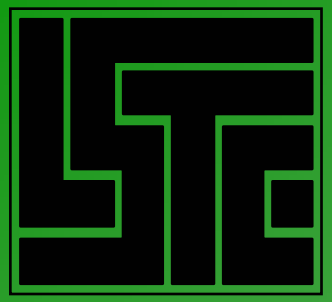

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# Probabilistic Analysis with LS-OPT

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***LSTC***

**Information Day**
"Nonlinear Optimization and Stochastic Analysis"
Mai 27, 2003

# Overview

- New Features in LS-OPT 2.1
- Probabilistic Structural Behavior
- LS-OPT Capabilities
- Example
- Summary
- Customer Feedback

# New Features: LS-OPT 2.1

- **Probabilistic Modeling**
  - Model and compute structural and response variation
- **Metamodeling**
  - Kriging Metamodel added to RSM and Neural Nets
- **Search Methods**
  - Sequential Random Search (SRS)
- **LS-DYNA interface**
  - Binary interface (LS970)
- **Other:**
  - Improved restart
  - GUI
- **<u>LS-OPT is free of charge on a LS-DYNA license</u>**

# Probabilistic Analysis
## Objectives

**1. Modeling of Variability**

- Repeatability of Response

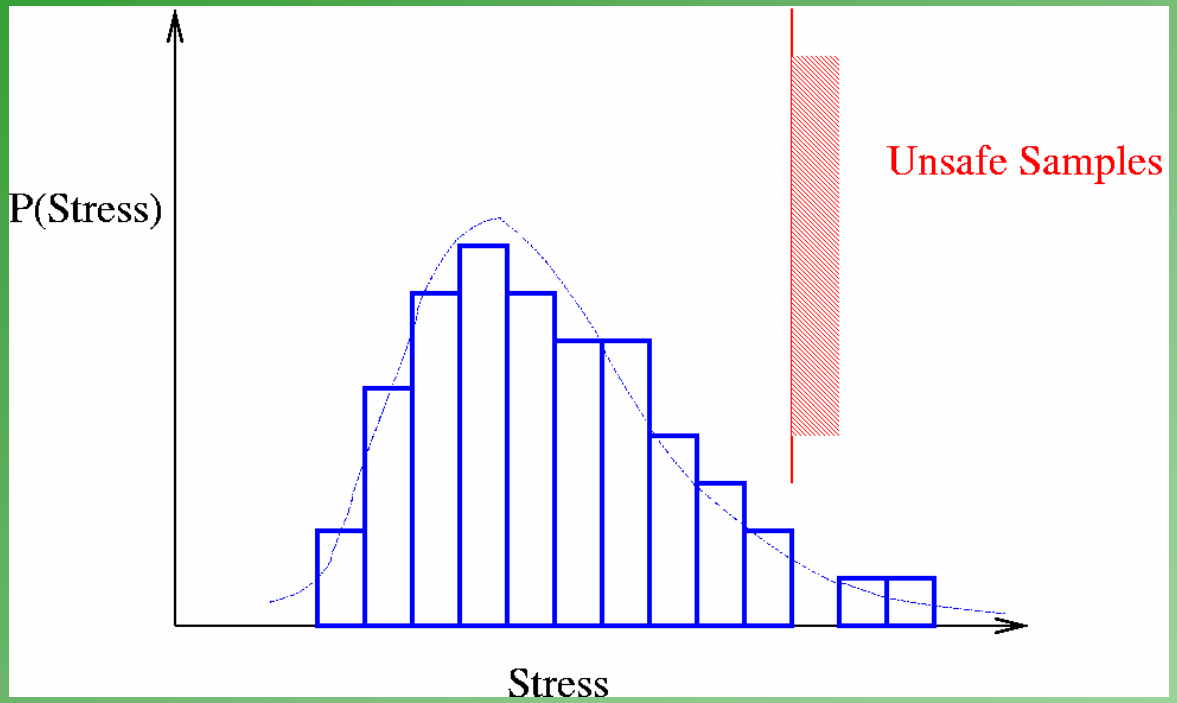
**2. Design Criteria**

- Probability of failure
- Robustness (Variance)

**3. Redesign**

- Source of variability

# Response Variability




**Response distribution**

- Mean
- Standard deviation

**Probability of Failure**

# Response Variation

- **Deterministic Variation**

  Due to change in a parameter value (controllable or uncontrollable)

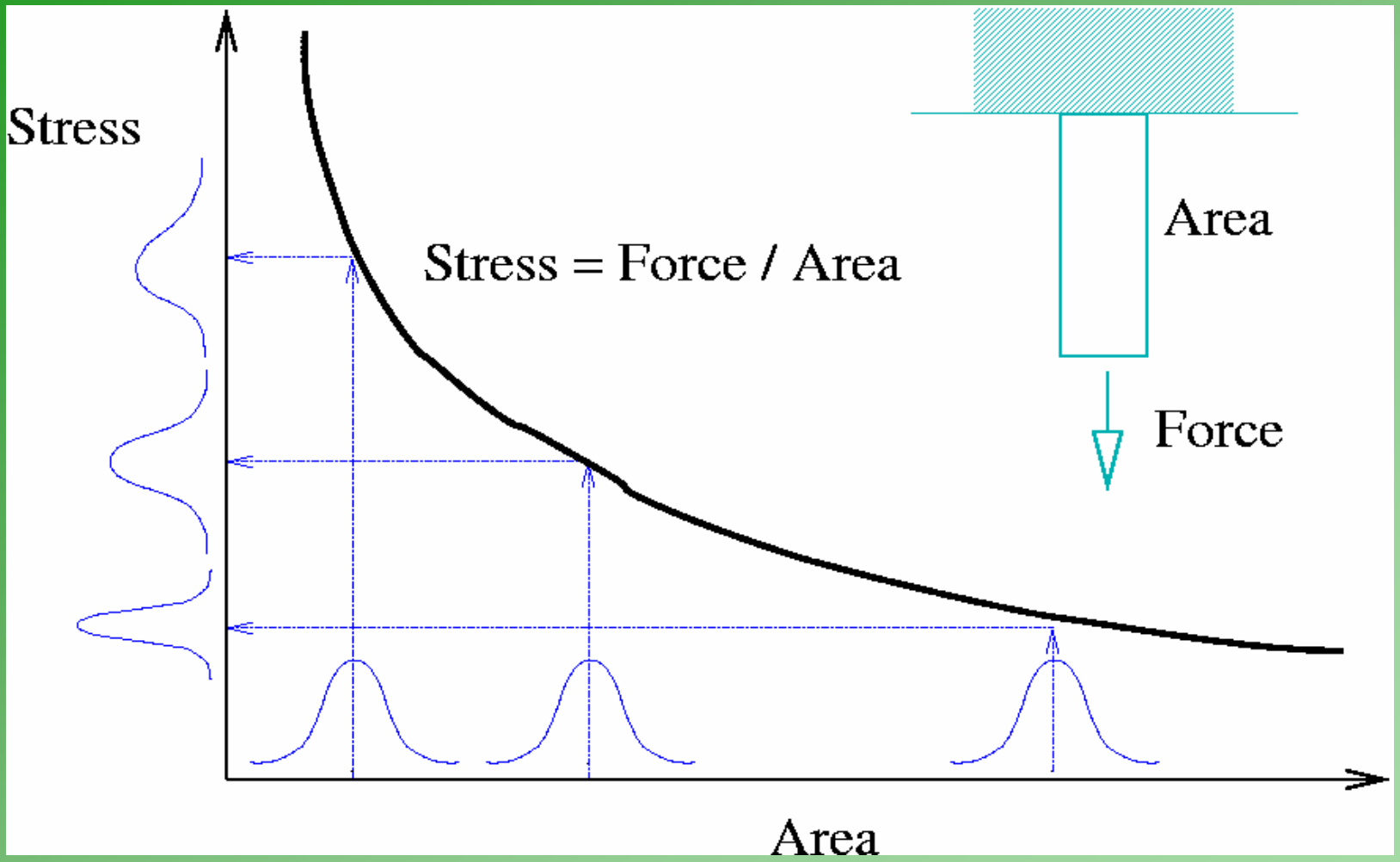
- **Chaotic Variation**

  Bifurcation

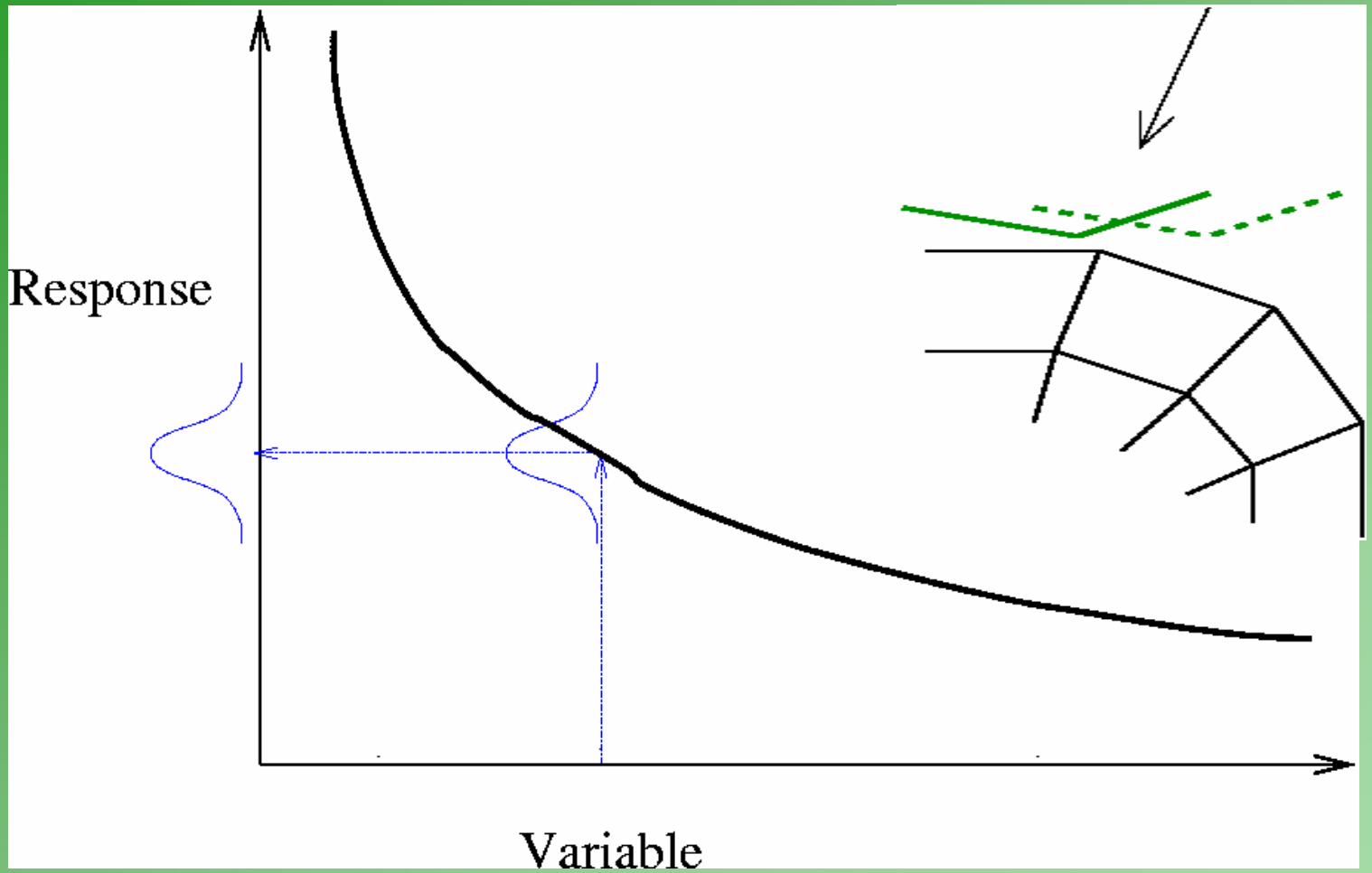
- **Random Variation**

  Variability not explainable by the design model, e.g. mesh, roundoff, lack of convergence

# Deterministic Variation



# Random Variation




# Sources of Variation

- **Structural**
  - Design parameters
- **Environment**
  - Load, material properties
- **Modeling**
  - Mesh density
- **Analysis**
  - Algorithm convergence, contact
- **Roundoff**

# Parameter Variation

- **Control Variables**

  **Values are controlled by designer**

  - Gauge
  - Shape

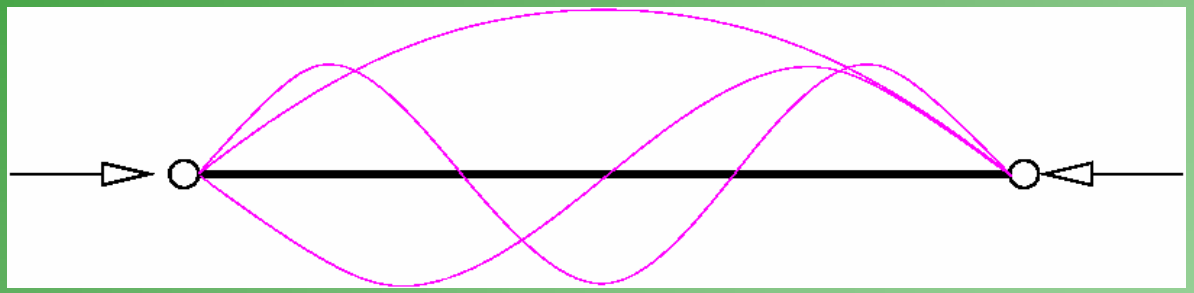
- **Noise Variables**

  **Values not controlled by designer but can vary**

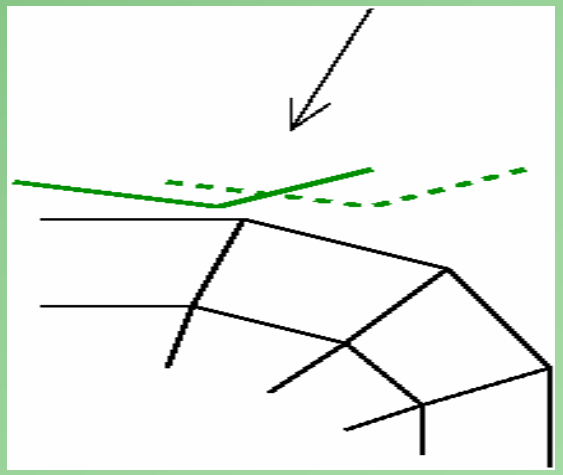
  - Load
  - Yield stress
  - Stiffness
  - Thermal

# Sources of Variation Classification

- **Analysis Variation**
  - Physical – buckling



  - Algorithmic – contact



# Sources of Variation Classification

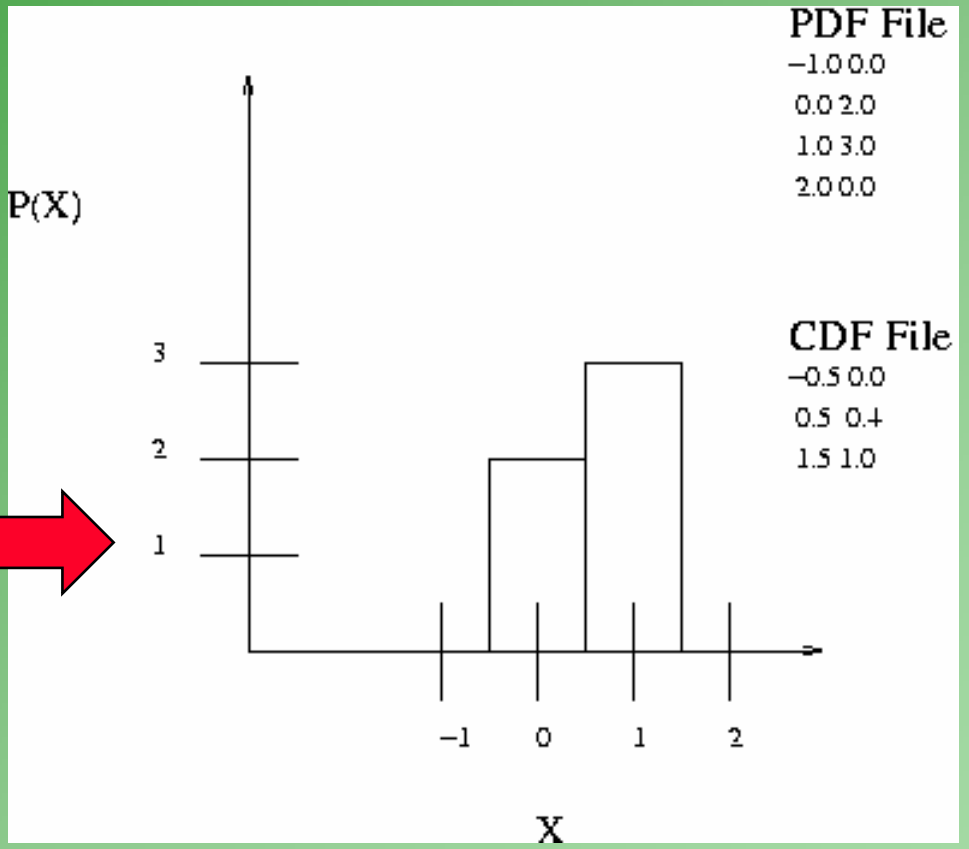
- **Modeling Variation**
  - FE mesh
  - Postprocessing, time step size and filter selection, convergence
  - Convergence: Iterative implicit solvers
  - Selection of node/element to monitor
- **Roundoff**
  - Machine precision
  - Different platforms give different results

# LS-OPT Probabilistic Capabilities

- **Statistical Distributions**
- **Stochastic Sampling Techniques**
  - Monte Carlo
  - Monte Carlo using Metamodels: Polynomials, Neural Nets
- **Design Criteria**
  - Probability of Failure
  - Robustness (Variance)
- **Distributed LS-DYNA job execution and data collection**

# Statistical Distributions

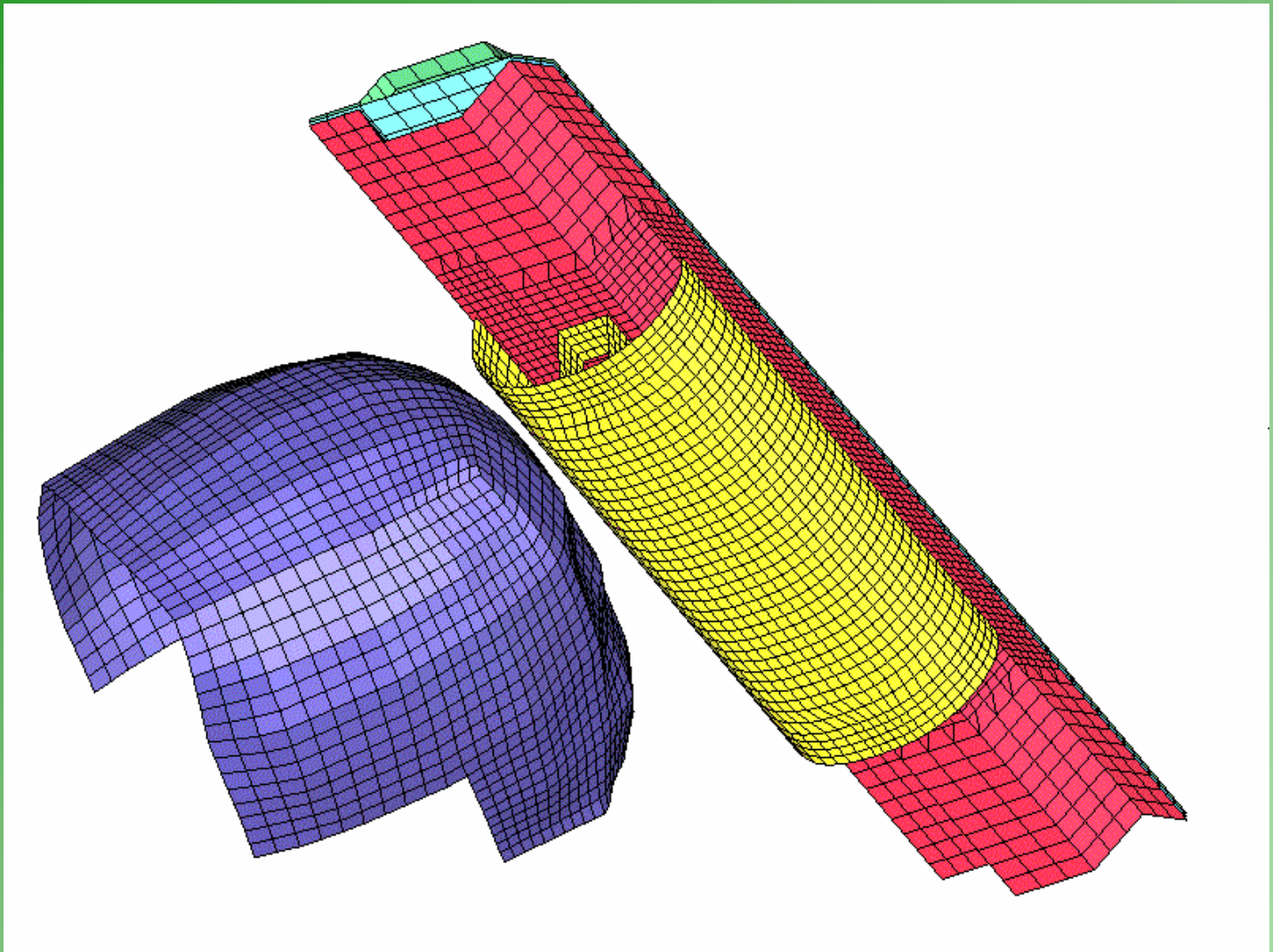
- Normal
- Uniform
- Lognormal
- User defined
- Weibull



# Sampling

- **Random**
- **Latin Hypercube**
  - Structured Monte Carlo
- **Space-filling**
  - Maximizes minimum distance between any two points

# Example – Head Impact Problem

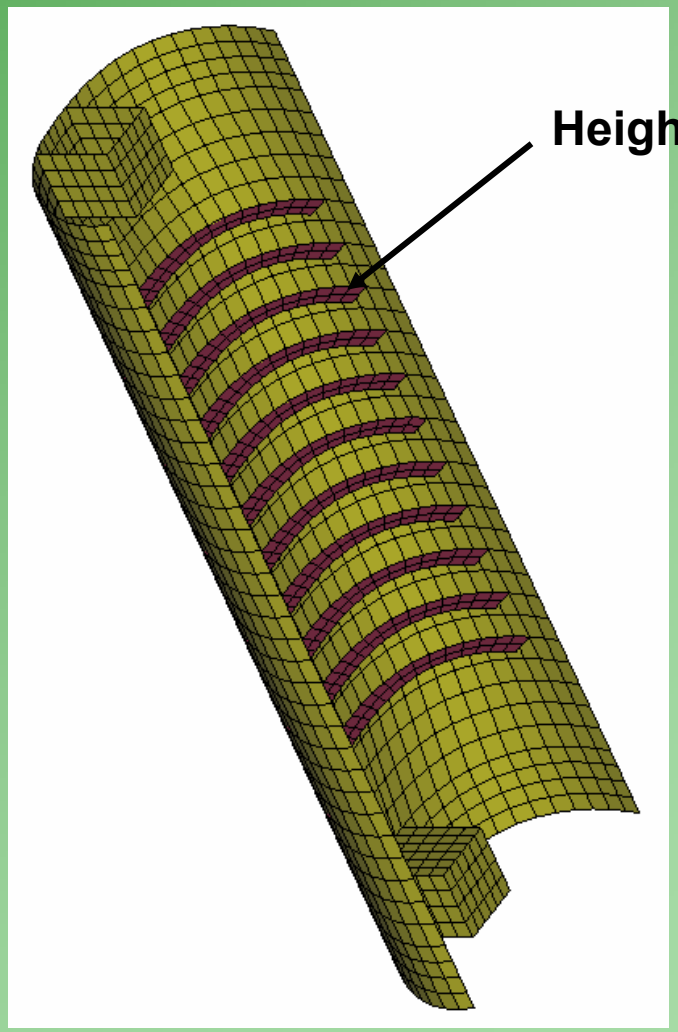


# Head Impact Problem

- **Monitor: Head Injury Criterion:**

  **HIC-d**

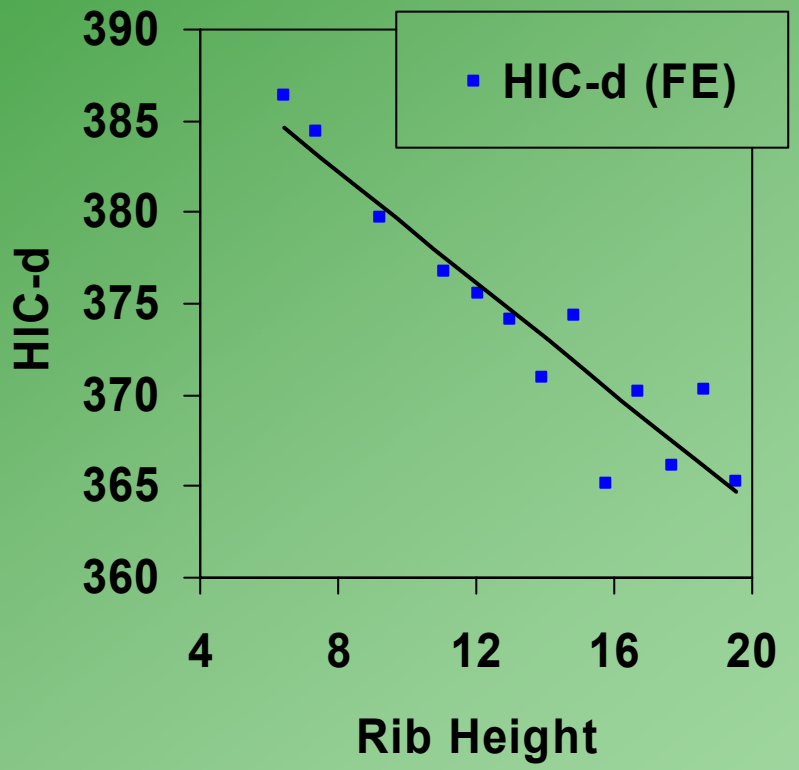
- **Variables:**
  - Hor. Angle of impact
    - 15 degrees
    - 10% standard deviation
  - Rib height
    - 12.5mm
    - 5% standard deviation



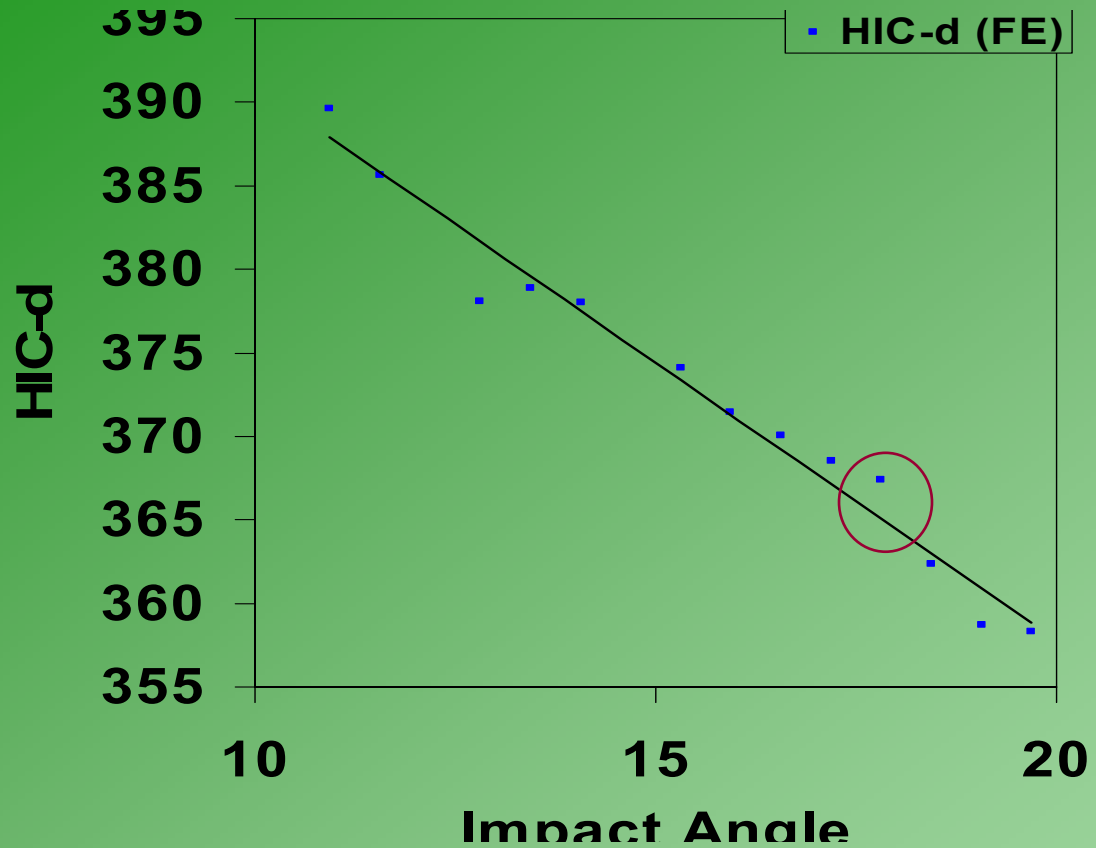
# Variation

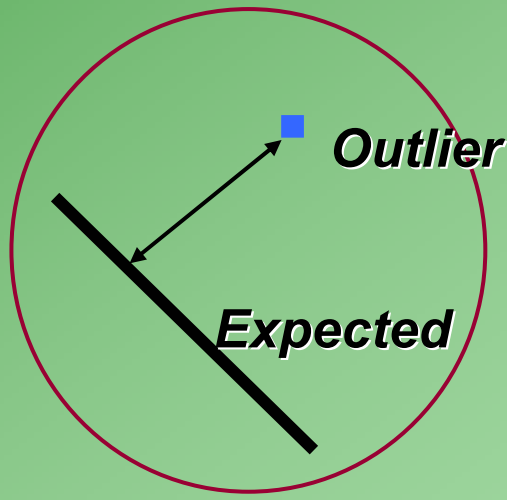
Vary one variable at a time to investigate curvature.

Linear response with some scatter (noise).



# Variation




- Quadratic Surface should fit accurately
- Range of response surface is $2\sigma$

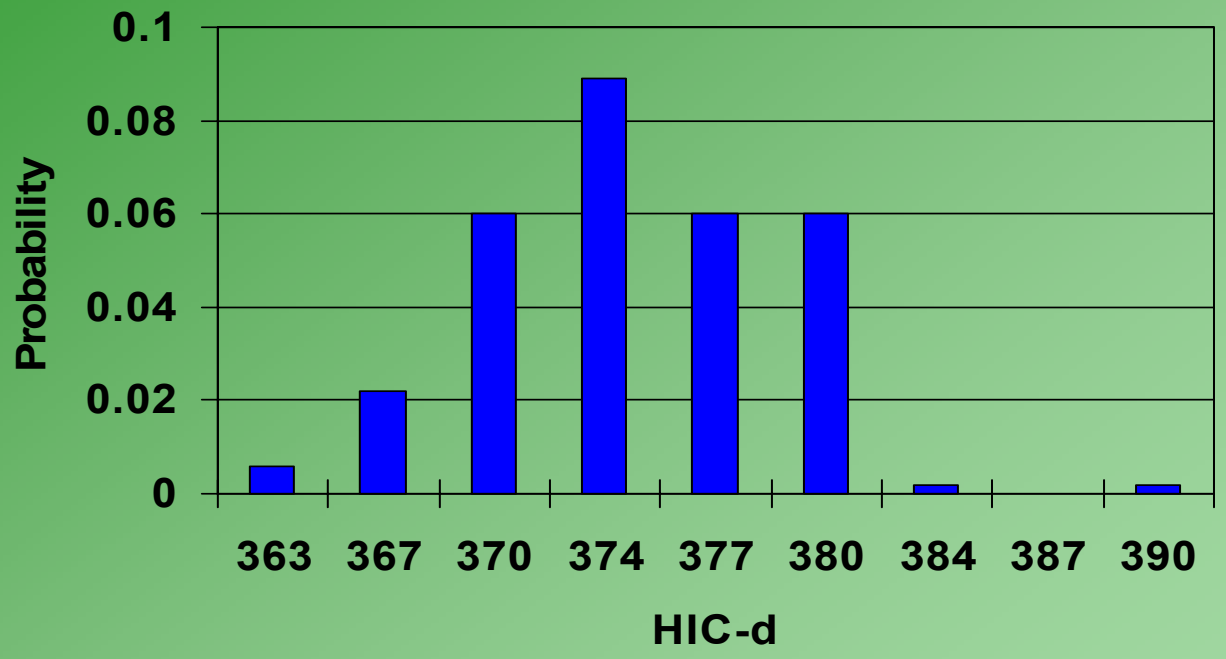
# Response Variation

- **Baseline Design:** HIC-d = 374.4
- **Monte Carlo Analysis:** 150 FE analyses
- **Quadratic Response Surface:** 60 FE analyses. Residuals have standard deviation of 2.35.

| | Monte Carlo (150 simulations) | Metamodel (60 simulations) |
|---|---|---|
| Mean | 373.9 | 373.9 |
| Standard deviation | | |
| ▪ Deterministic | | 4.21 (87%) |
| ▪ Deterministic + Outliers | 4.85 | 4.83 |

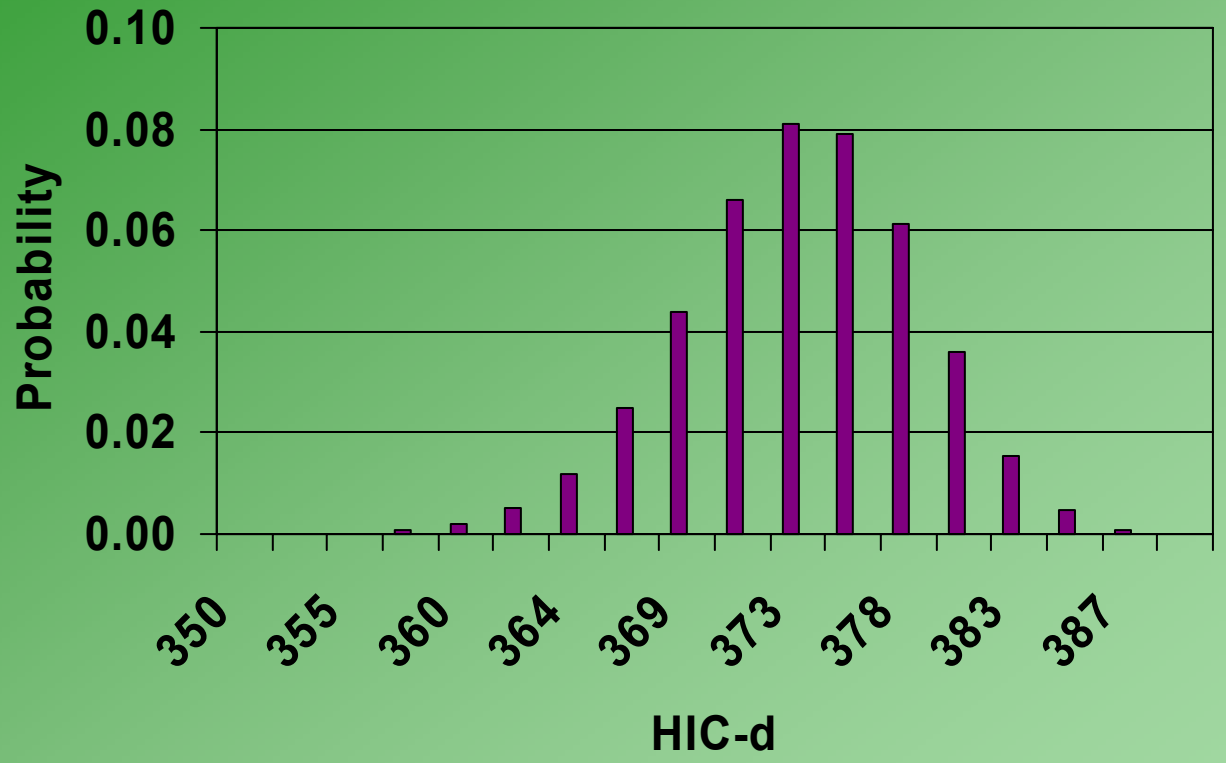
# Probability of Value

**Monte Carlo Analysis Values**

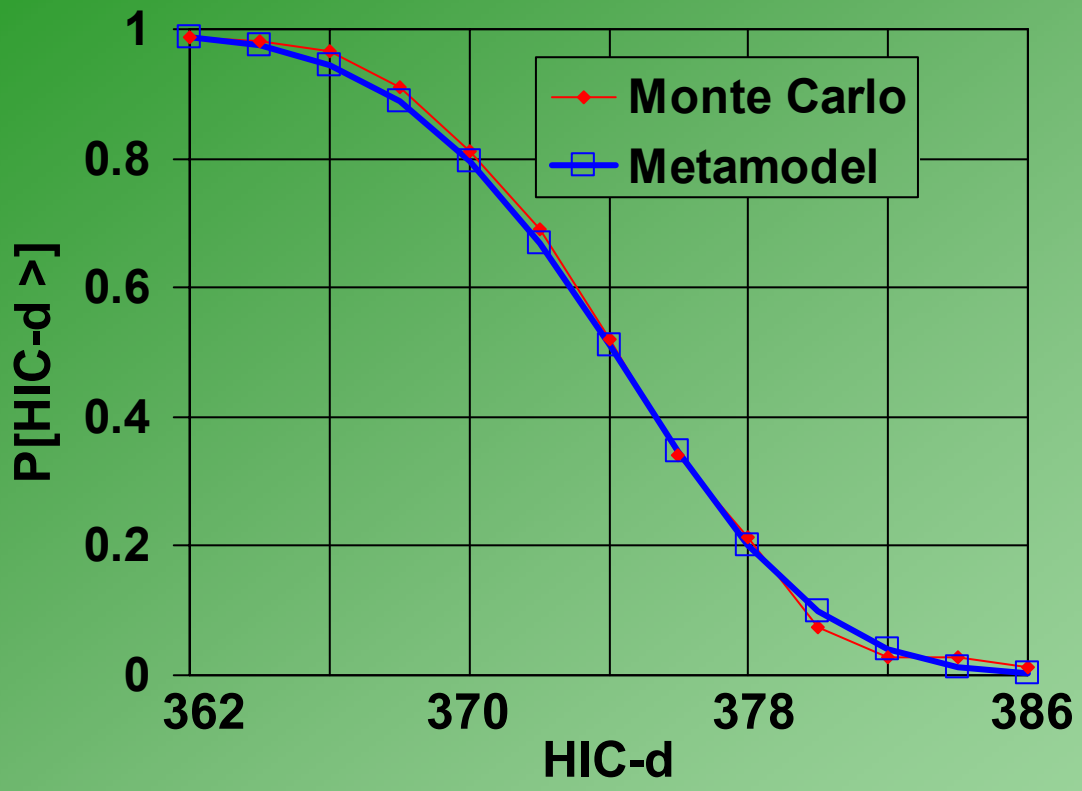


# Probability of Value

**Metamodel values**



# Probability of Exceeding Bound




# Derivatives

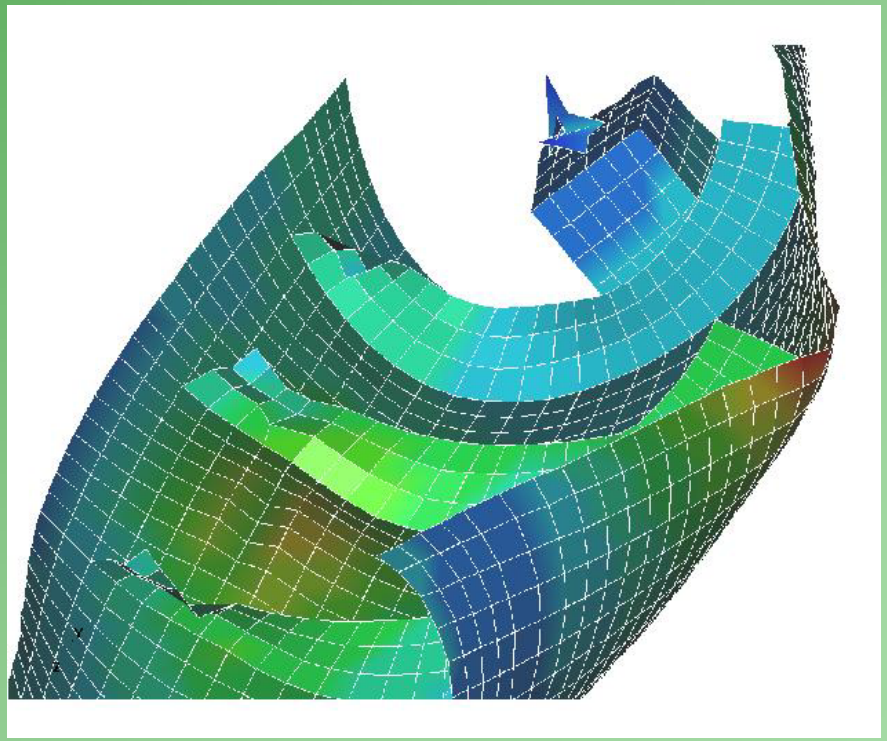
| | Angle of Impact | Rib Height |
|---|---|---|
| P[HIC-d >378 ] | -0.15 | -0.17 |

| | Std Dev(Angle) | Std Dev(Height) |
|---|---|---|
| Std Dev( HIC-d) | 2.1 | 1.0 |

# Displacement Variation

**Some displacements may be:**

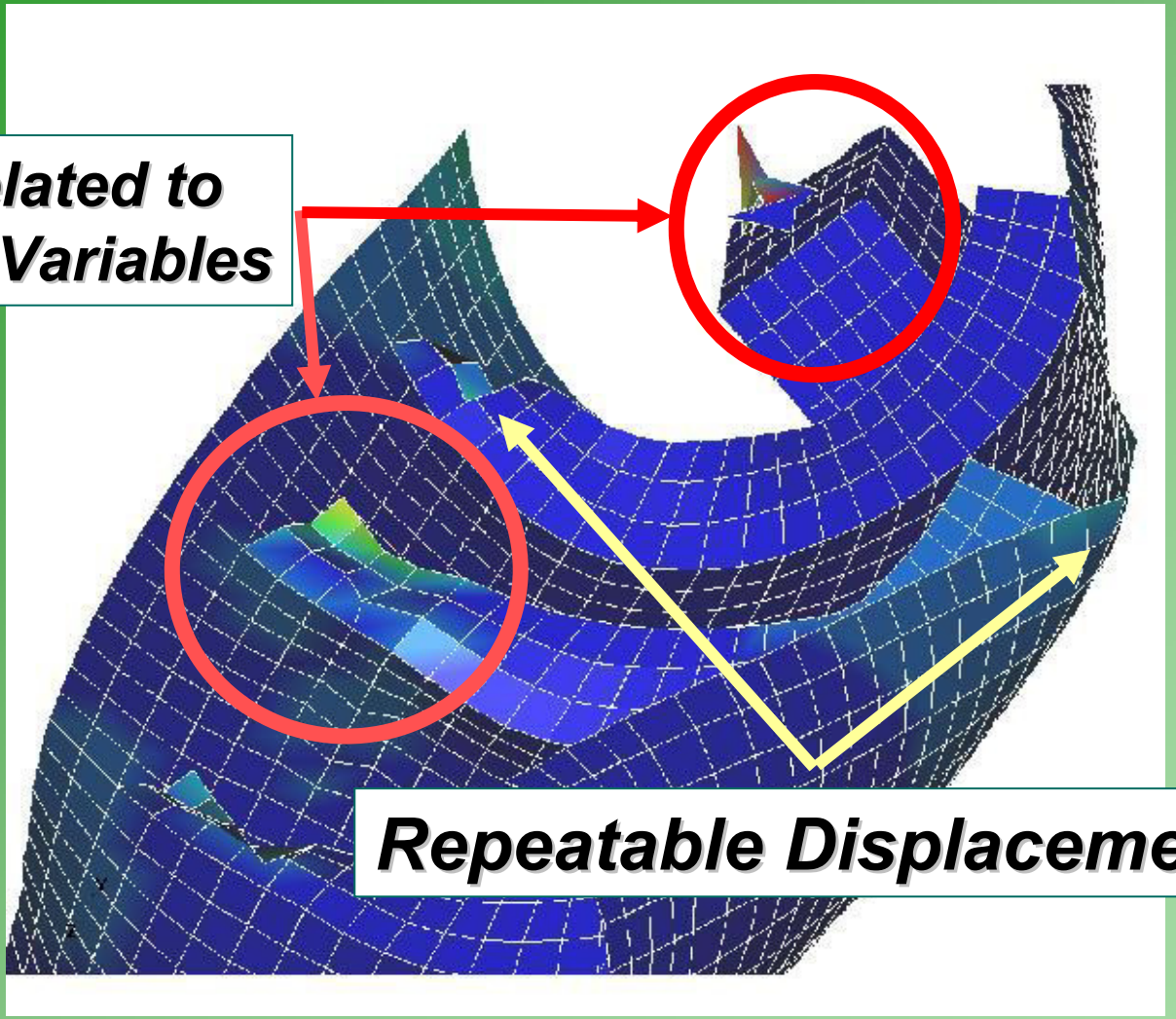
- Unrelated to a design variable change
- Not repeatable



# Displacement Variation

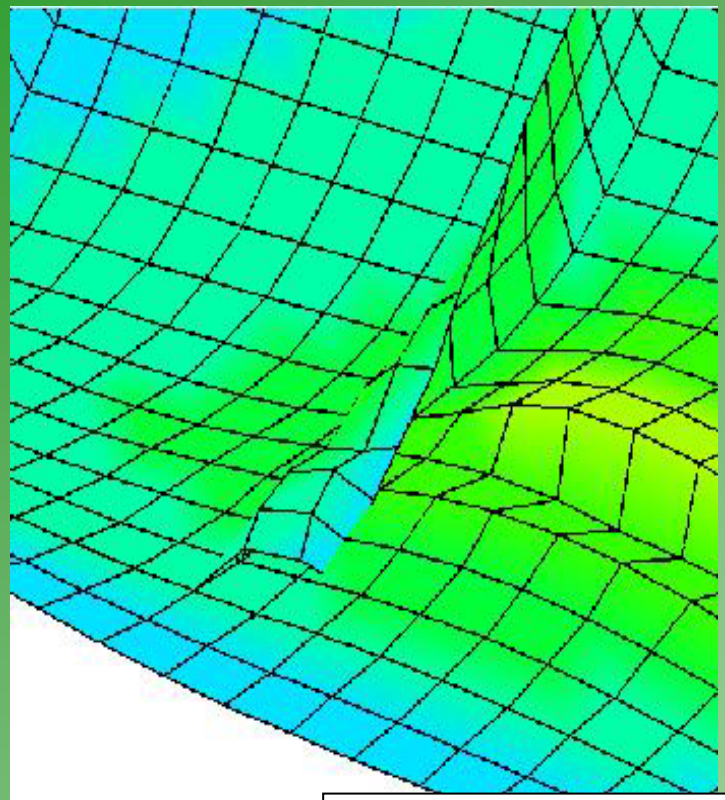
- **Create metamodel for each nodal displacement.**
- **Collect outliers (noise) not predicted by metamodel.**
- **Plot on model**
- **Investigate**
  - Modeling
  - Bifurcation

# Standard Deviation of Outliers

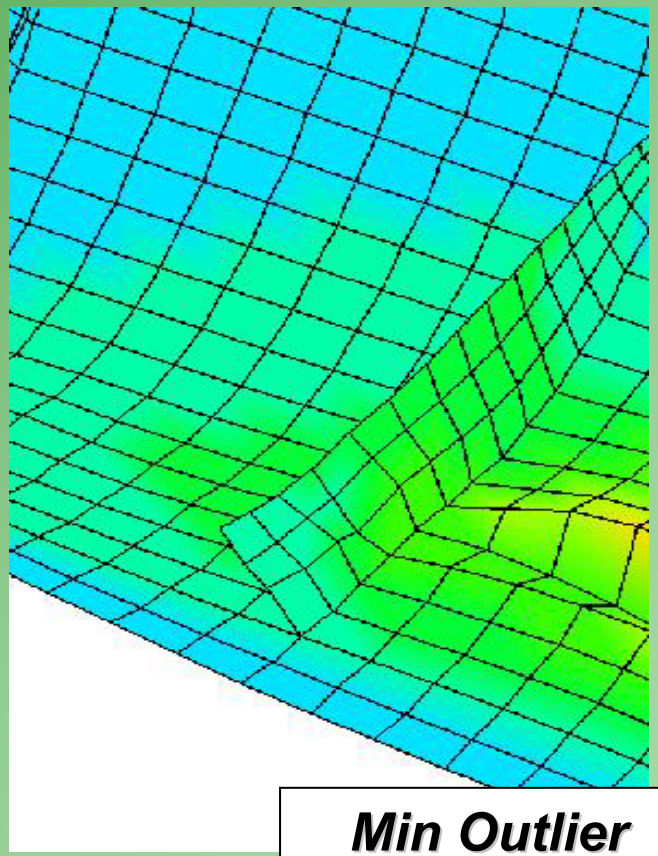


# Investigate Outliers

- **Different buckling modes**

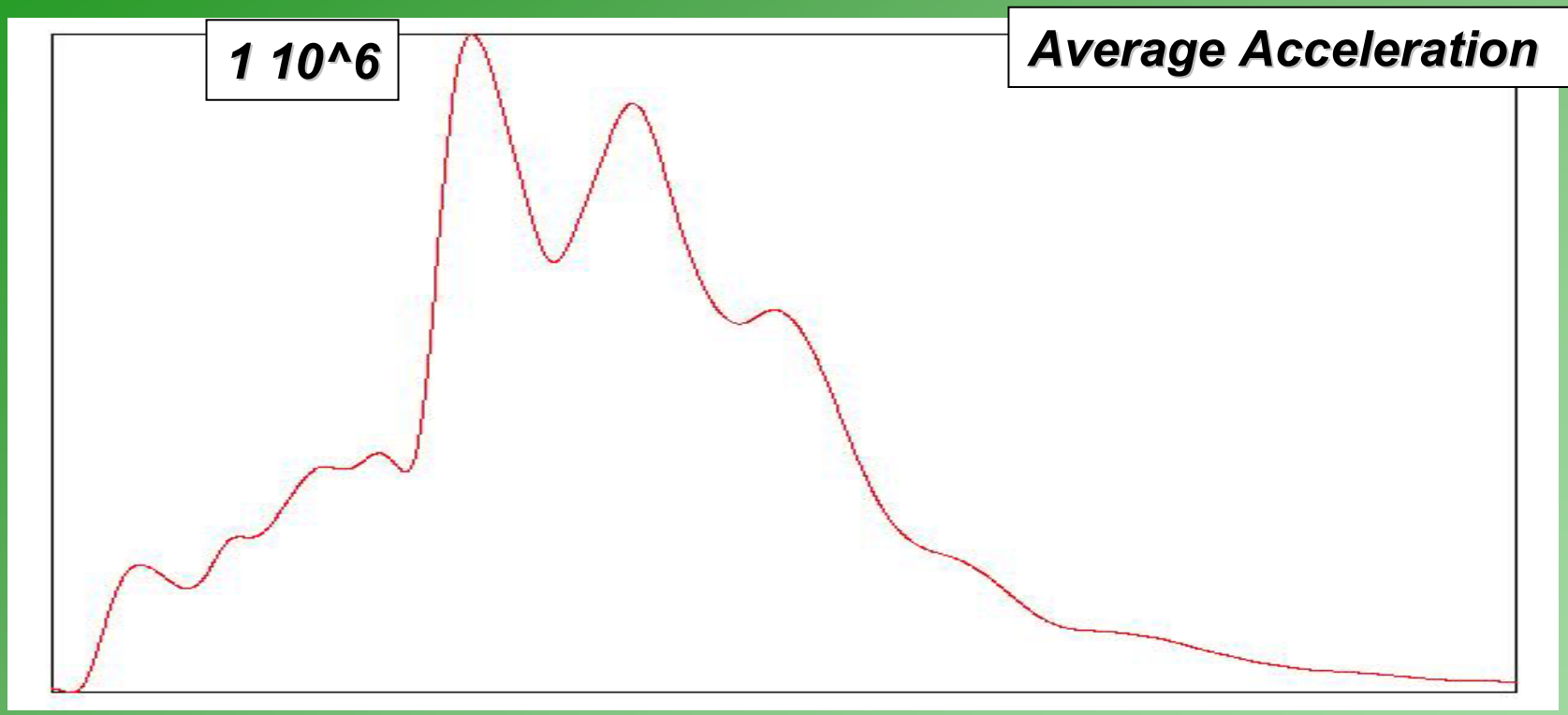


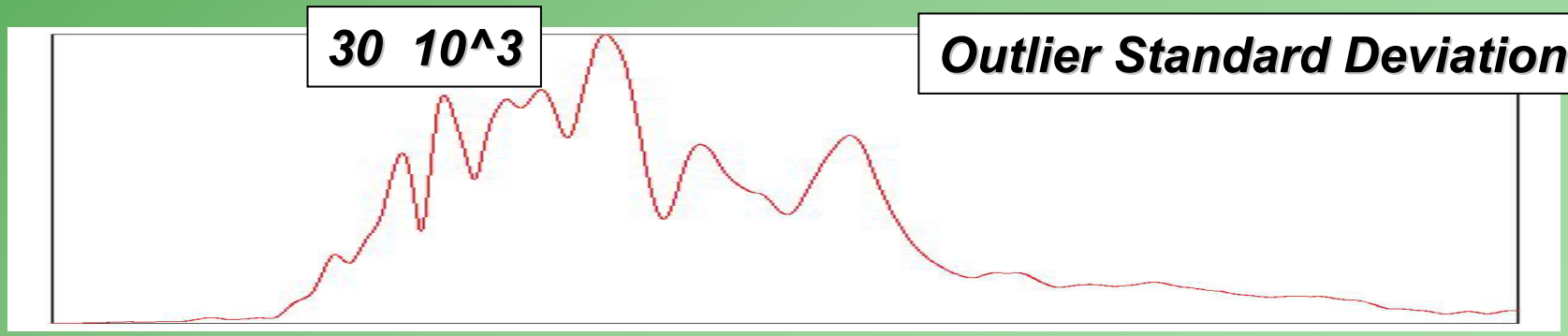
***Max Outlier***



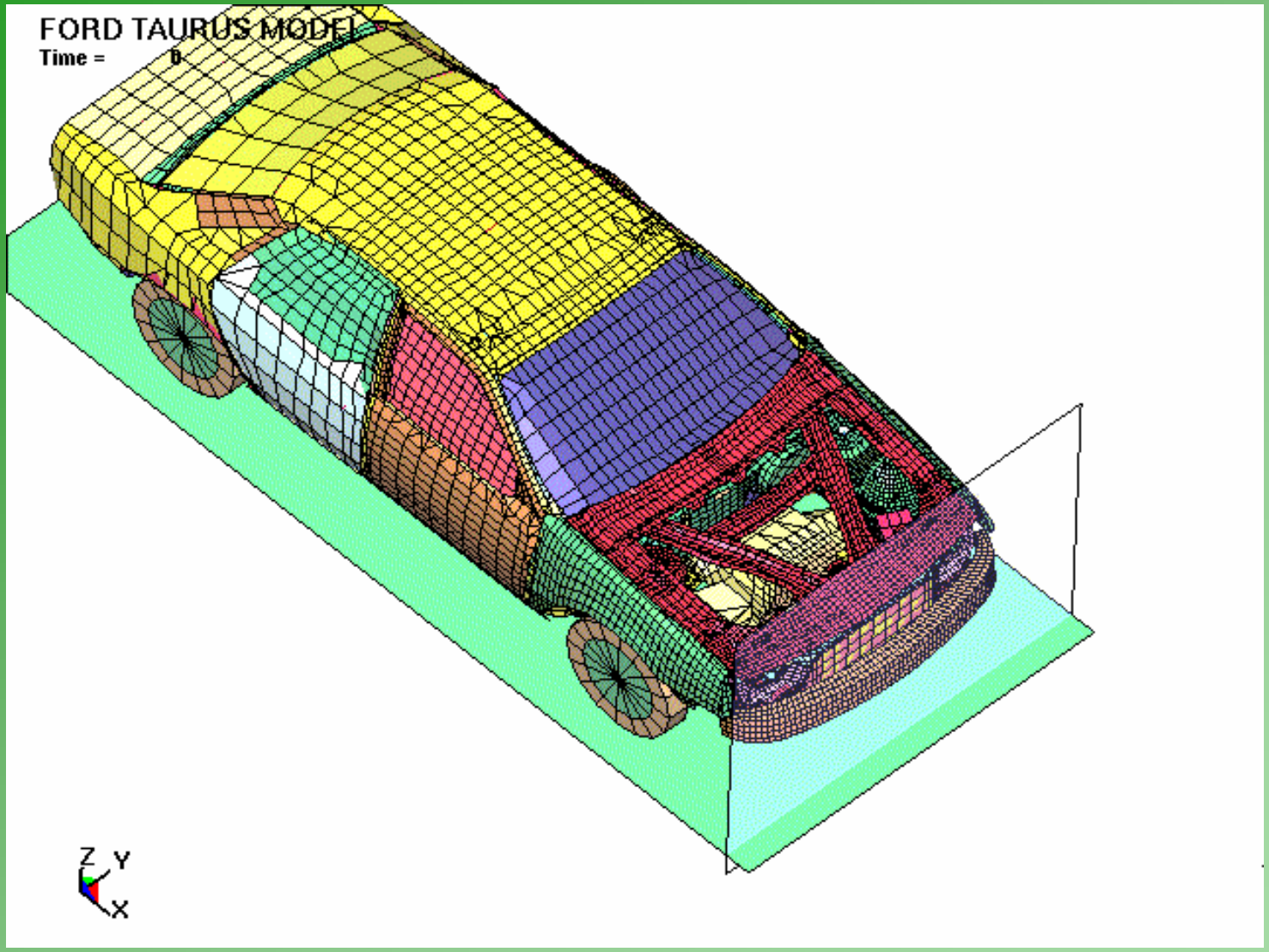
***Min Outlier***

# Acceleration History Variation

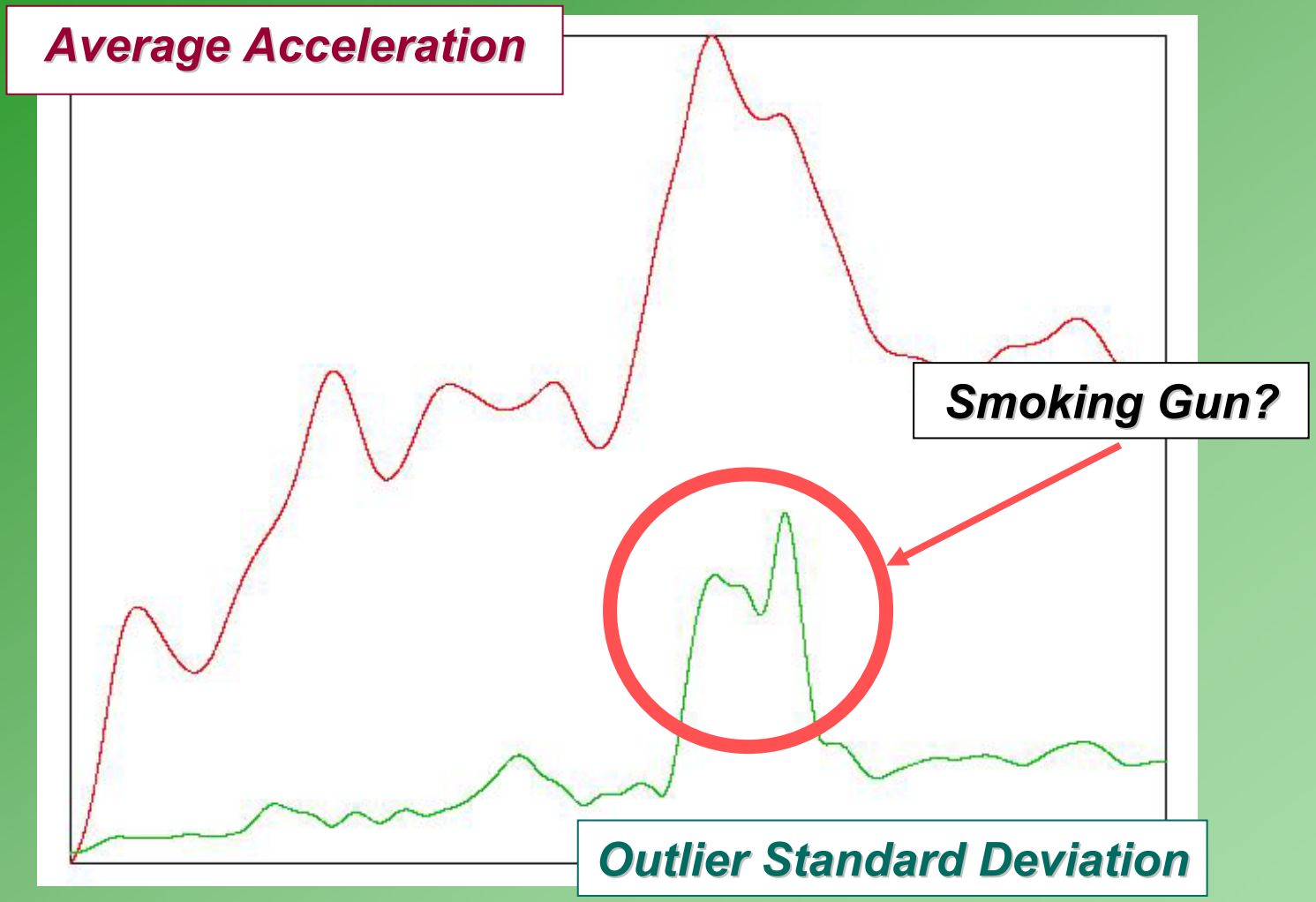


# Vehicle Crash

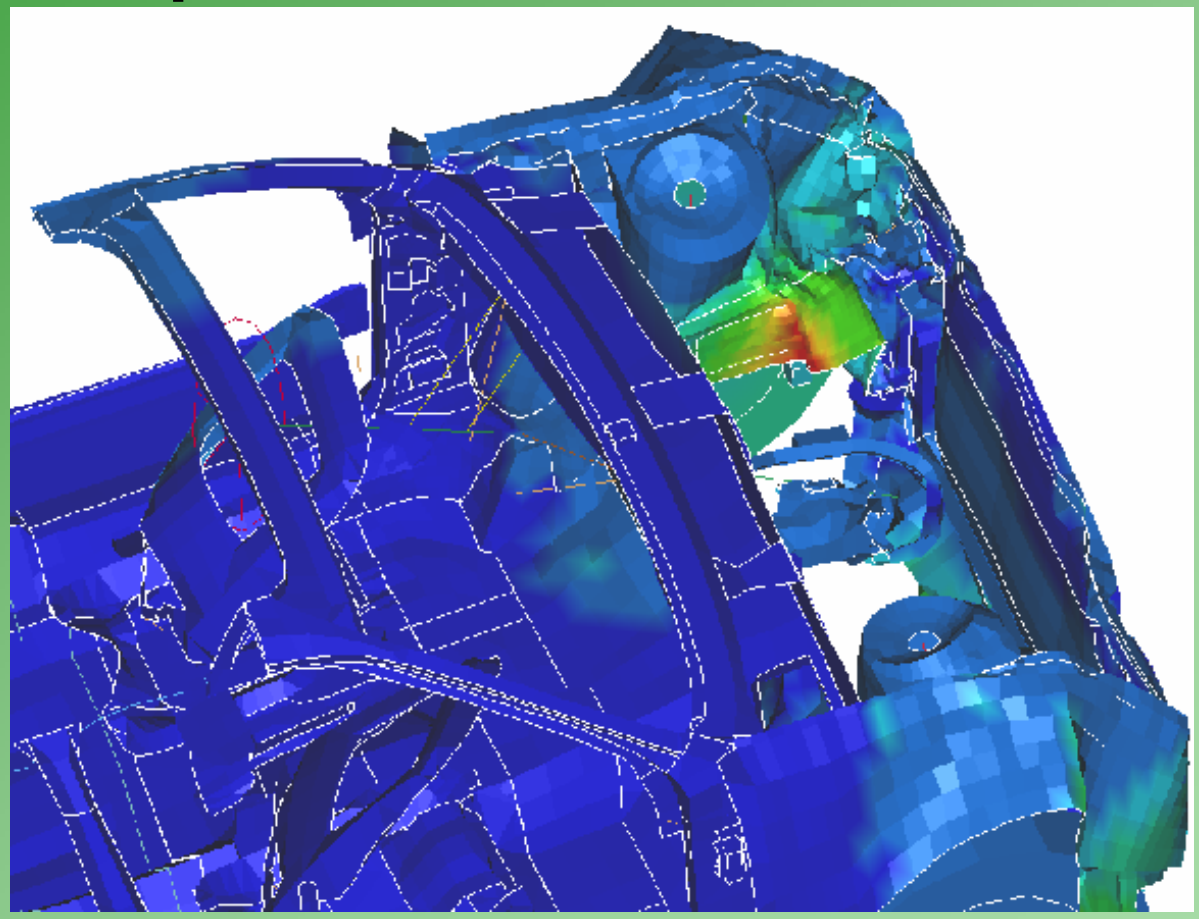


# History Variation



# Displacement Variation

- Vary angle of impact
- 25 FE Runs



# Summary

- Objective : Repeatable performance of design
- Monte Carlo
  - **Mean value**
  - **Standard deviation**
  - **Reliability**
  - **Indication of extreme values**
- Metamodels
  - **Allow cost savings**
  - **Separation of random components**
  - **Effect of design variable changes**
- Outliers can be informative