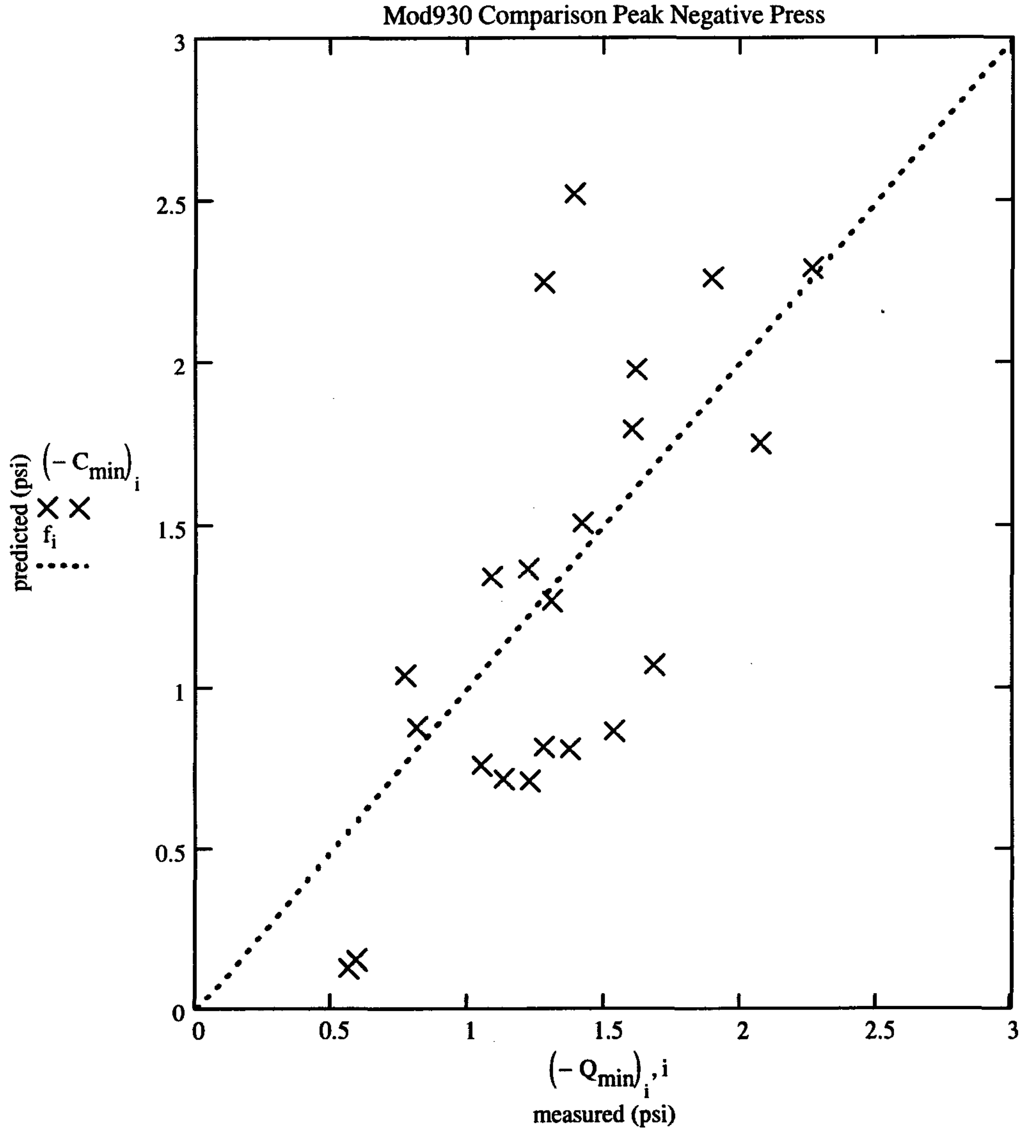


Figure 3 Peak Negative Pressure Comparison



3.3 Summary of Statistical Results

Review of Figures 1 through 3 and the data tables provides the following observations:

1) The Modified 930 MWe ACM predicts the highest RMS pressures fairly well. This reflects the criteria applied in the model tuning, which ensured that the four sensors nearest the nozzles (P-3, P-12, P-20, and P-21) would be predicted at no less than 90% of the measured response. The locations on the horizontal midplane of the dryer face tend to be the most underpredicted (P-2, P-5, P-8 and P11). The skirt locations are significantly overpredicted (P-22, P-24, P-25).
2) The peak positive pressures show a similar trend as the RMS plot. Most of the highest peak pressures are conservative relative to the data. The midrange peaks tend to fall slightly below and the lowest peaks show the most non-conservative trend.
3) The peak negative pressures show a similar trend to the peak positive pressures, with the largest peaks overpredicted and the smaller pressure points underpredicted.

Based on these observations, one cannot conclusively state that the Modified 930 MWe ACM provides a conservative pressure response at all locations. It does generally overpredict the largest RMS and peak pressures while underpredicting lower pressure points. Therefore, it is appropriate to consider additional statistical evaluation for the purposes of assessing an ACM uncertainty term to be applied.

3.4 Additional Statistical Considerations

In developing and applying evaluations of the Modified 930 MWe ACM, it is important to determine what parameter is most significant with respect to the overall process. If energy storage and buildup is observed in the structural model, which would be evidenced by the peak stresses building and reaching maximum values at or near the end of the analysis interval, RMS pressures would be the most appropriate choice. If the structure is being driven by the load, but not in a resonant response mode, the peak pressures are the most appropriate parameter to focus on. The frequency content of the load and the structural response provide a third possibility, that of ensuring the load content at a dominant frequency is conservatively determined. All three approaches will be examined.

3.4.1 Development of Bias Uncertainty

An additional statistical treatment was performed for the 22 sensor locations selected. Specifically, the mean of the prediction-measured data was divided by the mean of the measurements to develop a global sense of the model performance.

Table 7

	μ(Predicted- Measured)	*μMeasured*	*Bias % of measured*
RMS	-0.034	0.432	-7.8
Peak Pos.	0.04	1.324	3.2
Peak Neg.	0.036	-1.319	-2.7

Based on the above results, one would apply a bias correction of 7.8% to the RMS values, and a –0.5% bias correction to the peak-to-peak pressures.

3.4.2 Integration of 135-160 Hz PSD to Evaluate Frequency Content

A load ratio can be calculated based on the integrals of the predicted and measured PSDs for each sensor. The integrals are developed over the desired frequency interval and the ratio of the square roots of the integrals is compared. A value of load ratio greater than 1 indicates that the predicted value exceeds the measured data in that interval. The formulas used to develop this table are provided below:

$$\mathrm{PSDsumP} := \sum_{k=135}^{160} \mathrm{PSD\_D1}_k$$

$$\mathrm{PSDsumM} := \sum_{k=135}^{160} \mathrm{PSD\_Dm}_k$$

$$\mathrm{LoadRat} := \frac{\sqrt{\mathrm{PSDsumP}}}{\sqrt{\mathrm{PSDsumM}}}$$

Where:

$\mathrm{PSD\_D1}_k$=Power Spectral Density Coefficients (psi squared) Prediction

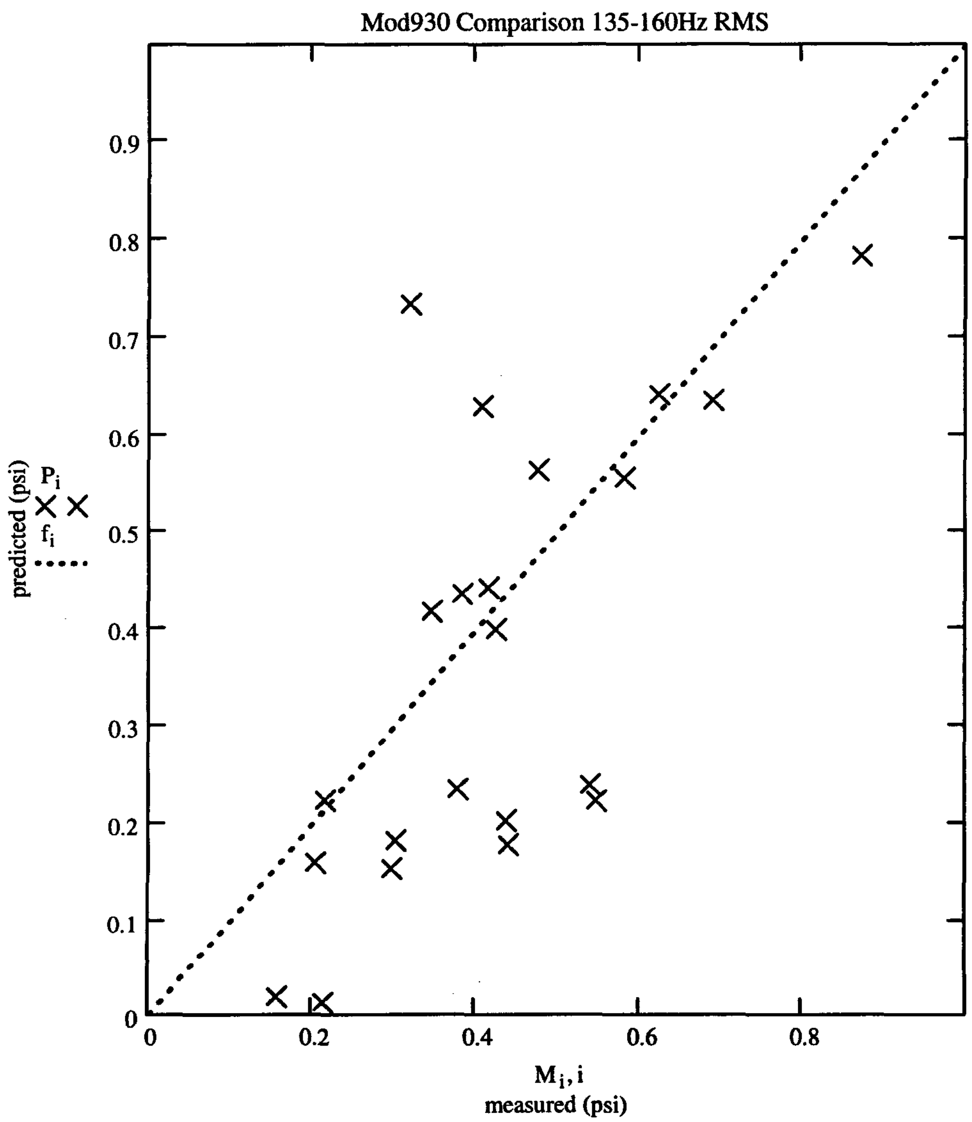
$\mathrm{PSD\_Dm}_k$=Power Spectral Density Coefficients (psi squared) Measured

PSDsumP=Area under the Predicted PSD curve in the frequency range of interest. The square root of this quantity is the RMS pressure.

PSDsumM=Area under the Measured PSD curve in the frequency range of interest. The square root of this quantity is the RMS pressure.

The predicted vs measured components of the Load Ratio are plotted in Figure 4 and provide comparable information to the Figure 1 RMS plot, but limited to the frequency interval of 135-160 Hz.

Figure 4 135-160 Hz RMS Comparison



Tables 8 and 9 provide the results obtained from this exercise as well as the global RMS and peak pressure ratios for comparison. In Table 8 the global RMS and peak pressure ratios are calculated by simple division of the predicted value by the measured value for each sensor location of interest. In Table 9, the interval RMS vs the global RMS are provided for comparison.

The following observations can be made:

1) The Load Ratio appears to correlate fairly well with the global RMS, particularly on the external hood locations. This would suggest that the differences observed in the frequency range of 135-160 Hz are likely responsible for the difference in global RMS observed.
2) The Load Ratio does not correlate as well with the peak pressure ratio calculated. This would suggest that peak pressures are not as directly affected as the RMS. This result is not unexpected, based on previous work to evaluate the distribution of pressures using histograms.
3) The interval and global RMS compare very favorably, with slightly more uncertainty resulting from the interval comparison.

Table 8 Results of 135-160 Hz Load Content Investigation

Sensor	*Load Ratio*	*RMS ratio (all frequencies)*	*Peak Positive Ratio (all frequencies)*
P-1 (hood)	0.939	0.963	0.928
P-2 (hood)	0.409	0.467	0.632
P-3 (hood)	1.028	1.081	1.207
P-4 (hood)	0.603	0.642	0.702
P-5 (hood)	0.52	0.589	0.663
P-6 (hood)	1.067	1.081	1.186
P-7 (hood)	0.626	0.65	0.732
P-8 (hood)	0.465	0.523	0.683
P-9 (hood)	0.956	1.003	1.157
P-10 (hood)	1.205	1.219	1.234
P-11 (hood)	0.403	0.473	0.581
P-12 (hood)	0.921	0.955	0.969
P-15 (side)	0.44	0.522	0.747
P-16 (exit plenum)	0.118	0.239	0.287
P-17 (side)	1.035	1.082	1.164
P-18 (hood)	1.136	1.128	1.138
P-20 (hood)	1.183	1.212	1.256
P-21 (hood)	0.897	0.910	1.113
P-22 (skirt)	1.55	1.664	2.082
P-24 (skirt)	0.791	1.116	1.186
P-25 (skirt)	2.3	2.244	1.966
P-27 (exit plenum)	0.05	0.151	0.228

Table 9 135-160 Hz Interval Statistics

	μ(Predicted- Measured)	*μMeasured*	*Bias % of measured*
RMS 135-160 Hz	-0.055	0.42	-13.1
Global RMS	-0.034	0.432	-7.8

4. Results

4.1 Summary of Uncertainty Terms

In Section 2, the uncertainties associated with measurement of steam line strain and components uncertainties of the dryer pressure instruments were developed. The main steam line strain gage measurement uncertainty is 5.03%. No adjustment to this value is applied internal to the ACM, which is a conservative treatment. The pressure instruments were shown to have an uncertainty of 2.9%, with a phenomenological bias of -3%.

Section 3 developed a comparison of the Modified 930 MWe ACM to the QC2 measured data at Test Condition 41. The data was examined in multiple ways to cover the RMS predictions, the peak pressure responses, and to determine the relative load content at the key frequency interval of 135-160 Hz, where significant acoustic loads have been observed. The following were key observations:

1) The Modified 930 MWe ACM tends to overpredict the largest pressures, RMS as well as peak, while underpredicting the lower measured pressures.
2) Based on the distribution of over and under predictions, a net bias based on 22 key sensor locations was developed. This bias is 7.8% for the RMS pressure, and –0.5% for the peak-to-peak, and 13.1% for the 135-160 Hz interval based RMS.
3) Since the highest pressures tend to be overpredicted by this model, it could reasonably be argued that no additional uncertainty should be applied to accommodate the shortfall in the low pressure response comparisons.
4) An uncertainty term that was pressure dependent would be optimal, but virtually impossible to use in practice in assessing appropriateness of stress analysis results. Therefore, applying a bias term globally to represent the average amount of margin required is a conservative alternative.

4.2 Combination of Uncertainty Terms

The uncertainty terms discussed are combined to develop an estimated uncertainty for the application of the Modified 930 MWe ACM to determining loads on the dryer. This combination does not reflect uncertainty or inherent conservatism in the Finite Element Model. Separate tables are provided, to reflect uncertainty calculated based on peak-to-peak pressure as well as uncertainty based on RMS pressure/frequency response. The uncertainty summaries are contained in the following tables. In the combination of the uncertainty components, bias terms are treated algebraically, while true uncertainty terms are combined by SRSS and then added to the total. These summaries are applicable to both Quad Cities units as well as projected applications at Dresden Unit 2 and Unit 3 when developing pressure time histories using this Modified 930 MWe ACM.

Table 10 Uncertainty Terms in Dryer Analysis (Peak Pressure Based)

Uncertainty Term	*Absolute Effect %*	*Effect on Analysis*
Strain Gage Measurement	5.03	+/- 5.03% based on assumption of linear model sensitivity
ACM Low Frequency Limitations		3% bias on peak-to-peak pressure
Pressure Sensor Measurement	3.9 Absolute 2.9 Relative	+/- 2.9%
Pressure Sensor Phenomenological	N/A	-3 to -8% bias on sensor reading
ACM Uncertainty		0.5% bias on peak-to-peak
Net Effect		0.5% net bias plus 5.81% (srss of measurement errors) Total=6.3%

Table 11 Uncertainty Terms in Dryer Analysis (RMS Pressure Based)

Uncertainty Term	*Absolute Effect %*	*Effect on Analysis*
Strain Gage Measurement	5.03	+/- 5.03% based on assumption of linear model sensitivity
ACM Low Frequency Limitations		0.4% bias on RMS pressure
Pressure Sensor Measurement	3.9 Absolute 2.9 Relative	+/- 2.9%
Pressure Sensor Phenomenological	N/A	-3 to -8% bias on sensor reading
ACM Uncertainty		7.8% bias on RMS
Net Effect		5.2% net bias plus 5.81% (srss of measurement errors) Total=11.0%

Table 12 Uncertainty Terms in Dryer Analysis (Interval RMS Pressure Based)

Uncertainty Term	*Absolute Effect %*	*Effect on Analysis*
Strain Gage Measurement	5.03	+/- 5.03% based on assumption of linear model sensitivity
ACM Low Frequency Limitations		0.4% bias on RMS pressure
Pressure Sensor Measurement	3.9 Absolute 2.9 Relative	+/- 2.9%
Pressure Sensor Phenomenological	N/A	-3 to -8% bias on sensor reading
ACM Uncertainty		13.1% bias on RMS
Net Effect		10.5% net bias plus 5.81% (srss of measurement errors) Total=16.3%

5. Conclusions/Discussion

A summary of the key uncertainties associated with the application of the Modified 930 MWe ACM has been developed. This development included a detailed review of the comparison of the Modified 930 MWe ACM to the QC2 Test Condition 41 in-vessel test data. This review focused on RMS pressures, peak pressures, and also included load content in the frequency interval containing the maximum responses. The following conclusions are made based on this work:

1) The ACM overpredicts most of the largest peak pressures and generally overpredicts the largest RMS values as well.
2) The ACM underpredicts the lower pressures, typically those situated on the horizontal midplane of the dryer face.
3) The ACM overpredicts the dryer skirt locations by a large margin, approximately a factor of two on RMS as well as peak pressure.
4) An uncertainty term based on net bias of RMS or peak pressure provides a simplified approach to defining margin requirements, and will yield compounded conservatism due to the ACM behavior noted above.
5) Uncertainties based on peak, RMS, and an interval based RMS have been developed. The selection between them should be based on review of the structural model results based on the observation of buildup in predicted strains in the analysis interval selected. If buildup is observed, RMS is the most appropriate, otherwise the peak pressure combination is recommended.
6) Use of the interval based RMS uncertainty would provide additional assurance of conservative application of the model.

Based on the development and consideration of uncertainties presented, a margin of 6.3% to 16.3% is recommended in the application of the Modified 930 MWe ACM. This uncertainty is independent of the structural finite element model, and any conservatism, inherent or designed, that are included in that model.

6. References

1. Structural Integrity Associates, Inc. 2005. Quad Cities Strain Gage Evaluation. Calculation Package File No. EXLN-20Q-301, Project No. EXLN-20Q. Revision 0.
2. C.D.I. Report No. 05-10 - Benchmarking of Continuum Dynamics, Inc. Steam Dryer Load Methodology Against Quad Cities Unit 2 In-Plant Data, Revision 0.
3. GE-NE-0000-0037-1951-01, Revision 0, "Dryer Vibration Instrumentation Uncertainty," April 2005.
4. GE-NE-0000-0038-2076-01, Revision 0, "Summary of the Effects of the Sensor Cover Plates on Dynamic Pressure Measurement," April 2005.
5. "Acoustic Circuit Benchmark, Quad Cities Unit 2 Instrumented Steam Path, 790 MWe and 930 MWe Power Levels," AM-2005-002, Revision 0, June 2005.
6. "An Assessment of the Effects of Uncertainty in the Application of Acoustic Circuit Model Predictions to the Calculation of Stresses in the Replacement Quad Cities Units 1 and 2 Steam Dryers," AM-2005-008, Revision 0, August 2005.

Appendix A– Test Description and Sensor Locations

Two power levels were selected for the acoustic circuit benchmarking effort, 790 MWe and 930 MWe. These power levels correspond to pre-EPU full power and post-EPU full power conditions. A blind test was performed using 790 MWe data. Following this test, model adjustments were allowed prior to the 930 MWe blind test. Following the 930 MWe test, a final adjustment was made to the acoustic circuit model. For this report, only the 930 MWe data will be compared to the pressure predictions obtained from the acoustic circuit analysis described in the prior section.

The following descriptions provide details with respect to the vessel pressure instrument and MSL strain gage placement.

MSL Strain Gauge Inputs:
Eight main steam line locations were instrumented with 16 pairs of strain gages for the acoustic circuit analysis. In the first blind test, CDI used the first two locations off the reactor pressure vessel nozzle and only one strain gage pair at each location.

- MSL "A" Elevation 651 S1/S3 pair Elevation 621 S5/S5a pair
- MSL "B" Elevation 651 S7/S9 pair Elevation 621 S11/S11a pair
- MSL "C" Elevation 651 S31/S33 pair Elevation 621 S35/S35a pair
- MSL "D" Elevation 651 S37/S39 pair Elevation 621 S41/S41a pair

Additional Strain gage pairs used in load development are as follows:

- MSL "A" Elevation 651 S2/S4 pair Elevation 621 S6/S6a pair
- MSL "B" Elevation 651 S8/S10 pair Elevation 621 S12/S12a pair
- MSL "C" Elevation 651 S32/S34 pair Elevation 621 S36/S36a pair
- MSL "D" Elevation 651 S38/S40 pair Elevation 621 S42/S42a pair

Based on the results obtained in the first blind test, it was determined that using both pairs of strain gages at each location provides a better measure of the piping breathing mode and therefore would provide improved (better frequency match) predictions. This approach continues to be applied to the maximum extent practicable.

Pressure Instrumentation:

Twenty-seven pressure instruments were mounted on the dryer surfaces. During the start-up test, measurements from P-19 became unreliable and it was declared to be non-functional. The drawings showing the locations of the sensors follow. The following are the general locations of the pressure sensors:

Sensors P-1 through P-12 are located on the hood of the 90° side of the dryer.

Sensor P-13 is internal to the hood directly adjacent to P-3.

Sensor P-14 is internal to the hood directly adjacent to P-20 on the 270° side.

Sensors P-15 and P-17 are located on the side of the dryer hood.

Sensor P-16 is located on the top of the dryer in the exit from an internal vane bank.

Sensors P-18 through P21 are located on the hood of the 270° side.

Sensors P-22, P-24, and P-25 are located on the skirt above the water level on the 90° side.

Sensor P-23 is located internal to the skirt, near P-22.

Sensor P-26 is located on the instrumentation mast on top of the dryer.

Sensor P-27 is located on the top of the dryer in the exit from an internal vane bank.

23406821	2

REVISIONS

1	APR 18 2005 RMCN06047	RJA
2	APR 22 2005 RMCN06057	RJA

✳ ACCELEROMETERS MOUNTED IN OPPOSITE DIRECTION DUE TO ACCESS AND SAFETY.

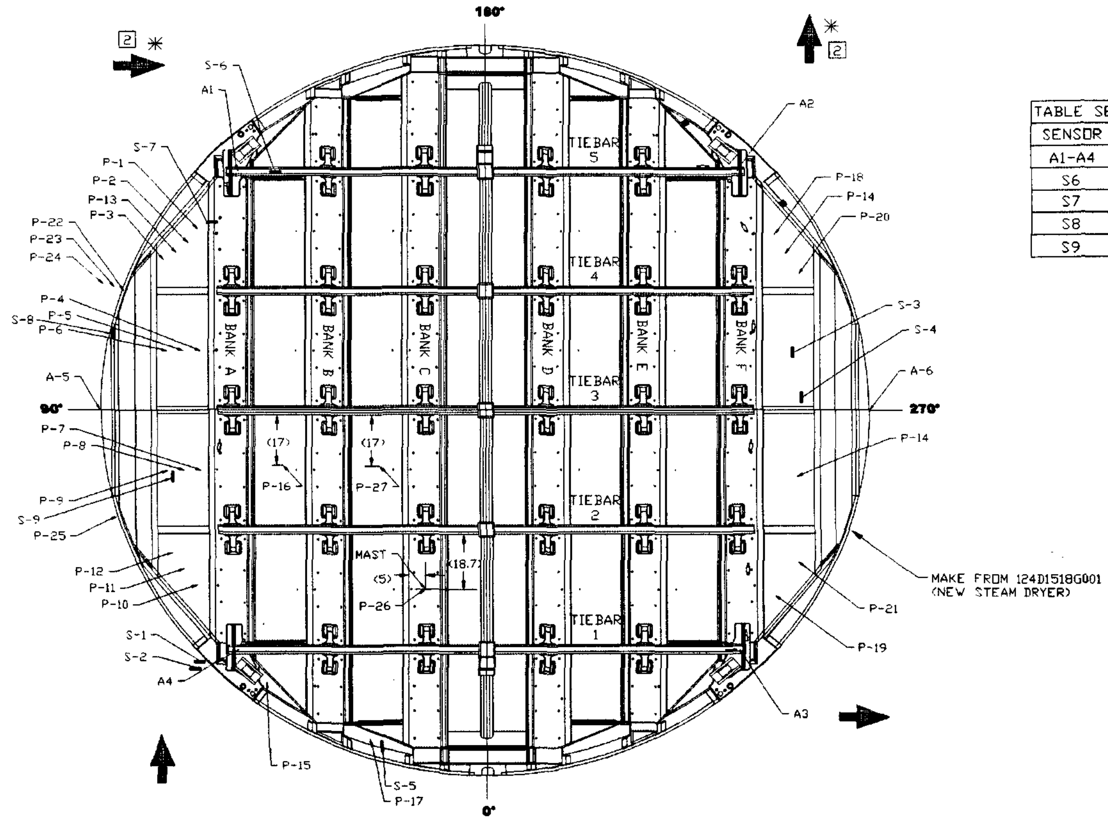


TABLE SENSOR MOUNTING	
SENSOR	MOUNT DETAIL
A1-A4	J
S6	H
S7	H
S8	J
S9	G

DRYER SENSOR LOCATIONS - TOP VIEW

GE Nuclear Energy — GENERAL ELECTRIC COMPANY San Jose CA	DAY	MO	YR	DWG NO. 23406821	REV. 2
DRAWN DH CHAN	28	01	01	FEB 28 2005	SH NO. 2 CONT ON 3
CHECKED NA					

1 AC-234C6821SH2

234C6821 SH NO 5

REVISIONS

1	APR 18 2005 RMCN06047	RJA

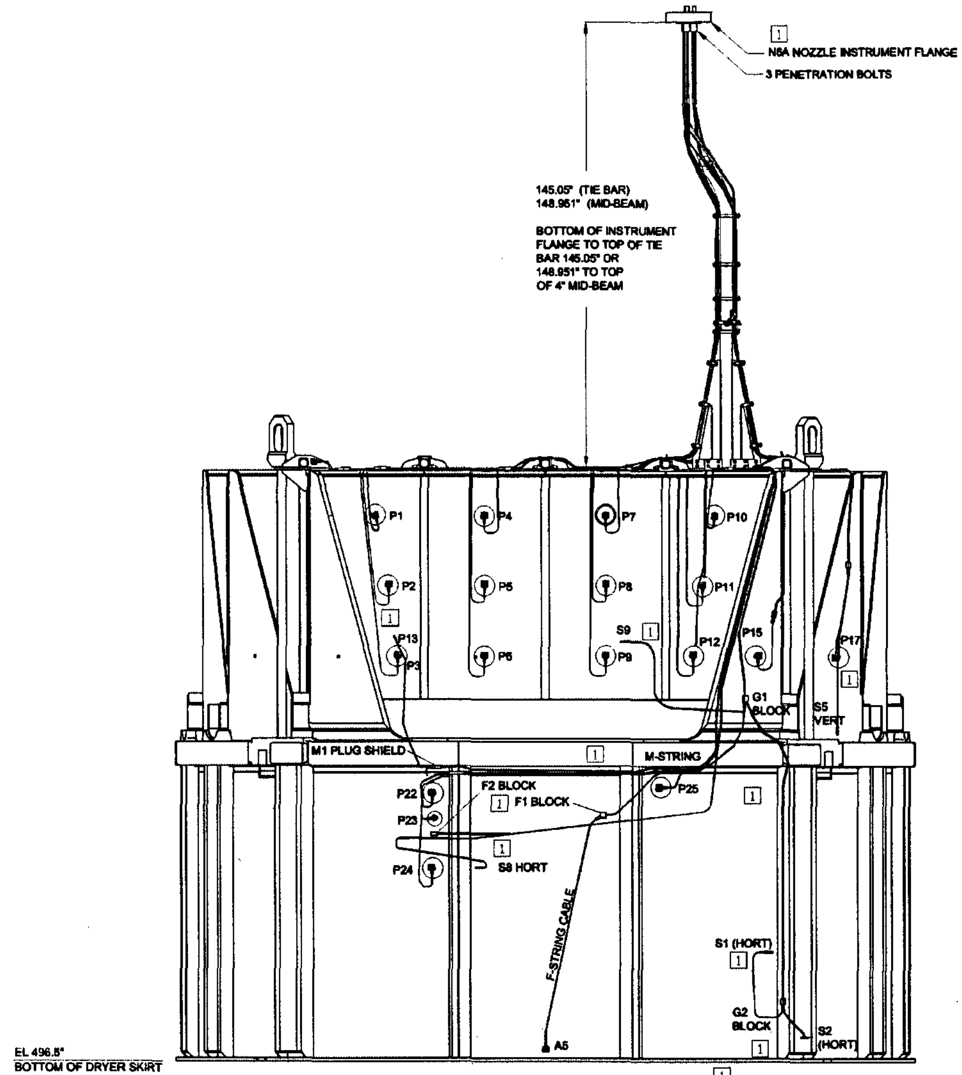


TABLE SENSOR MOUNTING		
SENSOR	MOUNT DETAIL	
P1	B	
P2	B	
P3, P13	D	
P4-P12	B	
P15	B (BOTTOM)	
P17	C (TOP)	
P22	B OR A	
P23	E (INTERNAL)	
P24	B, C, OR A	
P25	B	
S1	G (HORT)	1
S2	G (HORT)	
S8, S9	F (HORT)	1
A5	J (HORT)	

1

DRYER SENSOR LOCATIONS - 90° FACE

SCALE 1 / 20

GE Nuclear Energy

	DAY	MO	YR	DWG NO	REV
				234C6821	1
DRAWN DH CHAN	28	01	01	FEB 28 2005 SH NO 5 CONT ON 6	
CHECKED NA					

1 AC-234C6821SH5

234C6821	SH NO 6	
REVISIONS		
1	APR 18 2005 RMCN06047	RJA
2	APR 22 2005 RMCN06057	RJA

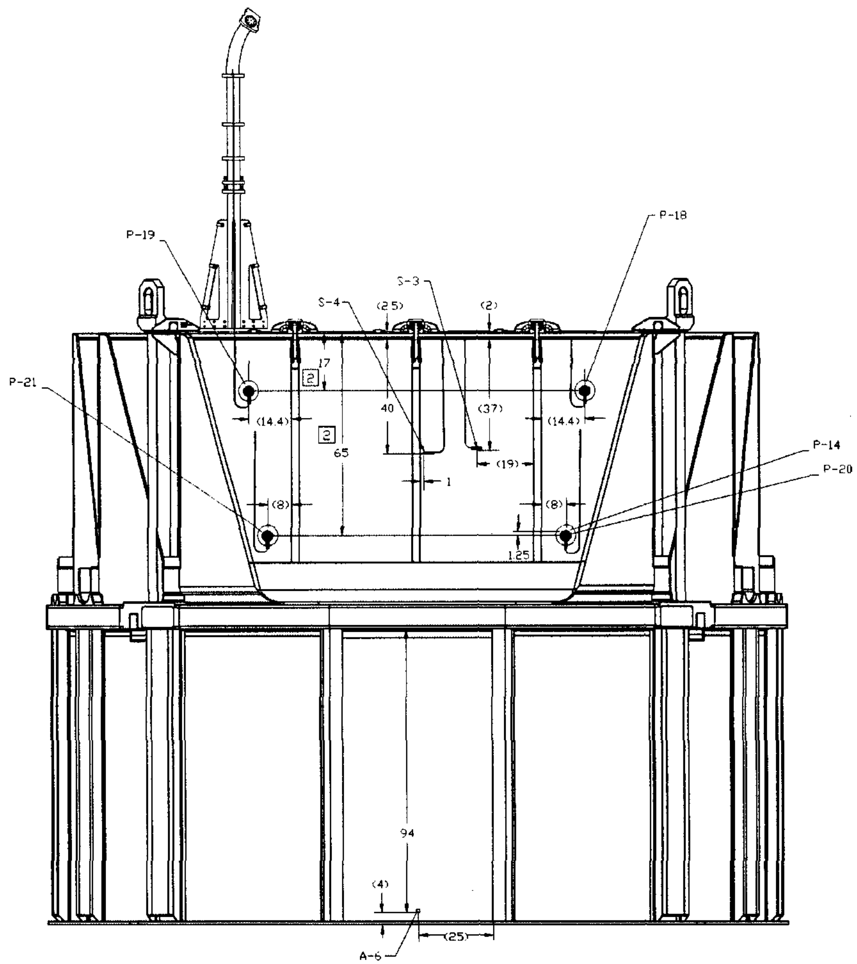


TABLE SENSOR MOUNTING	
SENSOR	MOUNT DETAIL
S-3	F (HORT)
S-4	F (HORT)
P18	B
P19	B
P20, P14	D
P21	B
A6	J (HORT)

270° FACE (LOOKING TOWARDS CENTER)

DRYER SENSOR LOCATIONS - 270° FACE

Nuclear Energy	DAY	MO	YR	DWG NO 234C6821	REV. 2
DRAWN DH CHAN	28	01	01		
CHECKED NA				FEB 28 2005 SH NO 6 CONT ON 7	

1 AC-234C6821SH6

SH NO 6 234C6821

Appendix B- Additional Uncertainty Cases Based on Data in the 135-160Hz Frequency Interval

Introduction

During the review of the uncertainty results presented in the main body of this report, some additional cases were identified as being potentially of interest. These cases were to be based on the frequency interval of 135-160 Hz, which contains the primary acoustic source frequencies seen in the Quad Cities 2 plant test data. Two cases are developed here to address this request:

a. A global uncertainty using the full set of 22 externally mounted sensors, a data range of 135-160 Hz, and based on the peak-to-peak pressures.
b. A local uncertainty using the hood-mounted sensor locations only, a data range of 135-160 Hz, and based on the peak-to-peak pressures. This uncertainty would be applicable only to the hood regions of the dryer.

The preparation of these cases involved a significant amount of data manipulation to digitally filter the data for the interval of interest and then compute the statistical parameters of interest. The data manipulations will be discussed in detail. The statistical characterization is exactly comparable to that provided in the main body of this report.

Data Analysis Methods

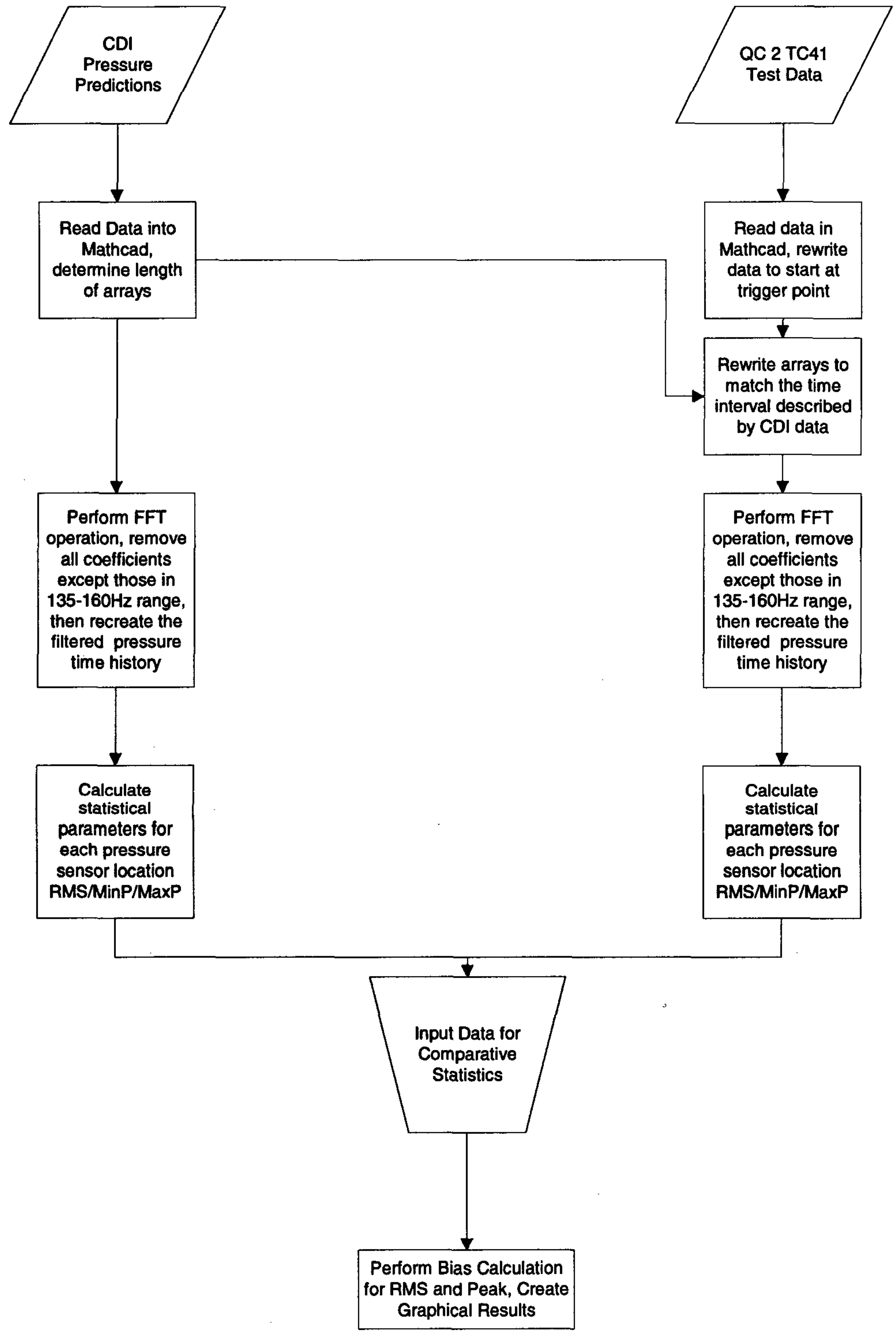
The method of data analysis needs to be described to ensure that the data manipulations are understood as well as to allow an appreciation of the extent of data included in this evaluation. The flow chart shown on the next page provides an overview of the data transfer and manipulation.

Each CDI pressure sensor location prediction consists of 65 seconds of pressure time history information, at a sample rate of 2000 samples/sec., for a total of approximately 131,000 data points. The plant data is first manipulated to account for the test trigger time, and then to obtain the same time interval as that predicted by CDI. The plant data is sampled at 2048 samples/sec. and therefore yields approximately 134,000 data points for the same 65 second interval for each sensor location considered.

Data Filtering and Statistical Analysis Flow Chart

135-160 Hz Filtering and Comparison

This flow chart describes the data manipulation performed on each pressure sensor location included in the comparison



We are interested in the frequency interval between 135 Hz and 160 Hz in order to better focus on the dominant acoustic sources identified in the QC2 power ascension testing. Subsequent to the data manipulation necessary to ensure comparable data time intervals, an FFT was taken of the data set. The complex version of the FFT was employed to allow use of arbitrary data set lengths. The Fourier coefficient matrix was then manipulated using digital logic filters to remove all coefficients except those in the range of interest. The inverse transform was then taken on the reduced coefficient array, producing a time history filtered to the desired frequency interval. Then standard statistical routines were applied to these time histories to generate RMS, maximum, and minimum pressures for this location. This approach was repeated for each predicted and measured sensor location desired and the individual data statistics were transferred to another worksheet to allow graphical representation and the calculation of bias terms.

Results

Case 1, Global uncertainty based on 22 sensors (filtered)

This case is directly comparable to that reported in the main report with the addition of the filtering. The RMS calculation based on the digital filtering is directly comparable to the interval RMS case. The interval RMS case employed an approximate integral of the power spectral density to obtain the interval information. By performing the detailed filtering, an exact interval RMS value is calculated.

Comparison plots of the RMS, positive maximum, and negative minimum pressures are provided in Figures B1, B2, and B3. The following observations can be made:

1) The Modified 930 MWe ACM predicts the highest RMS pressures fairly well. This reflects the criteria applied in the model tuning, which ensured that the four sensors nearest the nozzles (P-3, P-12, P-20, and P-21) would be predicted at no less than 90% of the measured response. The locations on the horizontal midplane of the dryer face tend to be the most underpredicted (P-2, P-5, P-8 and P-11). The skirt locations are significantly overpredicted (P-22, P-24, P-25).
2) The peak positive pressures show a similar trend as the RMS plot. Most of the highest peak pressures are conservative relative to the data. The midrange peaks tend to fall slightly below and the lowest peaks show the most non-conservative trend.
3) The peak negative pressures show a similar trend to the peak positive pressures, with the largest peaks overpredicted and the smaller pressure points underpredicted.

Figure B-1 Comparison of RMS Pressures (Filtered)

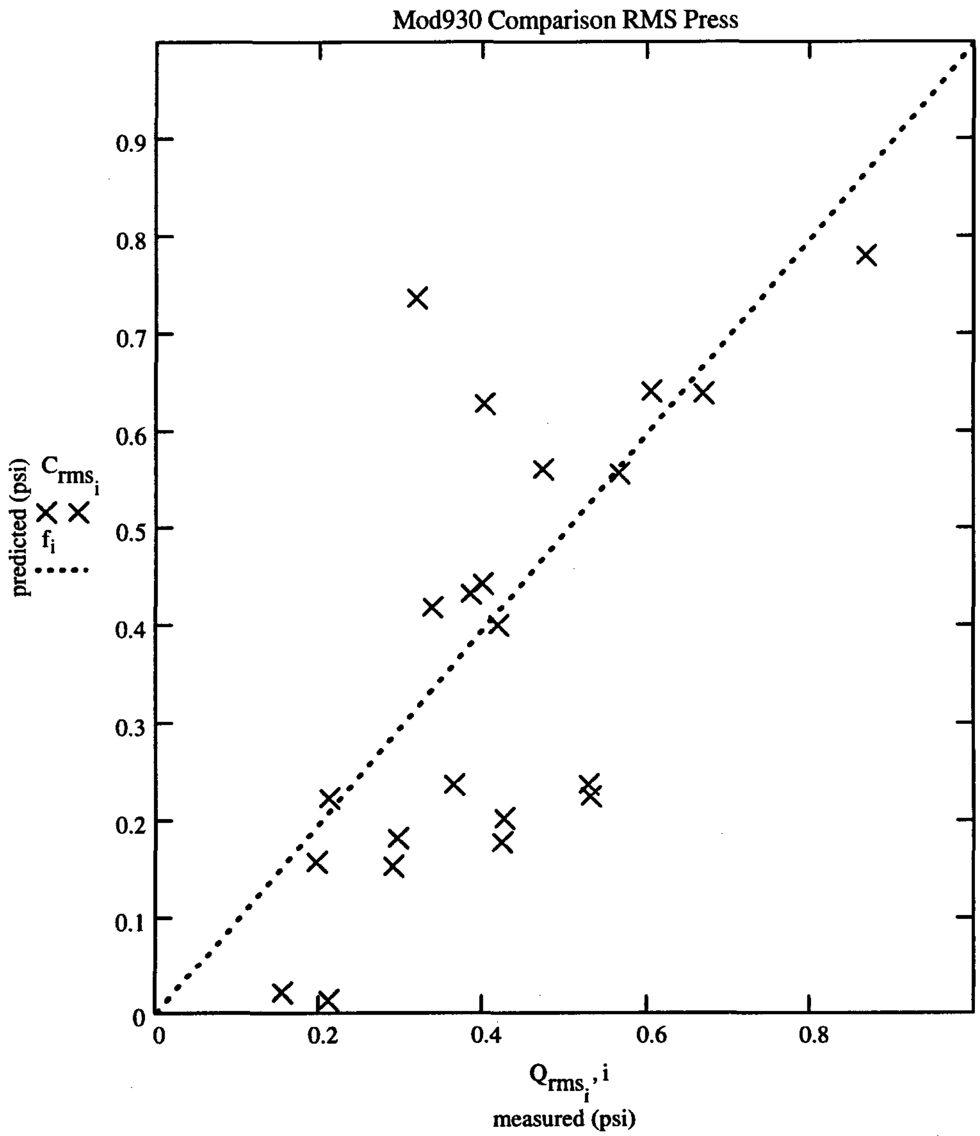


Figure B-2 Comparison of Peak Positive Pressures (Filtered)

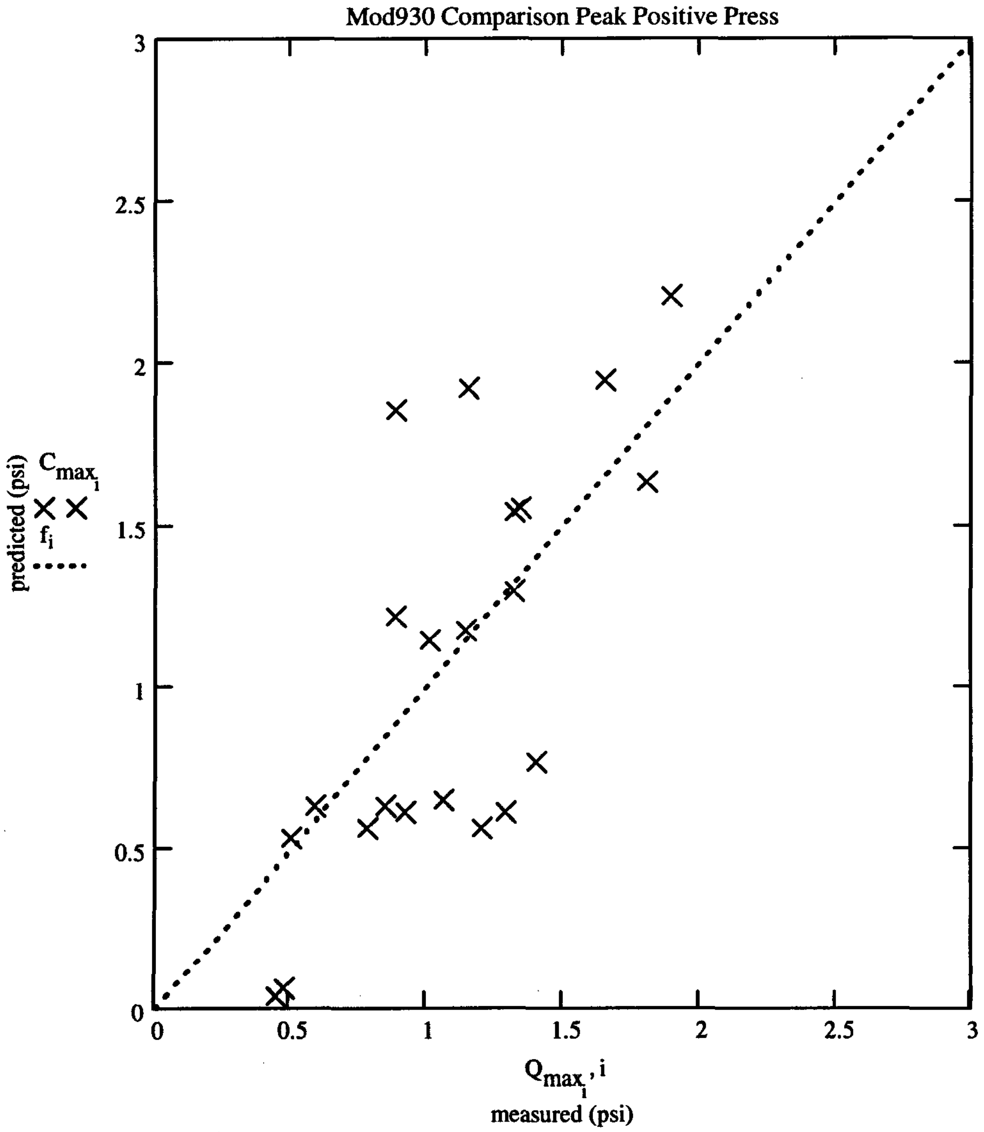
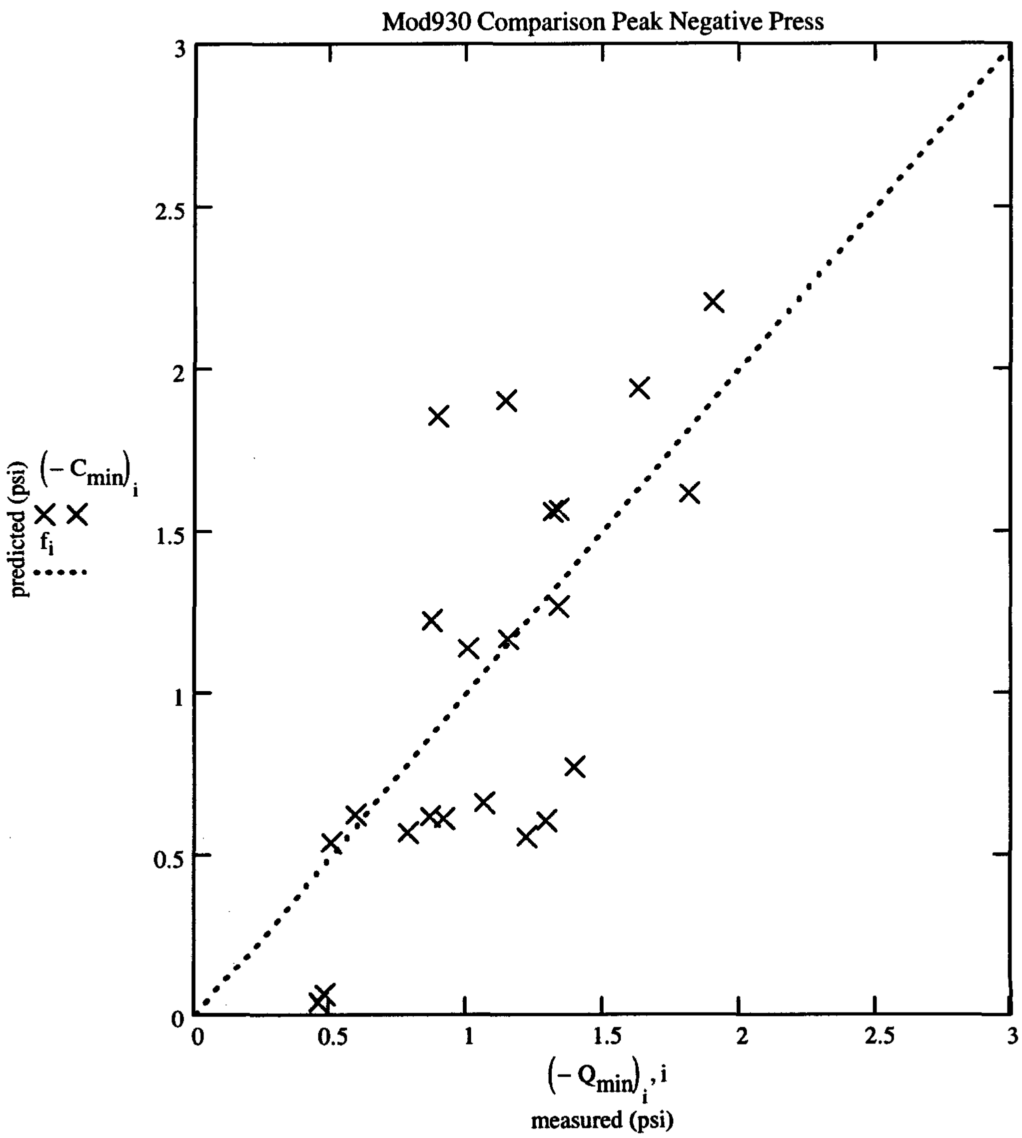


Figure B-3 Comparison of Peak Negative Pressures (Filtered)



As noted above, additional statistical treatment was performed for the 22 sensor locations selected. Specifically, the mean of the prediction-measured data was divided by the mean of the measurements to develop a global sense of the model performance.

Table B-1 Case 1 Statistical Results (Filtered)

	μ(Predicted- Measured)	*μMeasured*	*Bias % of measured*
RMS	-0.045	0.411	-10.9
Peak Pos.	-0.034	1.084	-3.2
Peak Neg.	0.035	-1.084	-3.1

Based on the above results, one would apply a bias correction of 10.9% to the RMS values, and a 6.3% bias correction to the peak-to-peak pressures. The RMS value calculated here compares to a value of 13.1% reported in the main report. The 13.1% value was based on approximate integration of the power spectral density plots and was conservative. A reduction to 10.9% can be justified since the digital filtering approach applied is exact and not dependent on an approximate numerical integration.

Case 2, Local Dryer Hood uncertainty based on 15 sensors (filtered)

This case is prepared to address concerns about the potential for the high powered acoustic sources to excite local mode shapes in the dryer. As demonstrated in the main report, as well as the Case 1 results, the Modified 930 MWe ACM tends to concentrate its underpredictions on the middle and to a lesser extent upper portions of the front hood, while being significantly over-conservative on other dryer locations, particularly the skirt regions. Therefore, an uncertainty term for application to the front hood, based on the principal acoustic loading frequency, and developed only from sensors mounted on the front hoods has been prepared. Sensor locations P-1 to P-12 on the 90° side and sensor locations P-18, P-20, P-21 on the 270° side represent the full set of hood-mounted sensors.

The same data manipulation to align, filter the data, and compute point statistics was performed for these 15 dryer hood data locations. Comparison plots of the RMS, positive maximum, and negative minimum pressures are provided in Figures B4, B5, and B6. The following observations can be made:

1) The RMS pressures tend to be conservative at the highest measured pressure points, except for location P-21, which is underpredicted. (As noted previously, this is a direct consequence of the acceptance measures applied in the creation of this predictive model, namely that the 4 sensor locations opposite the nozzles P-3, P-12, P-20, and P-21 and P-24 on the skirt match the plant data to within 10% RMS pressure.) The overall bias will be more negative than for the full 22 sensors, since the large conservative contributions of the skirt locations are absent.
2) The peak positive and peak negative pressure plots show that above 1.25 psi, most of the predicted pressures are conservative, or very close to the measurement. The largest group of non-conservative predictions falls at lower pressure values.

Figure B-4 Case 2 Comparison of RMS Pressures (Filtered)

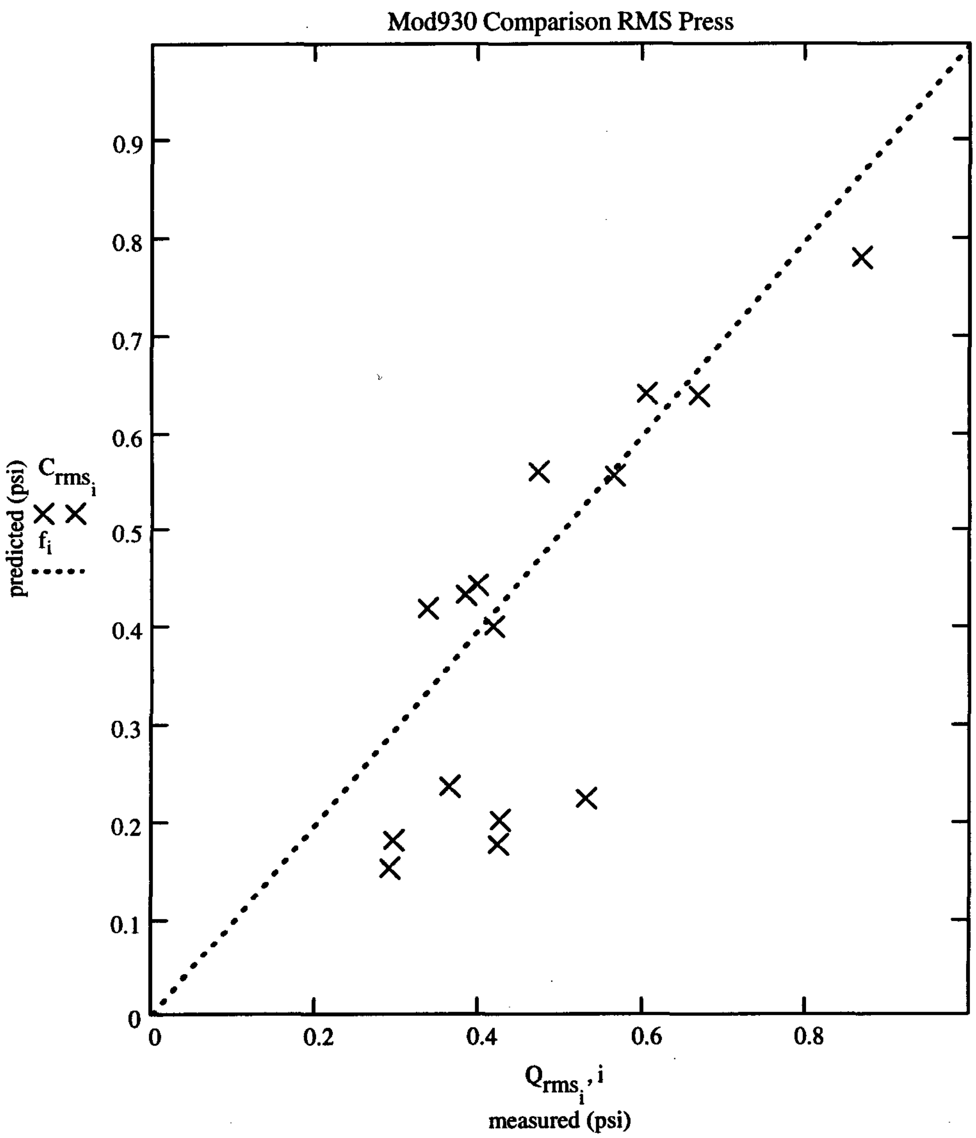


Figure B-5 Case 2 Comparison of Peak Positive Pressure (Filtered)

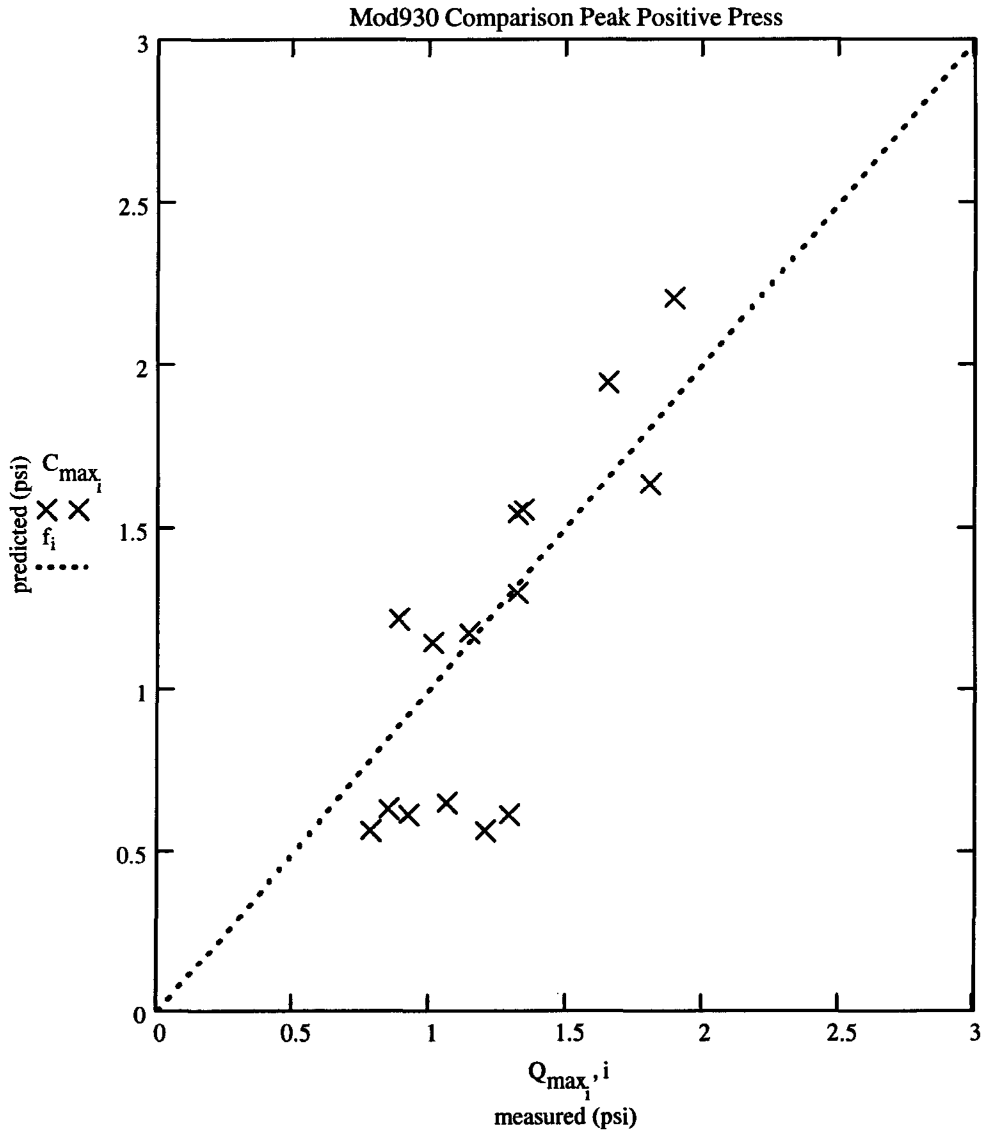
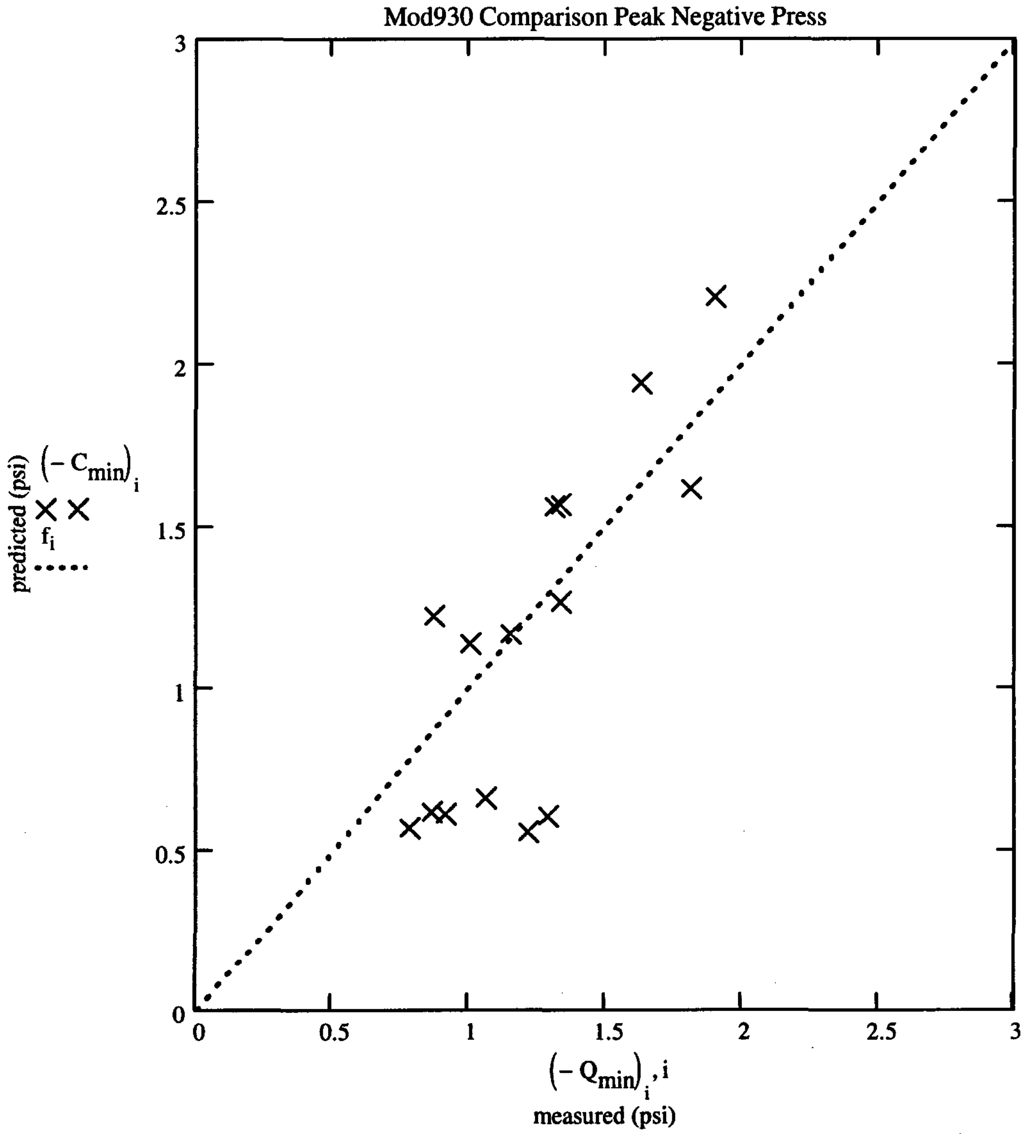


Figure B-6 Case 2 Comparison of Peak Negative Pressures (Filtered)



Similarly to Case 1, additional statistical treatment was performed for the 15 sensor locations selected. As before, the mean of the prediction-measured data was divided by the mean of the measurements to develop a global sense of the model performance.

Table B-2 Case 2 Statistical Results (Filtered)

	μ(Predicted- Measured)	*μMeasured*	*Bias % of measured*
RMS	-0.065	0.468	-14
Peak Pos.	-0.073	1.228	-6.0
Peak Neg.	0.075	-1.228	-6.1

Based on the above results, one would apply a bias correction of 14% to the RMS values, and a 12.1% bias correction to the peak-to-peak pressures. Since this case uses only the hood mounted sensors, this correction factor should be applied to hood locations only.

Combination of Uncertainty Terms

The uncertainty terms discussed in the main report are combined with the revised bias terms computed to develop an estimated uncertainty for the application of the Modified 930 MWe ACM in determining loads on the dryer. This combination does not reflect uncertainty or inherent conservatism in the Finite Element Model. Separate tables are provided, to reflect uncertainty calculated based on peak-to-peak pressure as well as uncertainty based on RMS pressure/frequency response. The uncertainty summaries are contained in the following tables. In the combination of the uncertainty components, bias terms are treated algebraically, while true uncertainty terms are combined by SRSS and then added to the total. These summaries are applicable to both Quad Cities units as well as projected applications at Dresden Unit 2 and Unit 3 when developing pressure time histories using this Modified 930 MWe ACM.

Table B-3 Uncertainty Terms in Case 1 (Peak Pressure Based)

Uncertainty Term	*Absolute Effect %*	*Effect on Analysis*
Strain Gage Measurement	5.03	+/- 5.03% based on assumption of linear model sensitivity
ACM Low Frequency Limitations	3% bias on peak-to-peak when considering all frequencies	N/A for a 135-160 Hz frequency window
Pressure Sensor Measurement	3.9 Absolute 2.9 Relative	+/- 2.9%
Pressure Sensor Phenomenological	N/A	-3% to -8% bias on sensor reading
ACM Uncertainty		6.3% bias on peak-to-peak
Net Effect		3.3% net bias plus 5.81% (srss of measurement errors) Total=9.11%

Table B-4 Uncertainty Terms in Case 1 (RMS Pressure Based)

Uncertainty Term	*Absolute Effect %*	*Effect on Analysis*
Strain Gage Measurement	5.03	+/- 5.03% based on assumption of linear model sensitivity
ACM Low Frequency Limitations	0.4% bias on peak-to-peak when considering all frequencies	N/A for a 135-160 Hz frequency window
Pressure Sensor Measurement	3.9 Absolute 2.9 Relative	+/- 2.9%
Pressure Sensor Phenomenological	N/A	-3% to -8% bias on sensor reading
ACM Uncertainty		10.9% bias on peak-to-peak
Net Effect		7.9% net bias plus 5.81% (srss of measurement errors) Total=13.71%

Table B-5 Uncertainty Terms in Case 2 (Peak Pressure Based)

Uncertainty Term	*Absolute Effect %*	*Effect on Analysis*
Strain Gage Measurement	5.03	+/- 5.03% based on assumption of linear model sensitivity
ACM Low Frequency Limitations	3% bias on peak-to-peak when considering all frequencies	N/A for a 135-160 Hz frequency window
Pressure Sensor Measurement	3.9 Absolute 2.9 Relative	+/- 2.9%
Pressure Sensor Phenomenological	N/A	-3% to -8% bias on sensor reading
ACM Uncertainty		12.1% bias on peak-to-peak
Net Effect		9.1% net bias plus 5.81% (srss of measurement errors) Total=14.91%

Table B-6 Uncertainty Terms in Case 2 (RMS Pressure Based)

Uncertainty Term	*Absolute Effect %*	*Effect on Analysis*
Strain Gage Measurement	5.03	+/- 5.03% based on assumption of linear model sensitivity
ACM Low Frequency Limitations	0.4% bias on peak-to-peak when considering all frequencies	N/A for a 135-160 Hz frequency window
Pressure Sensor Measurement	3.9 Absolute 2.9 Relative	+/- 2.9%
Pressure Sensor Phenomenological	N/A	-3% to -8% bias on sensor reading
ACM Uncertainty		14% bias on peak-to-peak
Net Effect		11% net bias plus 5.81% (srss of measurement errors) Total=16.81%

Summary and Conclusions

Two additional cases have been computed to investigate the uncertainty associated with the application of the Modified 930 MWe ACM to the analysis of steam dryer unsteady loads. Specifically:

1) Case 1 performed a bias calculation for the 22 sensor locations on the dryer external surfaces that was based on the frequency content between 135 Hz and 160 Hz. This combination is considered appropriate as a general uncertainty estimate for all locations except the dryer hood. The computed uncertainties were 9.11% for peak pressure uncertainty and 13.71% for an RMS pressure based uncertainty.
2) Case 2 performed a bias calculation for the 15 sensor locations on the dryer hood, to compute a local uncertainty on the portion of the structure that the ACM performs the least conservatively. The frequency content was also restricted to the range of 135-160 Hz. The computed uncertainties were 14.91% for peak pressure uncertainty, and 16.81% for an RMS based uncertainty.

These uncertainties should be applied in analogous fashion to those computed in the main report, e.g., the peak pressure uncertainty is the most appropriate for the responses observed in the structural model. The Case 1 uncertainty is appropriate for general application to the dryer structures. The Case 2 uncertainty is directly applicable to the dryer hood locations only, but would be conservative in application to other dryer locations. Case 1 and Case 2 are alternative uncertainty developments that supplement but do not supercede those calculated in the main report. Use of Case 1 uncertainty terms is conservative relative to the previous uncertainty terms developed, by approximately 3%. The Case 2 uncertainty terms add approximately 9% to the previous uncertainty terms.