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RMS Error and Correction Factors

Stephen Cumblidge
Office of Nuclear Reactor Regulations
Division of Engineering
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Introduction

- On March 16 PDI presented a statistical analysis, performed by Glenn White, on the correction factors proposed by the industry and the NRC staff.
- NRC staff have studied the statistical analysis of the various correction factors.
- Our goal was to reproduce their results, evaluate what has been done, and perform independent analysis of the statistics to address some of our concerns.

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The Issue at Hand

- The ID inspections of large bore welds have a very high POD, and it would be beneficial for all concerned if a consensus could be reached on a correction factor.
- The NRC has not generically accepted the RMS Error - 0.125 inch factor
- Industry does not use, and has presented statistical evidence against, the 2 x RMS Error correction factor.

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Correction Factors

- The purpose of using a correction factor in depth sizing is to provide sufficient confidence in the flaw evaluations for high RMS error examinations.
- A correction factor could be tailored to that end.
- Any such correction factor needs to have a well-understood and defensible technical basis.

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How to Analyze the Statistics?

- A common assumption when dealing with data that contains random measurement errors is that it can be described using the normal distribution.
  - The validity of using the normal distribution will be discussed later.
- The normal distribution is defined by some center and a standard deviation “Sigma.”
- Sizing errors at PDI are scored using the Root Mean Square Error, which is similar to the standard deviation Sigma.
- The work by Glenn White uses the normal distribution.

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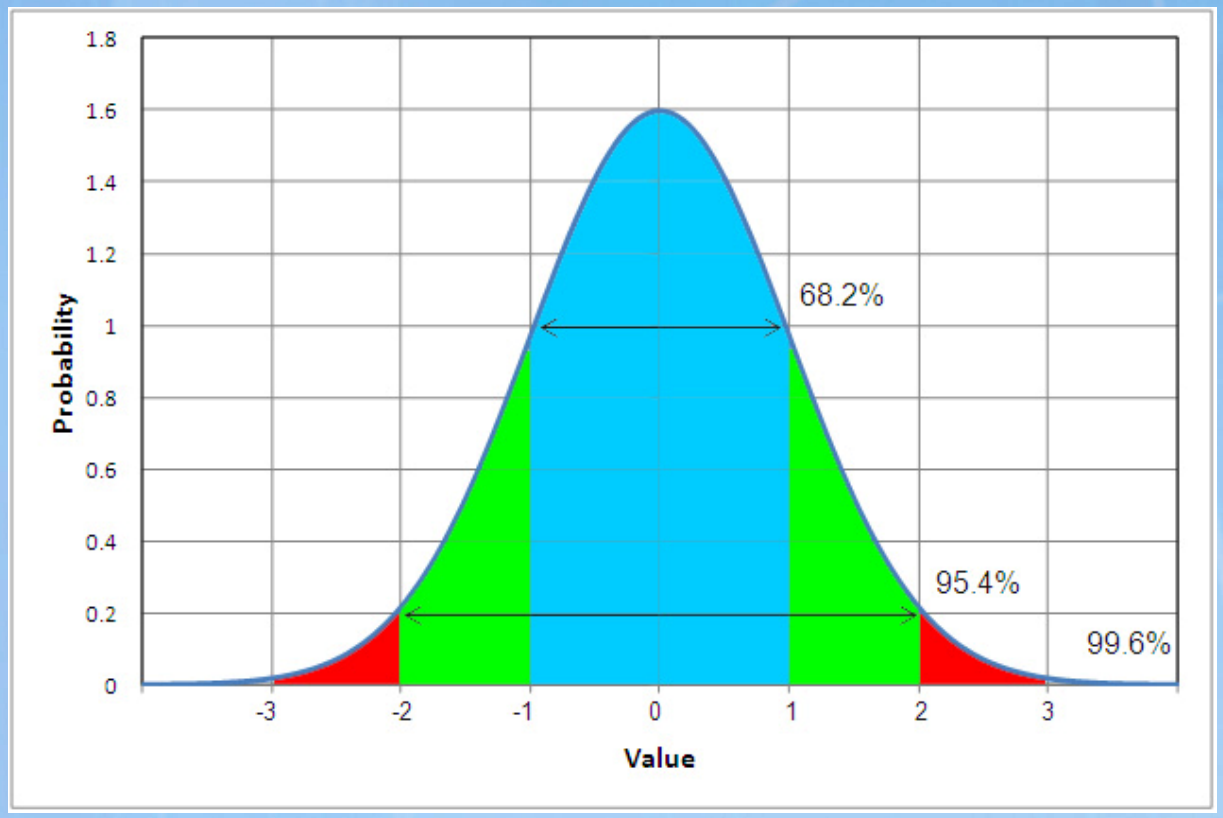
Normal Distribution

- What does the normal distribution look like?



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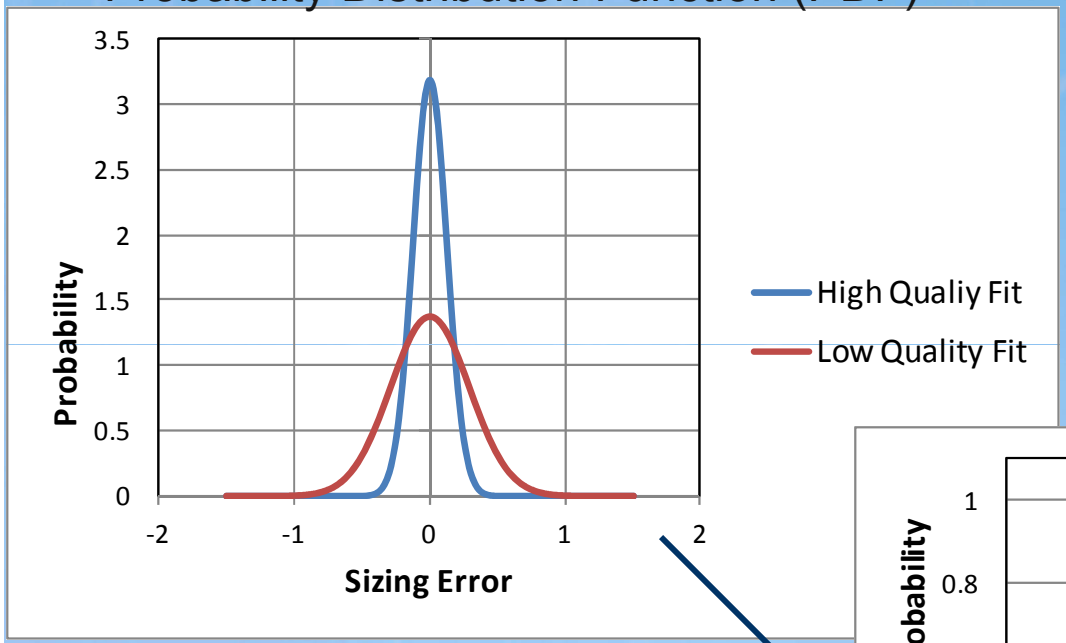
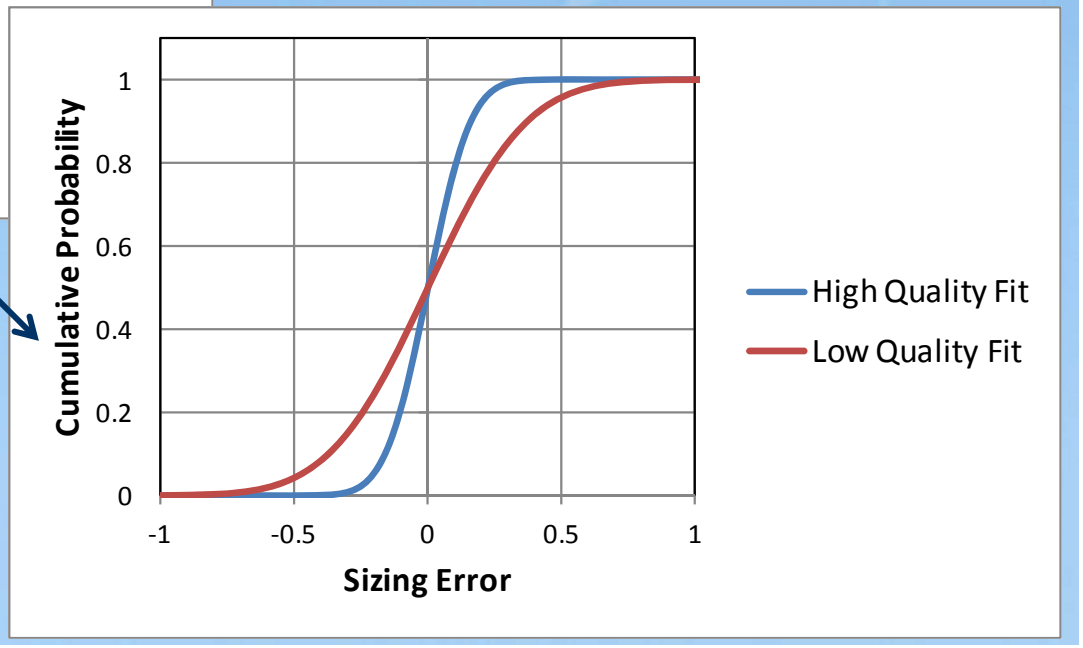
Comparing Distributions

Probability Distribution Function (PDF)



Cumulative Distribution Function (CDF)



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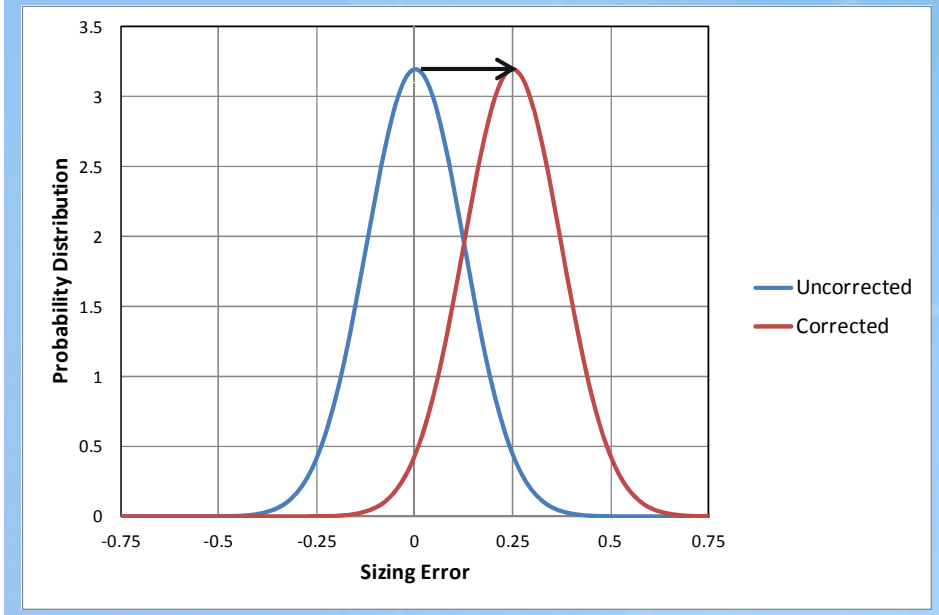
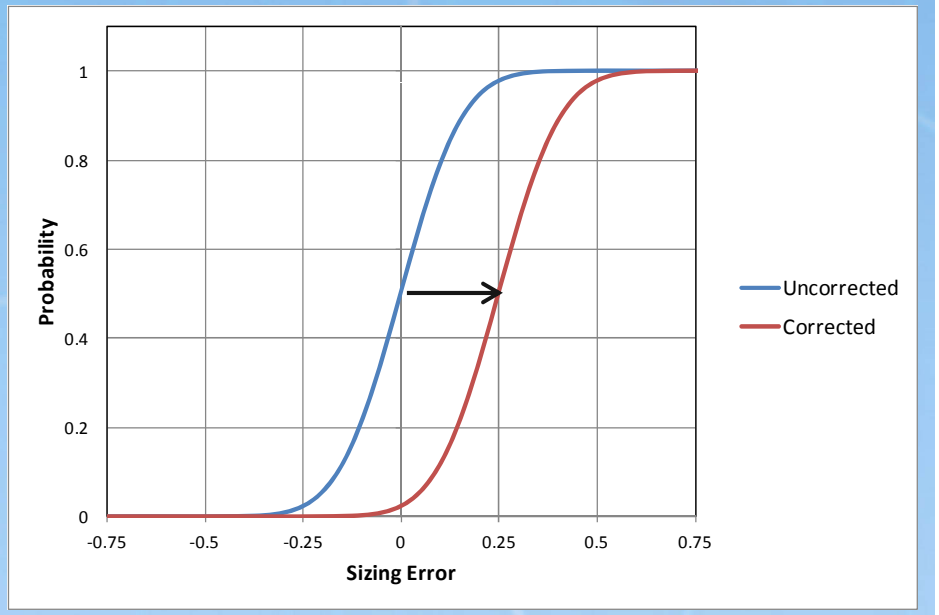
Correction Factors

What do Correction Factors do to the distributions?

Effects of a 0.25 Inch Offset to a 0.125 RMS Error Distribution





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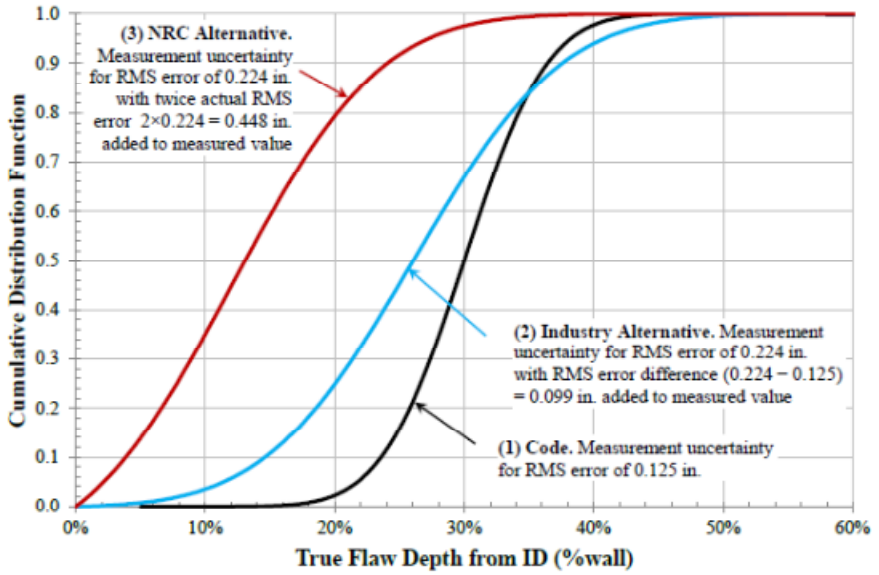
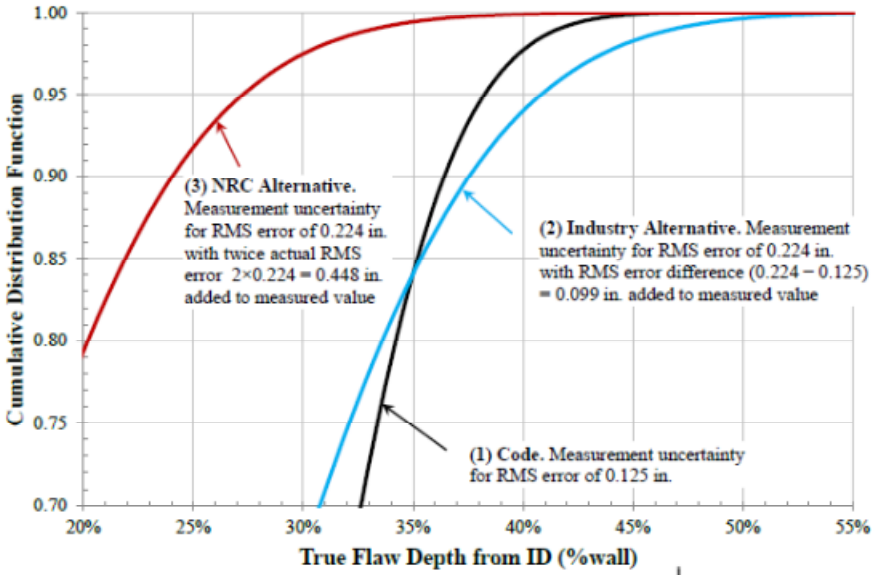
Industry Comparisons

- Glenn White presented an analysis that uses a truncated through-wall depth analysis and compared CDFs directly
- The 2 x RMS Error Solution appeared to be very conservative





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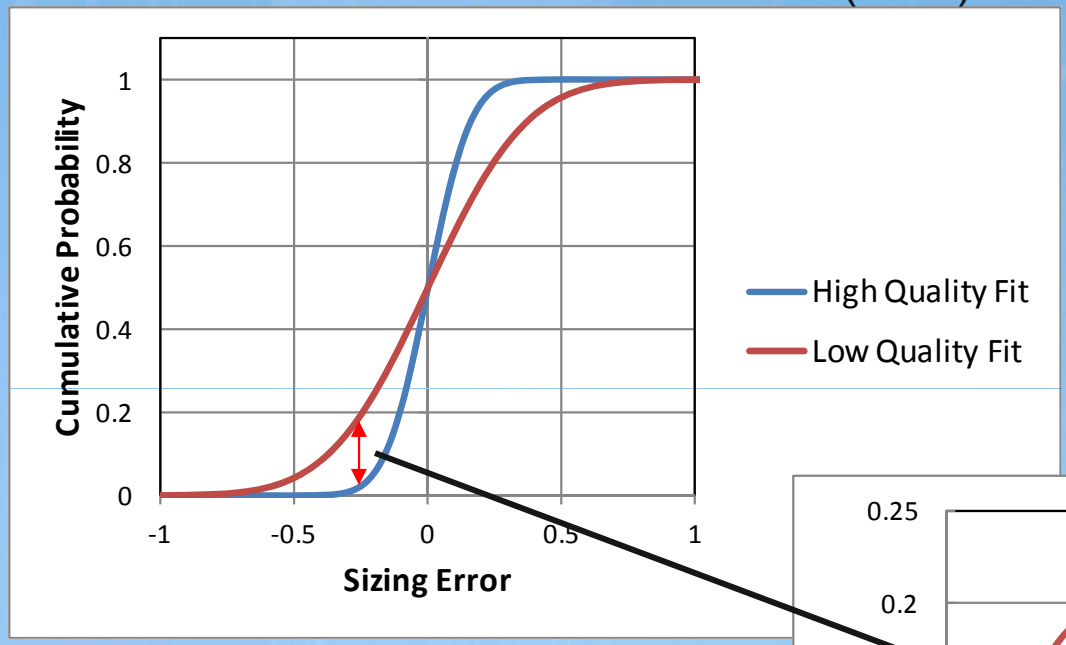
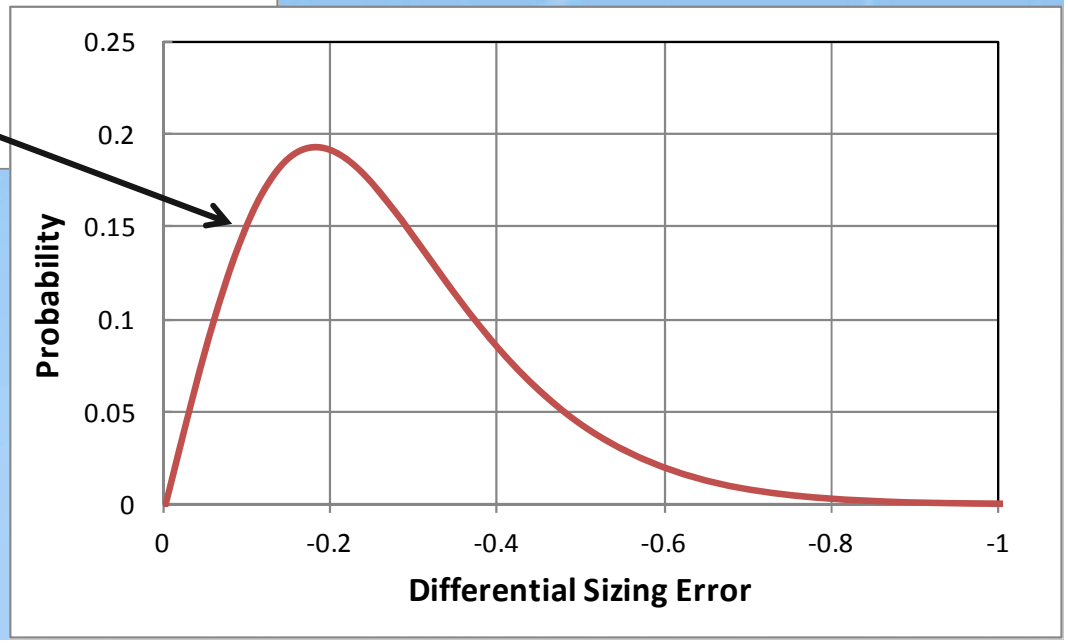
Comparison Aid

Cumulative Distribution Function (CDF)



Subtracted (CDF)



As we are comparing the alternatives to a fit meeting 0.125 inch RMS error, we can subtract the CDF of the good fit from the fit being evaluated to see where they differ and by how much they differ. Also, as we are only interested in undersizing, only half of the CDF will be evaluated.

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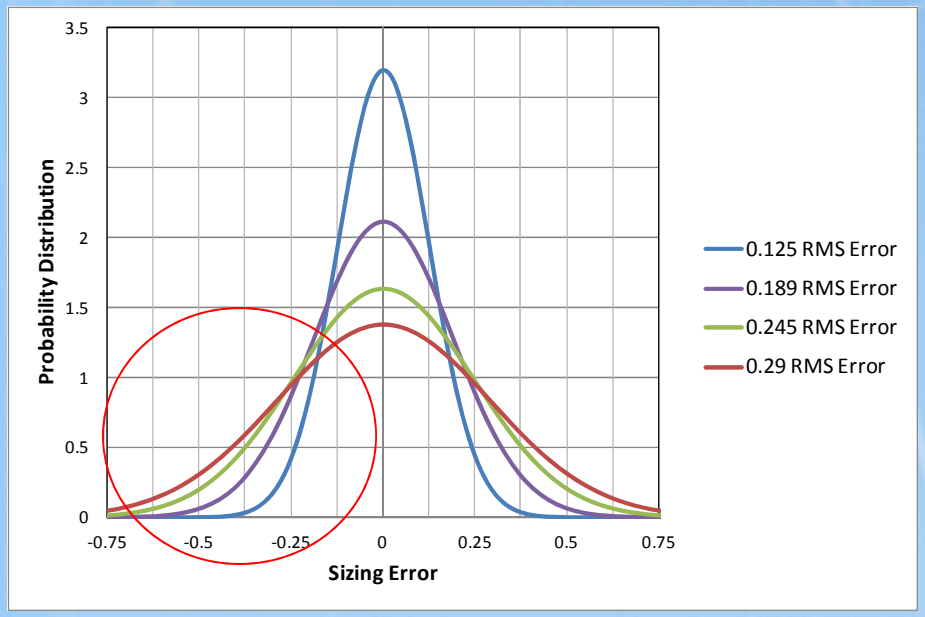
High RMS Error Fits

The high RMS Errors from the PDI procedure demonstrations suggest that the procedures would have a high probability of significantly undersizing flaws in the field if no correction factor is applied.

Until qualified procedures and personnel are developed, a correction factor may be useful until then.

Probability Distribution



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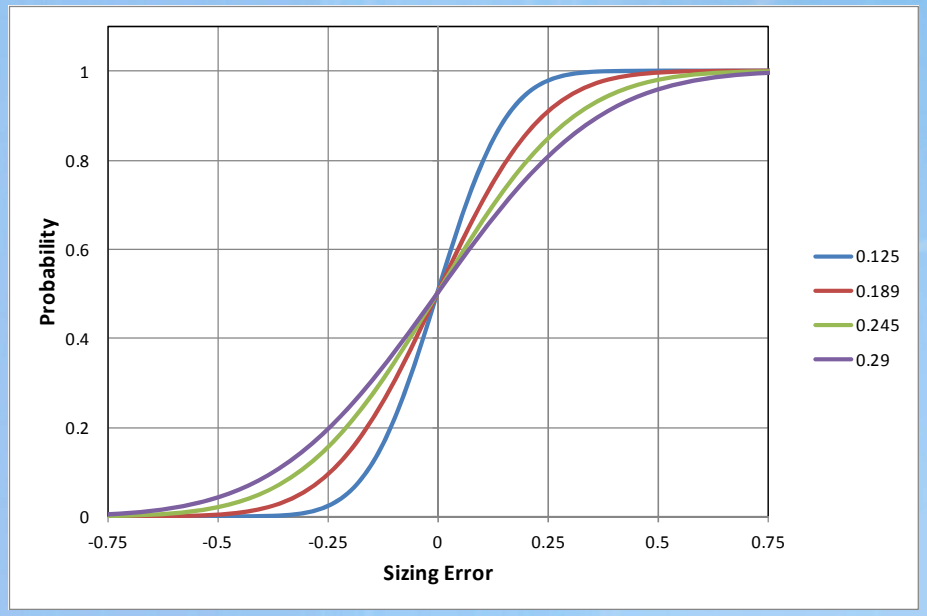
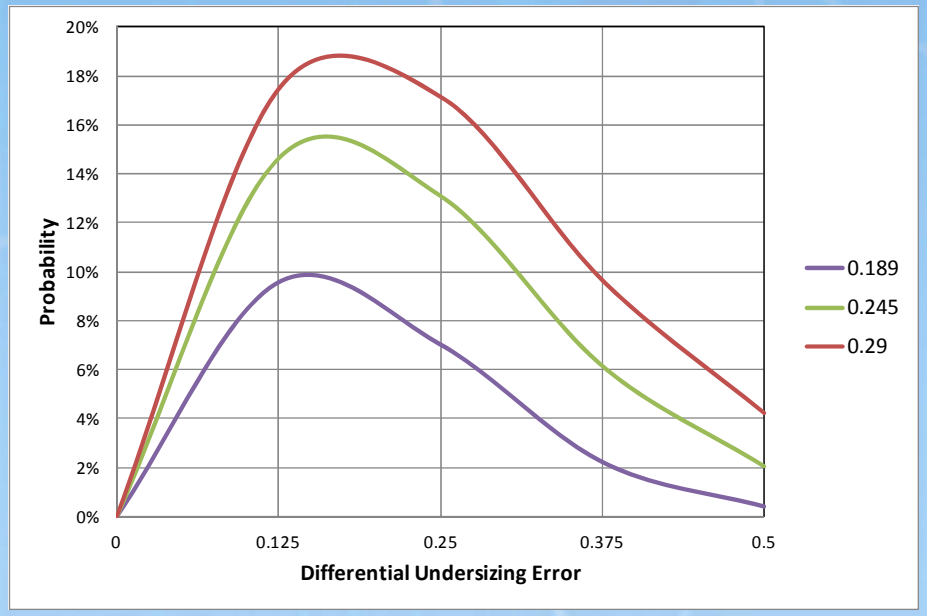
CDFs For No Correction

Cumulative Probability Functions



Cumulative Undersizing Probability Relative to 0.125 RMS Error



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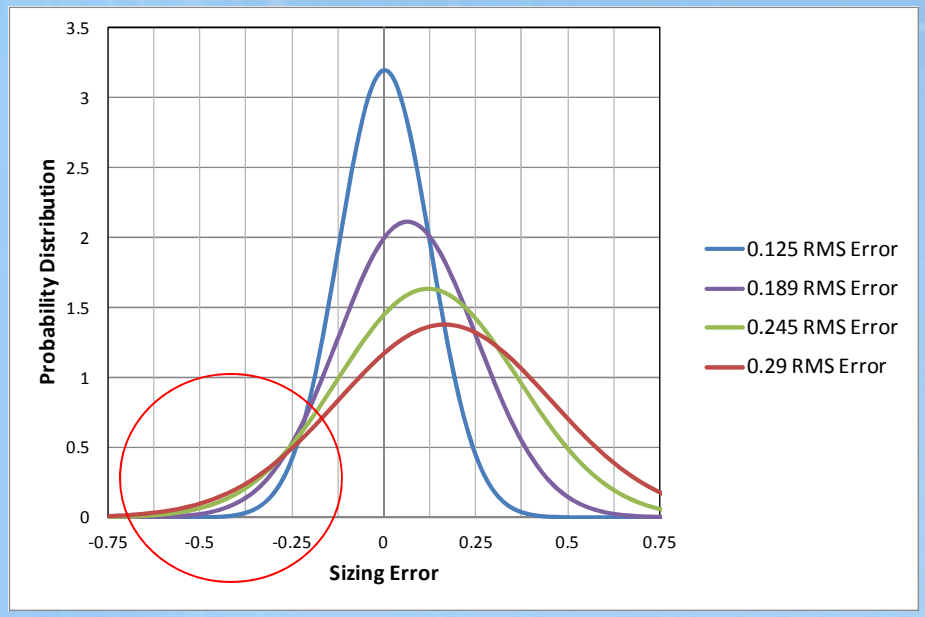
Industry-Proposed Correction Factor

The correction factors shift the centers of the distributions, reducing the fraction of the distribution that causes undersizing.

The use of the RMS Error – 0.125 inches improves the outlook, but is not conservative relative to the accepted 0.125 inch standard for larger errors

Probability Distributions



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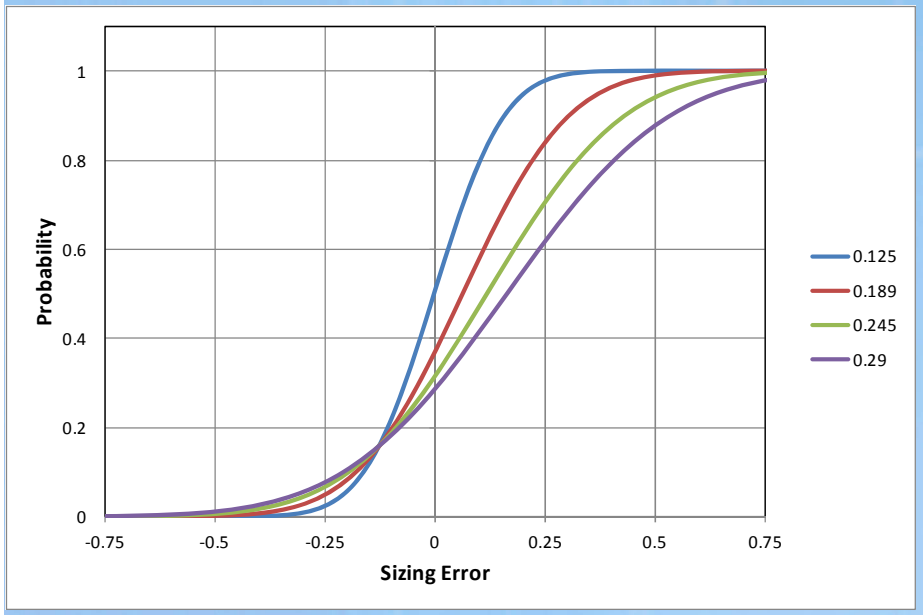
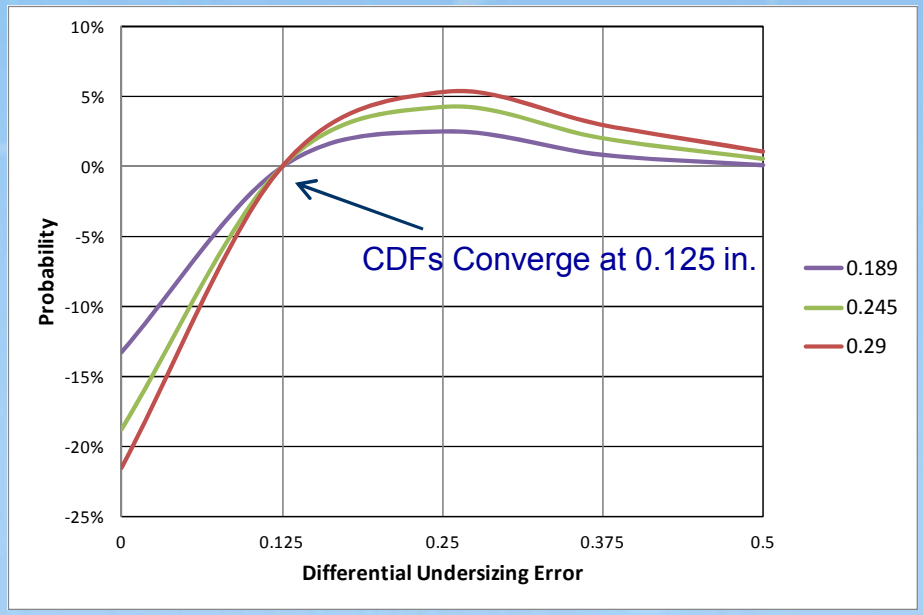
CDFs For Industry Correction

The RMSE - 0.125 Correction factor makes all CDFs match at 16% at 0.125 Inches

Cumulative Probability Functions



Cumulative Undersizing Probability Relative to 0.125 RMS Error



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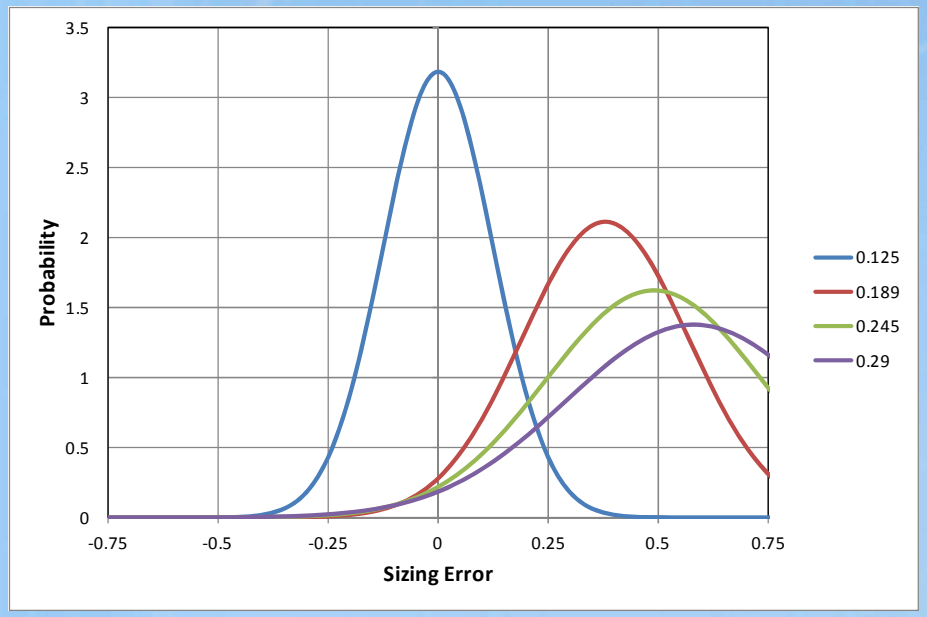
How Does 2x RMS Error Compare?

The 2xRMS Error value was chosen to eliminate outliers and correct for what appeared to be a non-normal distribution in the sizing errors. If one uses the normal distribution the 2 x RMS Error correction factor is conservative relative to a fit meeting 0.125 inch RMS Error



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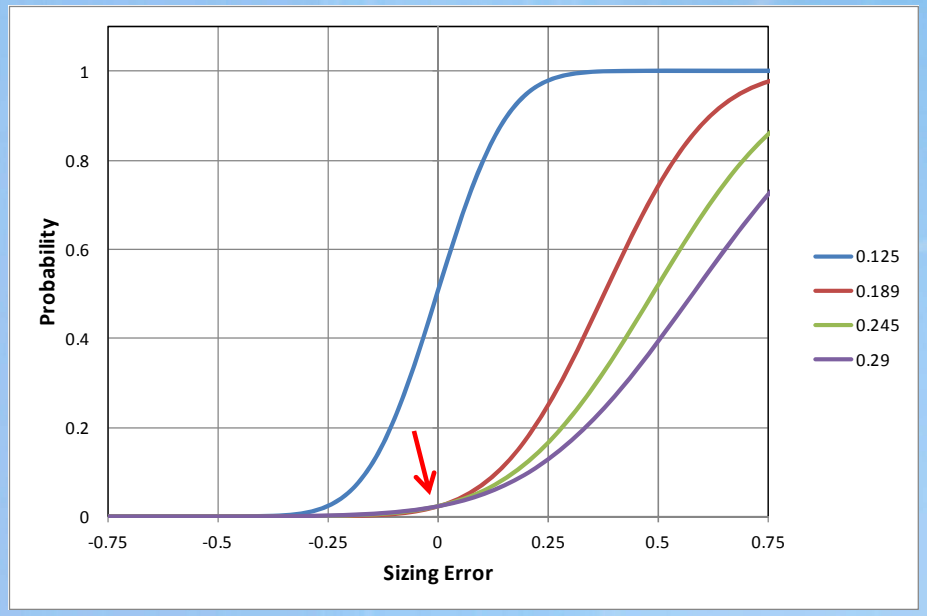
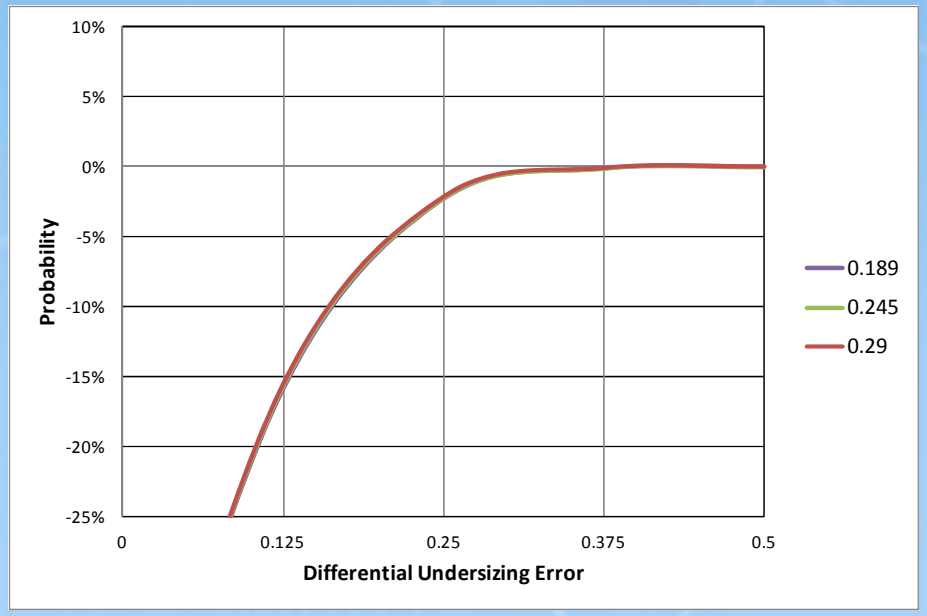
How Does 2x RMS Error Compare?

The 2 x RMS Error value makes corrected CDFs converge at 2.3% at 0





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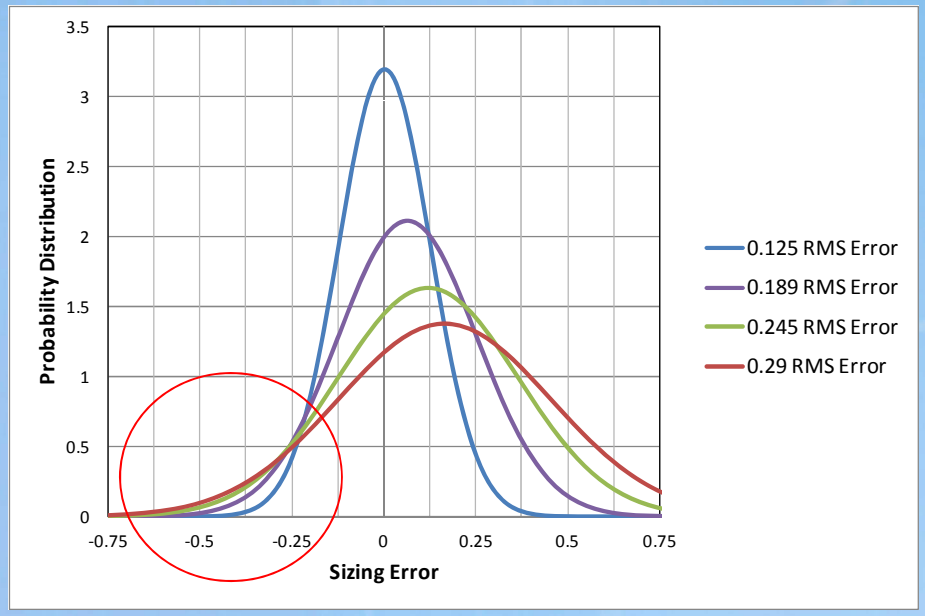
Discussion

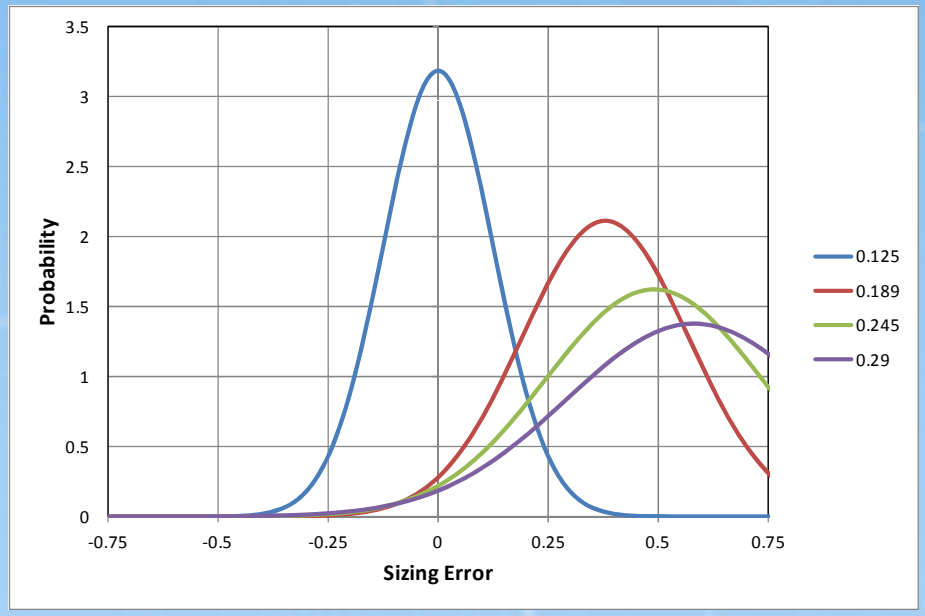
Comparing the two Proposed Correction Factors

RMS Error – 0.125



Increased chances of large undersizing

2 x RMS Error



Significant Oversizing Challenging for MSIP

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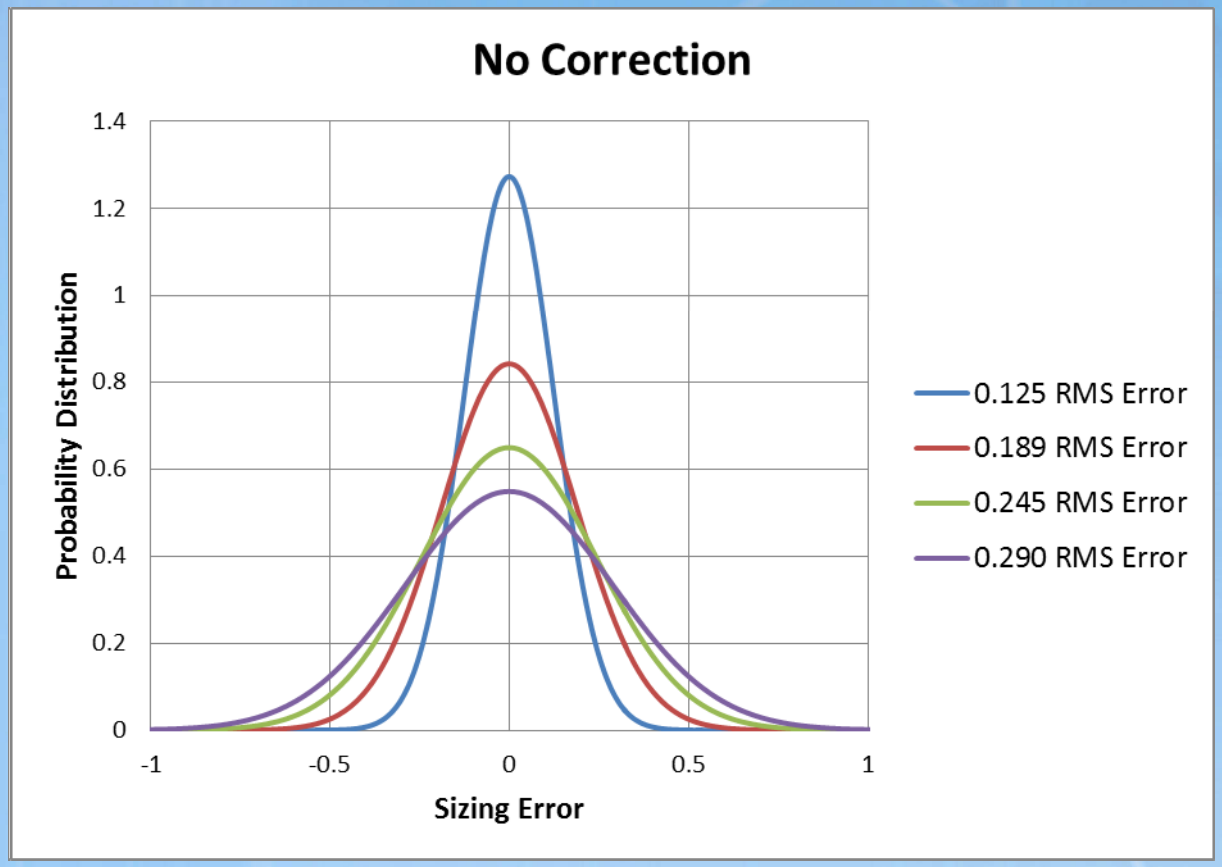
Choosing the Correct Factor



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Is the Normal Distribution Correct?

- All of the analysis have assumed a normal distribution.
- Is this assumption valid?
- Is a bimodal distribution more accurate?
- There are (at least) two distinct situations, good ultrasonic coupling and bad ultrasonic coupling
- What effects would this have on the statistics?

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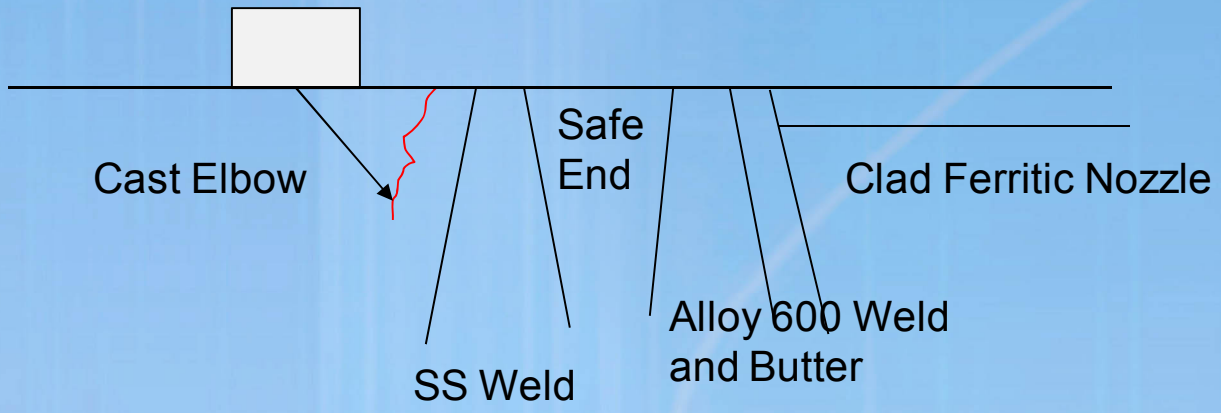
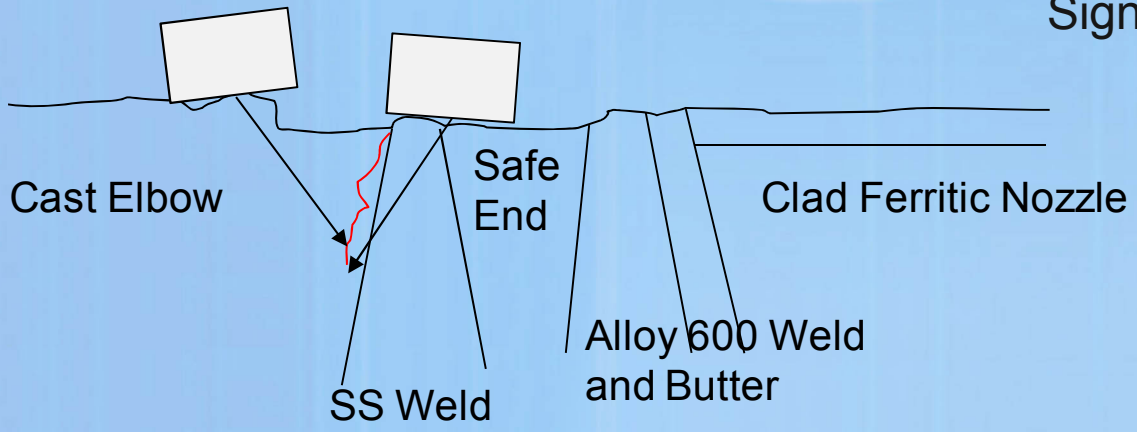
Bimodal Sizing Error?

Close to 0.125 inch RMS Error



Significantly Worse RMS Error



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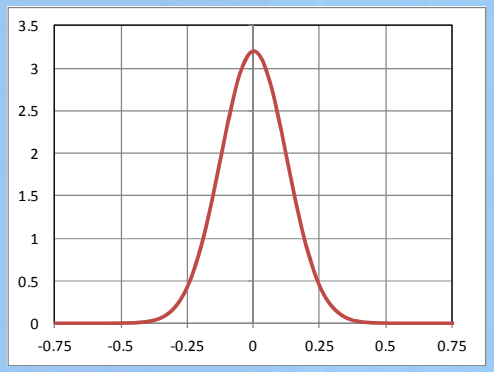
Testing Correction Factors for Bimodal Data

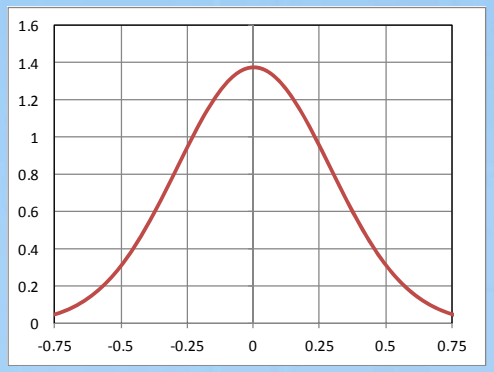
- The statistical analysis was performed aging using two combined standard deviations
- One distribution used a standard deviation of 0.125 inches
- The second varied between 0.3 inches and 0.5 inches
- The fractional contribution of the two distributions was allowed to vary to fine tune the RMS error of the combined distribution

73% with 0.125 inch Sigma



+

27% with 0.300 inch Sigma



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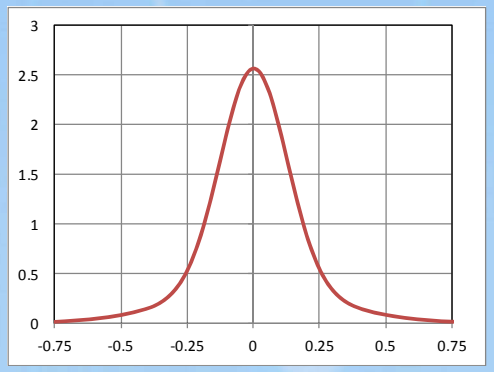
Bimodal Distribution with 0.189 inch RMSE



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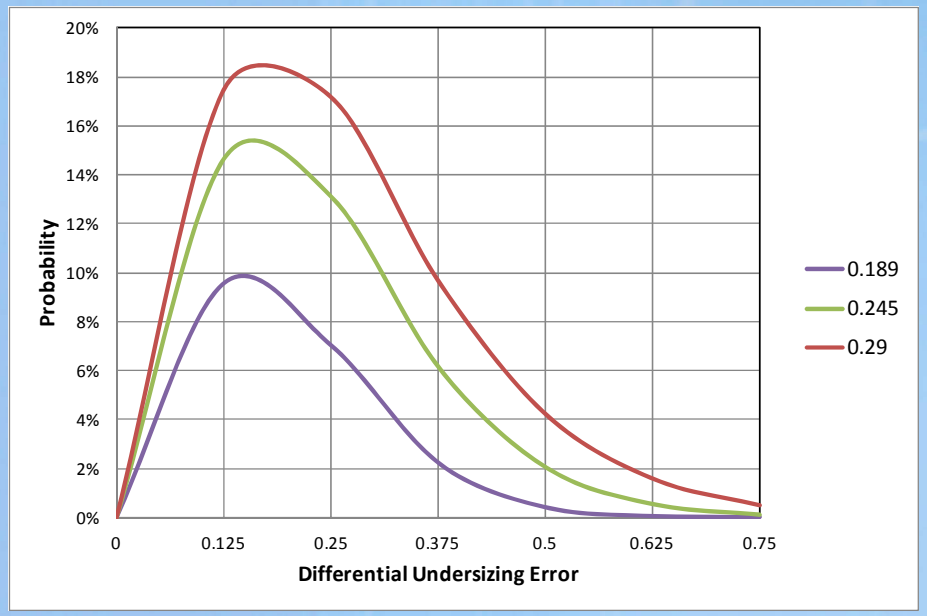
Effects of Bimodal Distribution

Based on the examination, using a bimodal distribution does affect the probabilities of larger error, but not by a large amount

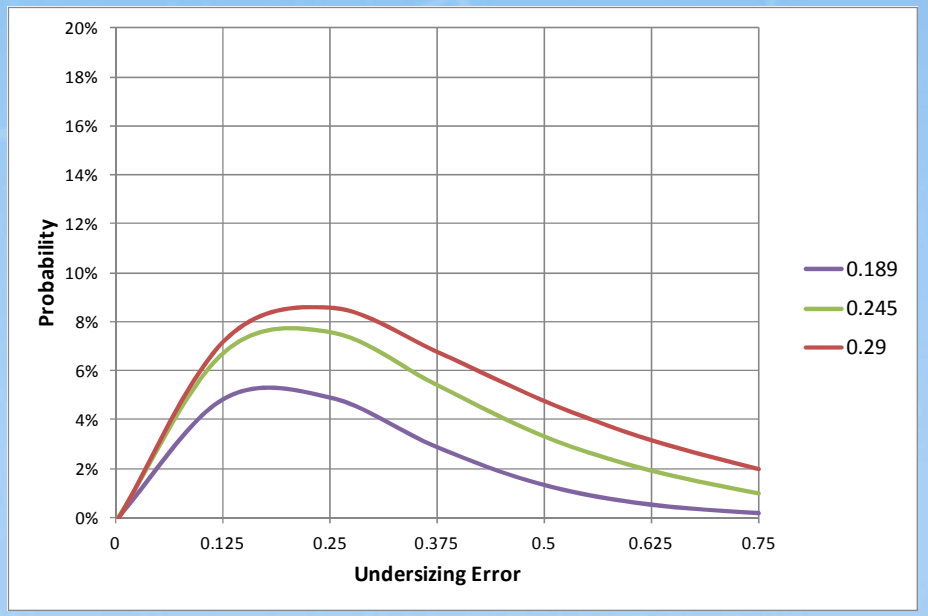
The Bimodal distribution produces a lower probability for small errors when no correction factor is applied

CDFs Relative to 0.125 RMS Error with no Correction Factor

Normal



Bimodal



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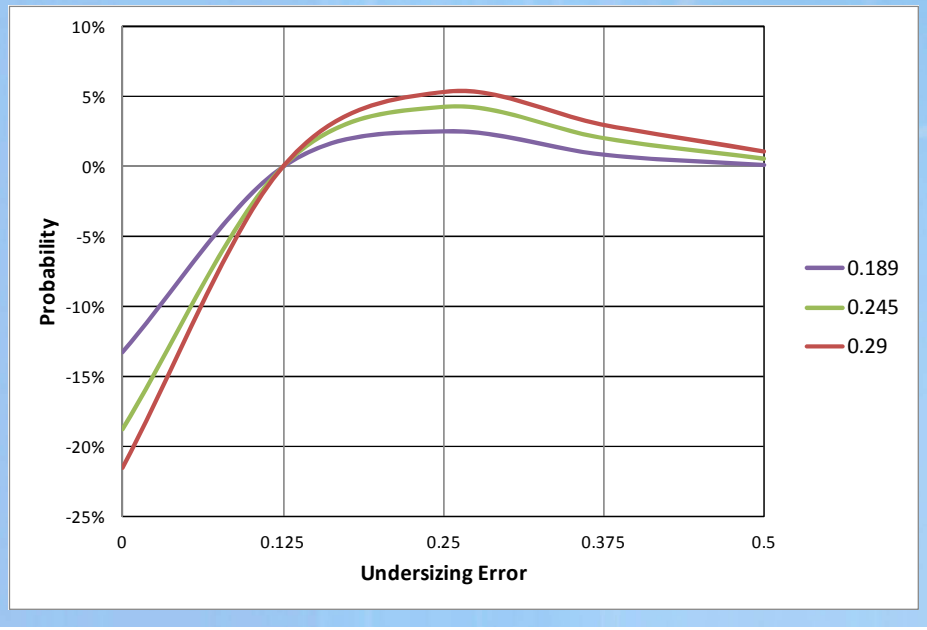
Industry Correction Factor for Bimodal Distribution

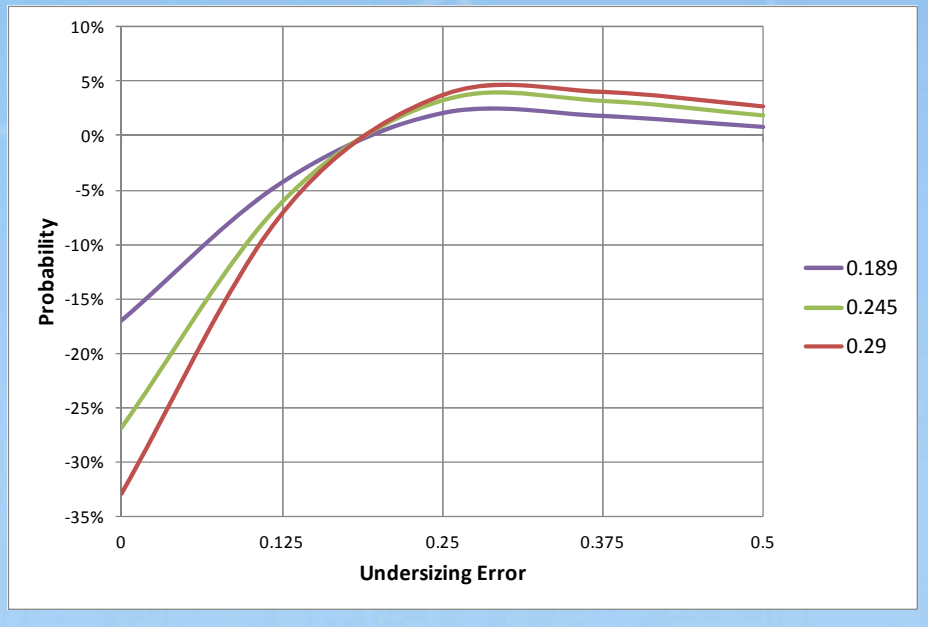
The long tails of the bimodal distribution increases the sizes of the undersizing for the RMS Error – 0.125 inch correction.

CDFs Relative to 0.125 RMS Error with RMS – 0.125 in. Correction Factor

Normal



Bimodal



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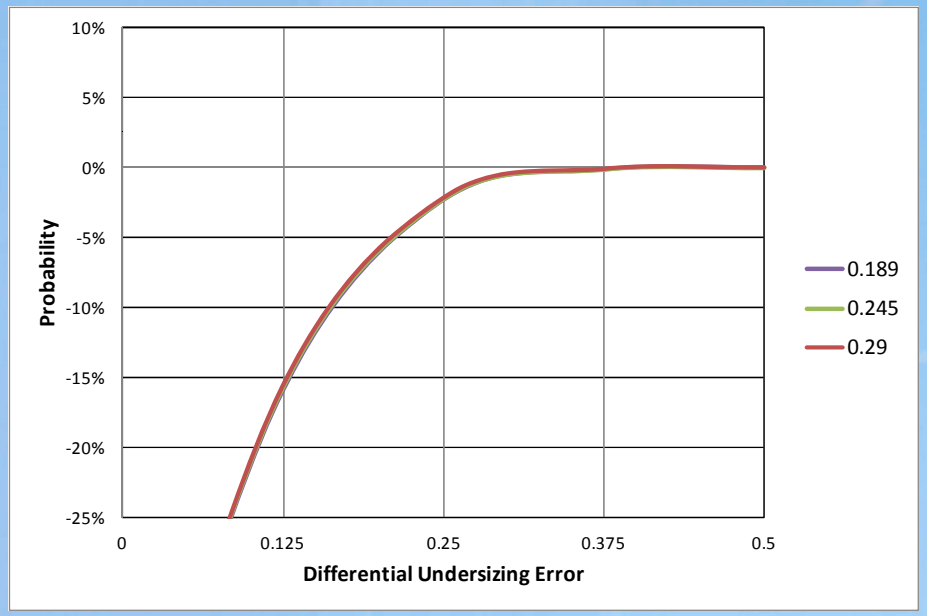
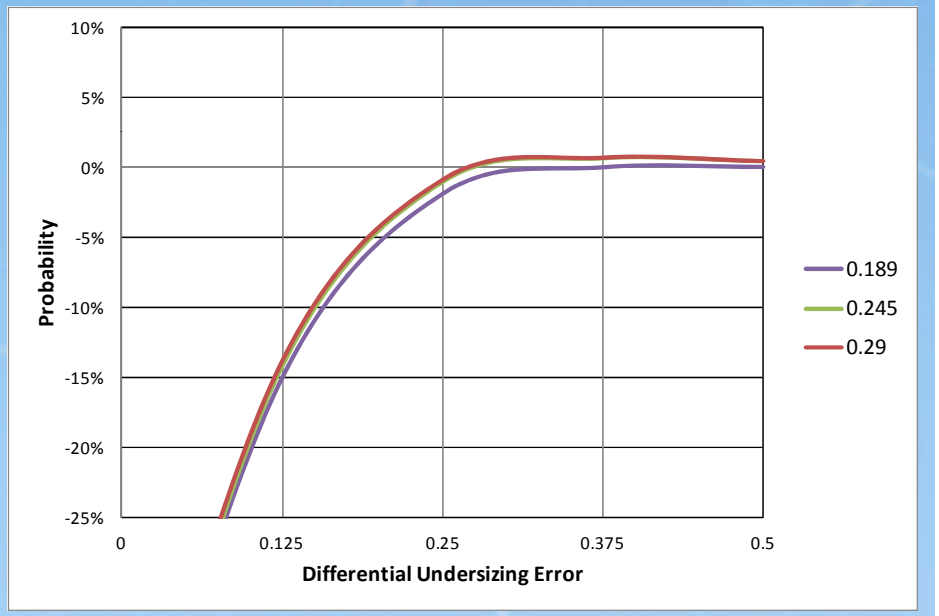
2xRMS Error

CDFs Relative to 0.125 RMS Error with 2xRMS Error Correction Factor

Normal



Bimodal



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Discussion

- What goals can we agree on for the statistical analysis?
  - As conservative as a fit meeting 0.125 inch RMSE?
  - Low probability of a large undersizing error?
- What should be the target for the correction factor?
  - Make all CDFs converge at 0.125 inch?
  - Make corrected CDFs converge at 0?
  - Make CDFs converge somewhere else?
- What statistical model should we use?
  - Normal?
  - Bimodal?
  - Something else?

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Discussion

- The industry proposed correction factor is much better than using no correction factor, but is not as conservative as a 0.125 inch RMS Error fit.
- The 2 x RMS Error correction factor is almost always conservative, as it reduces the possibility of undersizing at all from 50% to 2.3% (assuming normal distribution).
- A bimodal distribution of sizing errors does affect the probability of gross undersizing, but appears to be mitigated by the correction factors.

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Path Forward

- PDI and NRC staff will meet in late July to evaluate the sizing data at PDI
- The sizing data will be tested to determine if it fits the normal distribution or some other distribution
- The effect of different correction factors will be evaluated