simulating REALITY™

MSC Software

Simulation-Supported Decision Making

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Simulation – A Tool for Decision Making

- **Quickly Identify and Understand How a Product Functions:**
  - **What are the major variables driving functionality?**
  - **What are the combinations of variables that lead to problems in complex systems?**
- **Ability Exists Today**
  - **Due to advances in compute capability**

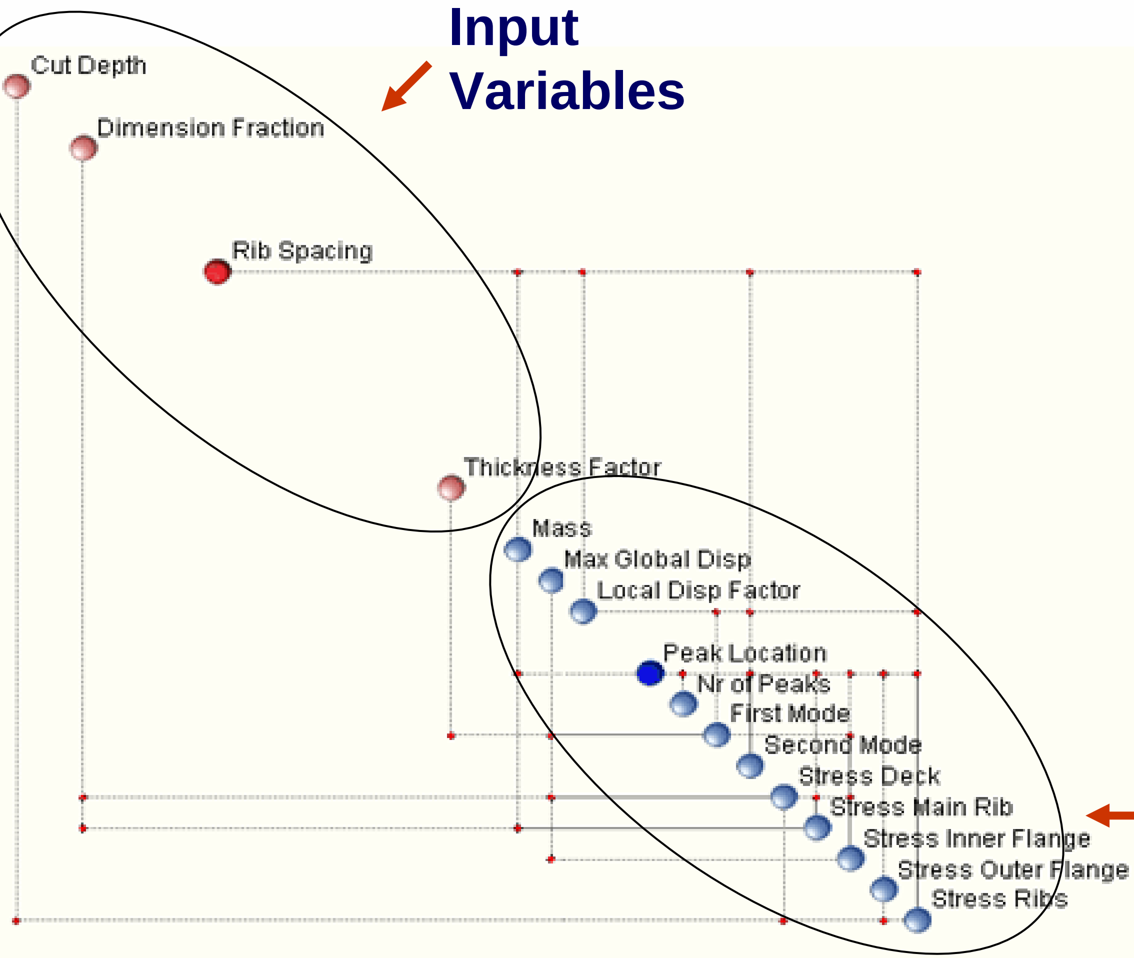
Decision Maps

Generation of Decision Maps

Decision Map – a 2-D view correlating Results generated from Monte Carlo Analysis

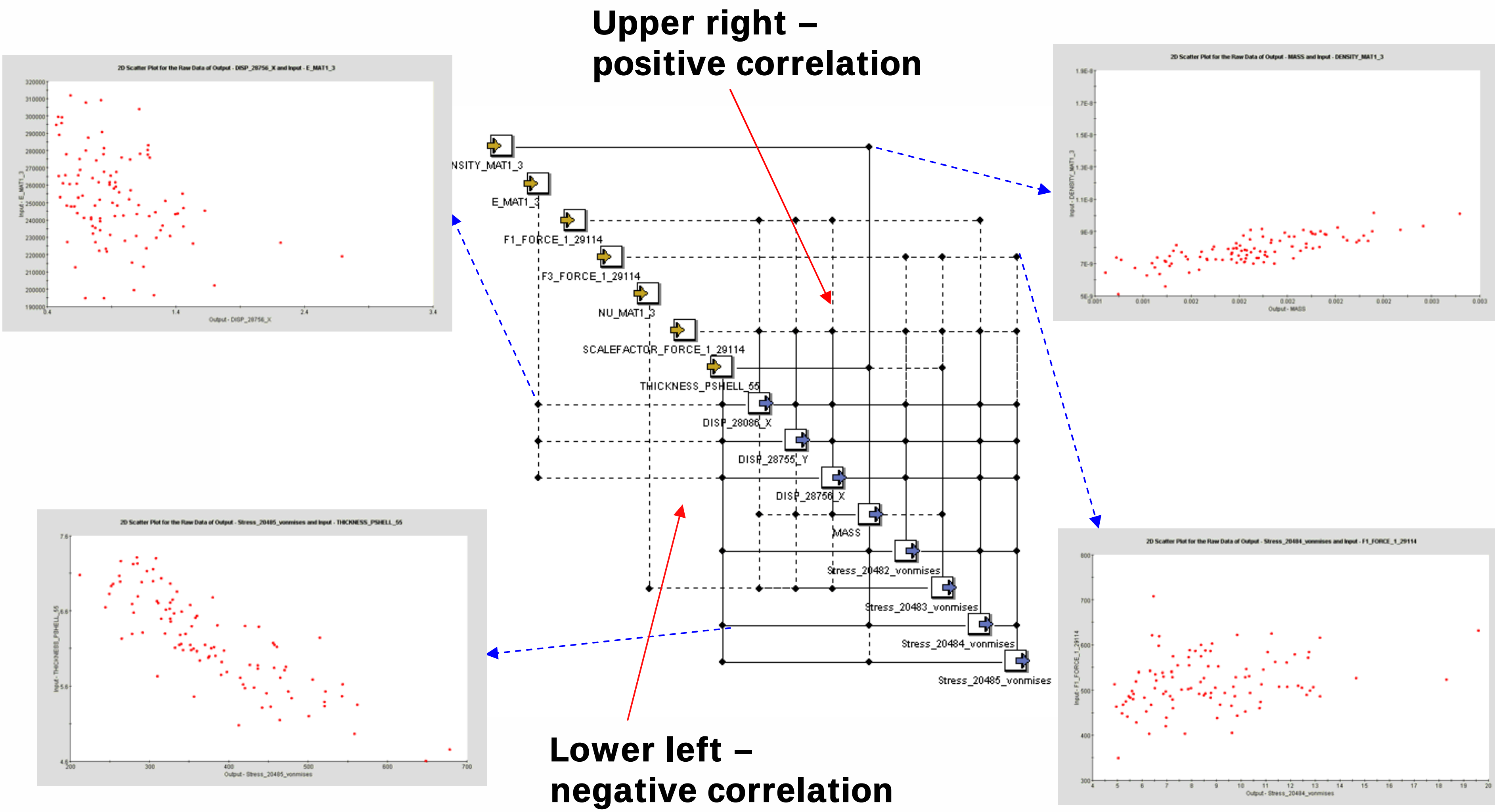
- Incorporates Variability and Uncertainty
- Updated Latin Hypercube sampling
- Independent of the Number of Variables
- Results with 100 runs
- Does Not Violate Physics
    - No assumptions of continuity
- "Not elegant, only gives the right answers."

Decision Maps to Understand Cause & Effect

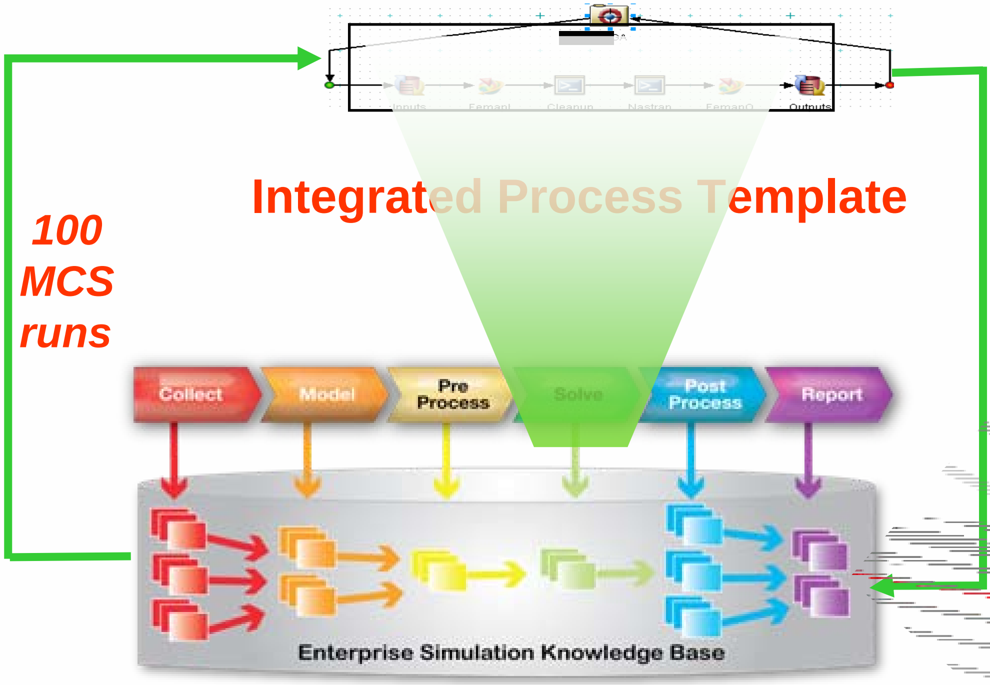


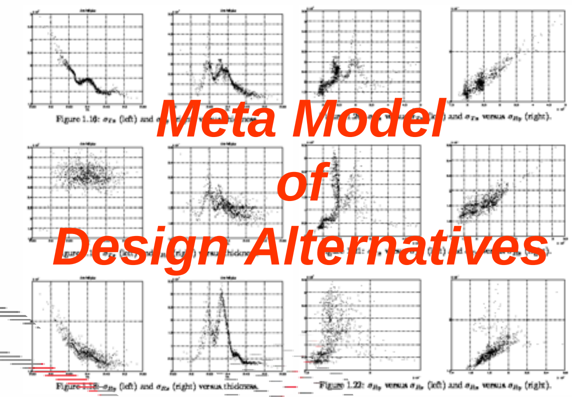
- **Ranks input variables and output responses by correlation level**
- **Follows MIT-developed Design Structure Matrix model format**
- **Filters Variables Based on Correlation Level**

A Decision Map



Generation of Decision Maps

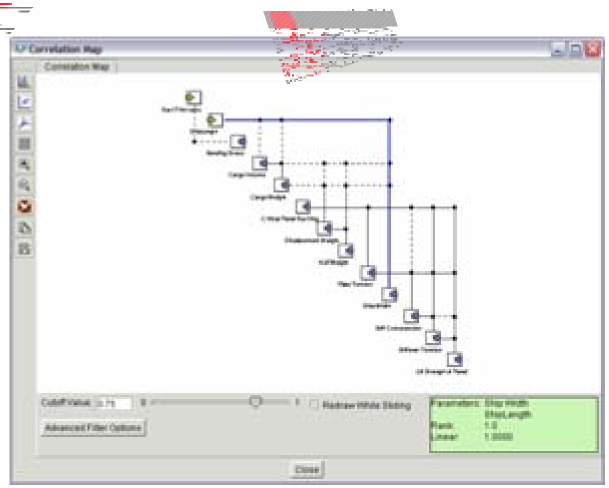




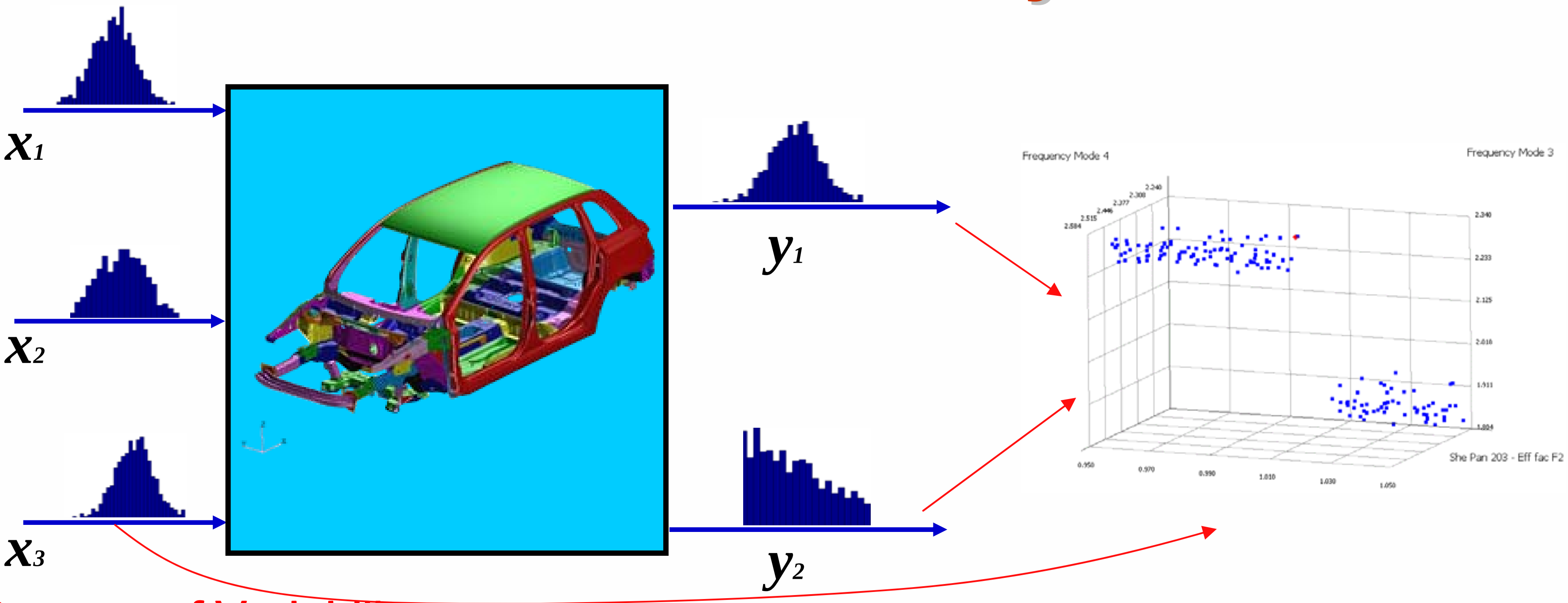
Correlation Map:

- Includes All Results

- Highlights Key Variables



Monte Carlo Analysis



Sources of Variability

- **Material Properties**
- **Loads**
- **Boundary and initial conditions**
- **Geometry imperfections**
- **Assembly imperfections**
- **Solver**
- **Computer (round-off, truncation, etc.)**
- **Engineer (choice of element type, algorithm, mesh band-width, etc.)**

Solution:

Establish tolerances for the input and design variables.

Measure the system's response in statistical terms.

The Fundamental Problem …

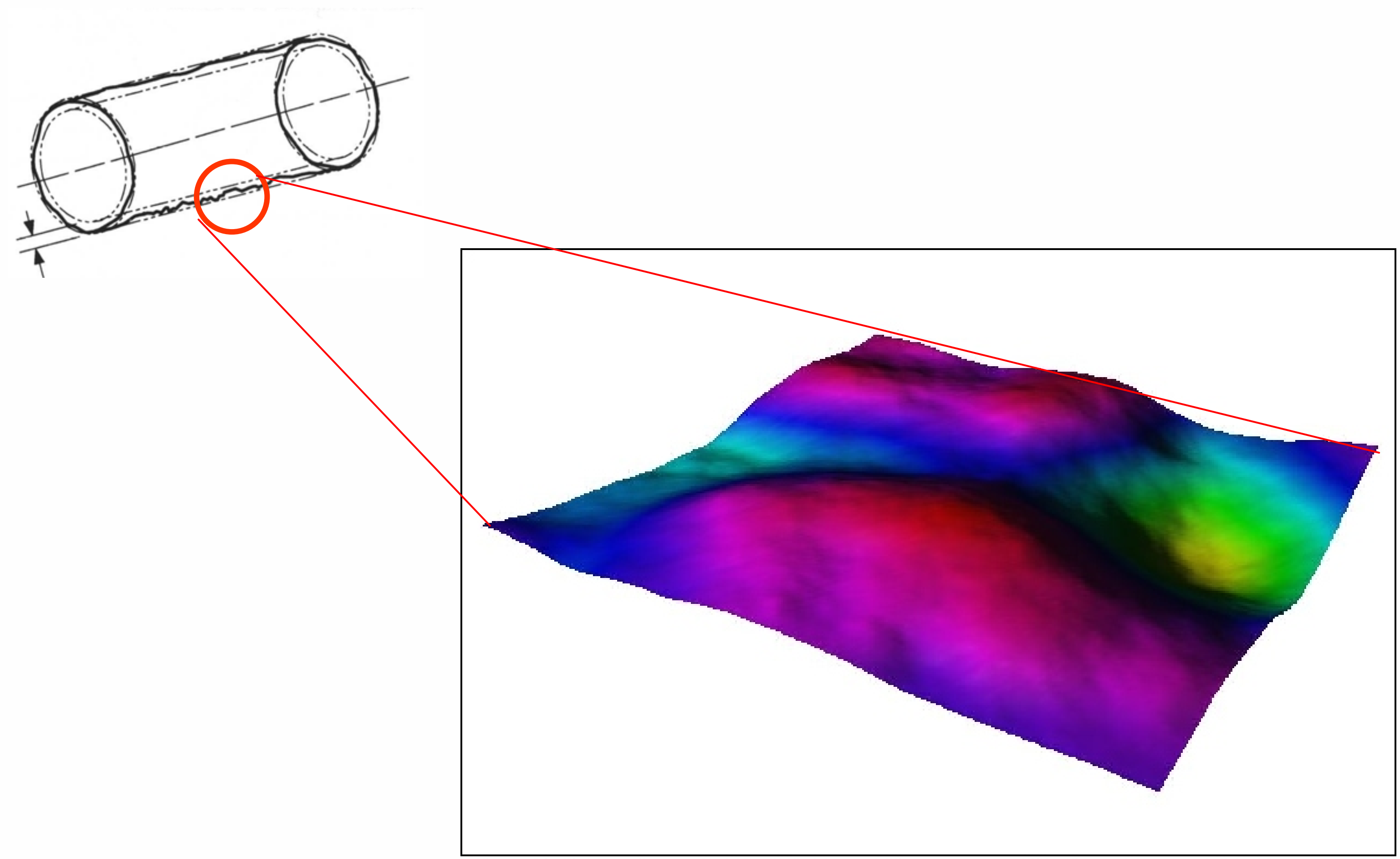
Structural Material Scatter

MATERIAL	CHARACTERISTIC	CV
Metallic	Rupture	8-15%
	Buckling	14%
Carbon Fiber	Rupture	10-17%
Screw, Rivet, Welding	Rupture	8%
Bonding	Adhesive strength	12-16%
	Metal/metal	8-13%
Honeycomb	Tension	16%
	Shear, compression	10%
	Face wrinkling	8%
Inserts	Axial loading	12%
Thermal protection (AQ60)	In-plane tension	12-24%
	In-plane compression	15-20%

Source: Klein, M., Schueller, G.I., et.al.,Probabilistic Approach to Structural Factors of Safety in Aerospace, Proceedings of the CNES Spacecraft Structures and Mechanical Testing Conference, Paris, June 1994, Cepadues Edition, Toulouse, 1994.

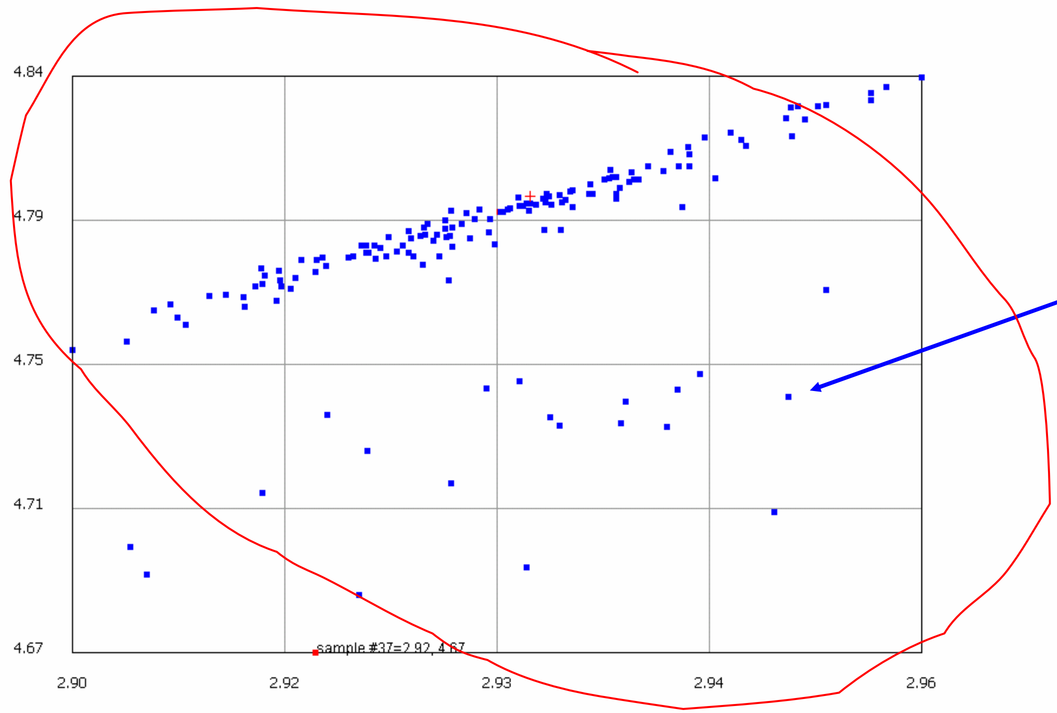
The Deception of Precise Geometry

Geometry imperfections should be described as stochastic fields.



Monte Carlo Results show Reality

<u>Collection</u>
of computer
runs =
<u>Simulation</u>



<u>Single</u>
computer
run =
<u>Analysis</u>

Understanding the physics of a phenomenon is equivalent to the understanding of the topology and structure of these clouds.

Understanding MCS Results

- Simulation generates a large amount of data.
  - A typical simulation run requires around 100 solver executions.
  - Each combination of hundreds to thousands of variables produces a point cloud. In each cloud:
    - POSITION provides information on PERFORMANCE
    - SCATTER represents QUALITY
    - SHAPE represents ROBUSTNESS

KEY:

- REDUCE the Multi-Dimensional Cloud to EASILY UNDERSTOOD INFORMATION
  - Condense into a DECISION MAP
  - Variables are sorted by the strength of their relationship

Monte Carlo Simulation Results

Number of 2D Views of Results = Sum of all integers from 1 to (Number of Variables -1)

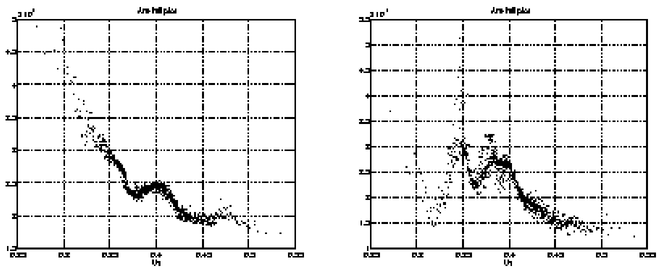


Figure 1.16: σ_{Tx} (left) and σ_{Ty} (right) versus thickness.

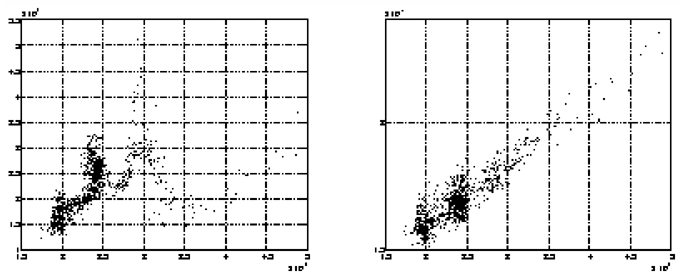
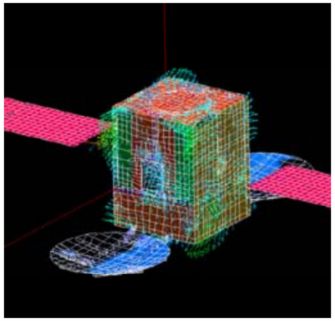


Figure 1.20: σ_{Tx} versus σ_{Ty} (left) and σ_{Tx} versus σ_{Ry} (right).



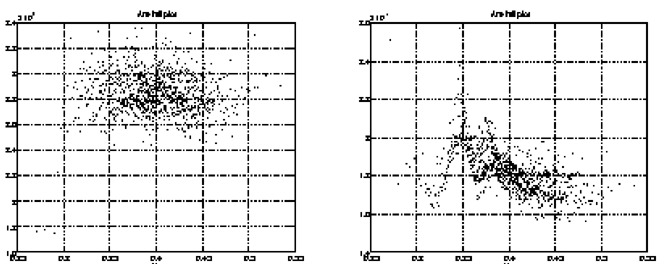


Figure 1.17: σ_{Tz} (left) and σ_{Rx} (right) versus thickness.

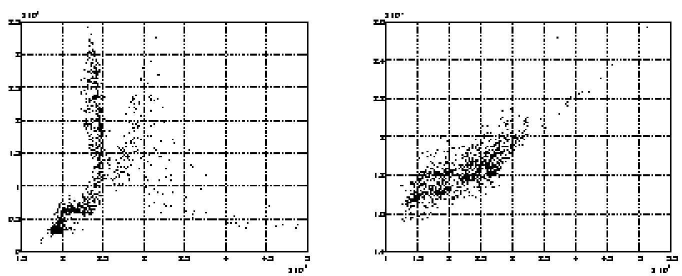


Figure 1.21: σ_{Tx} versus σ_{Rx} (left) and σ_{Ty} versus σ_{Rx} (right).

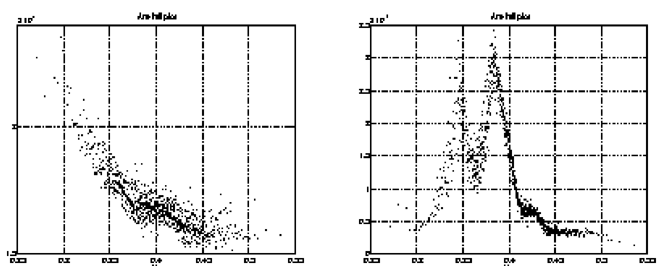


Figure 1.18: σ_{Ry} (left) and σ_{Rz} (right) versus thickness.

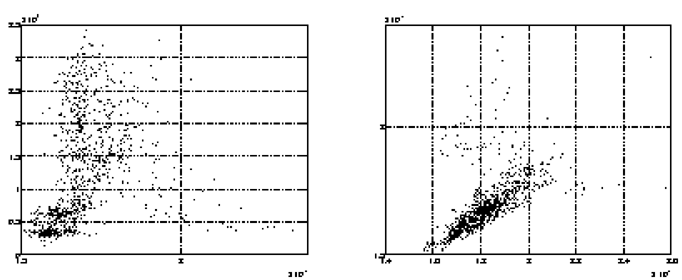


Figure 1.22: σ_{Ry} versus σ_{Rx} (left) and σ_{Rx} versus σ_{Ry} (right).

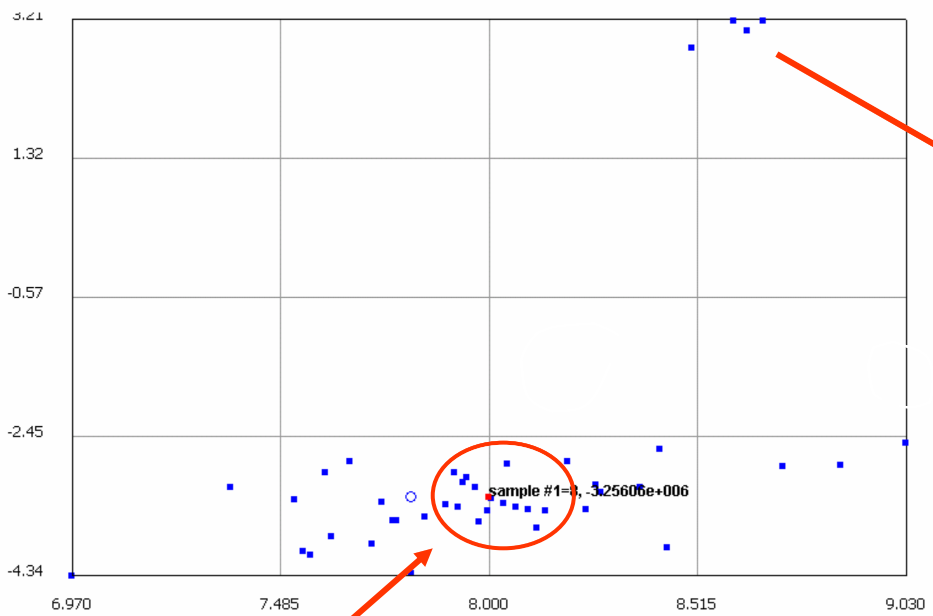
12 of the 78 2D views that resulted from a simulation with 6 outputs from a scan of 7 inputs with uniform distributions.

Decision Maps: Understanding Cause and Effect

- Displays condensed information from hundreds of analysis runs.
- Decision Map = Structured Information = Knowledge
- A Decision Map helps an engineer:
  - Understand how a system works.
    - How information flows within the system.
    - how variables and components correlate.
  - Make decisions on how a design may be improved.
    - Identify dominant design variables.
    - Use as input for stochastic design improvement.
  - Find the weak points in a system.
  - Find redundancies in a design.
  - Identify rules that govern the performance ("if A and B then C").

There are NO algorithms to learn. The engineer concentrates on engineering, not on numerical analysis.

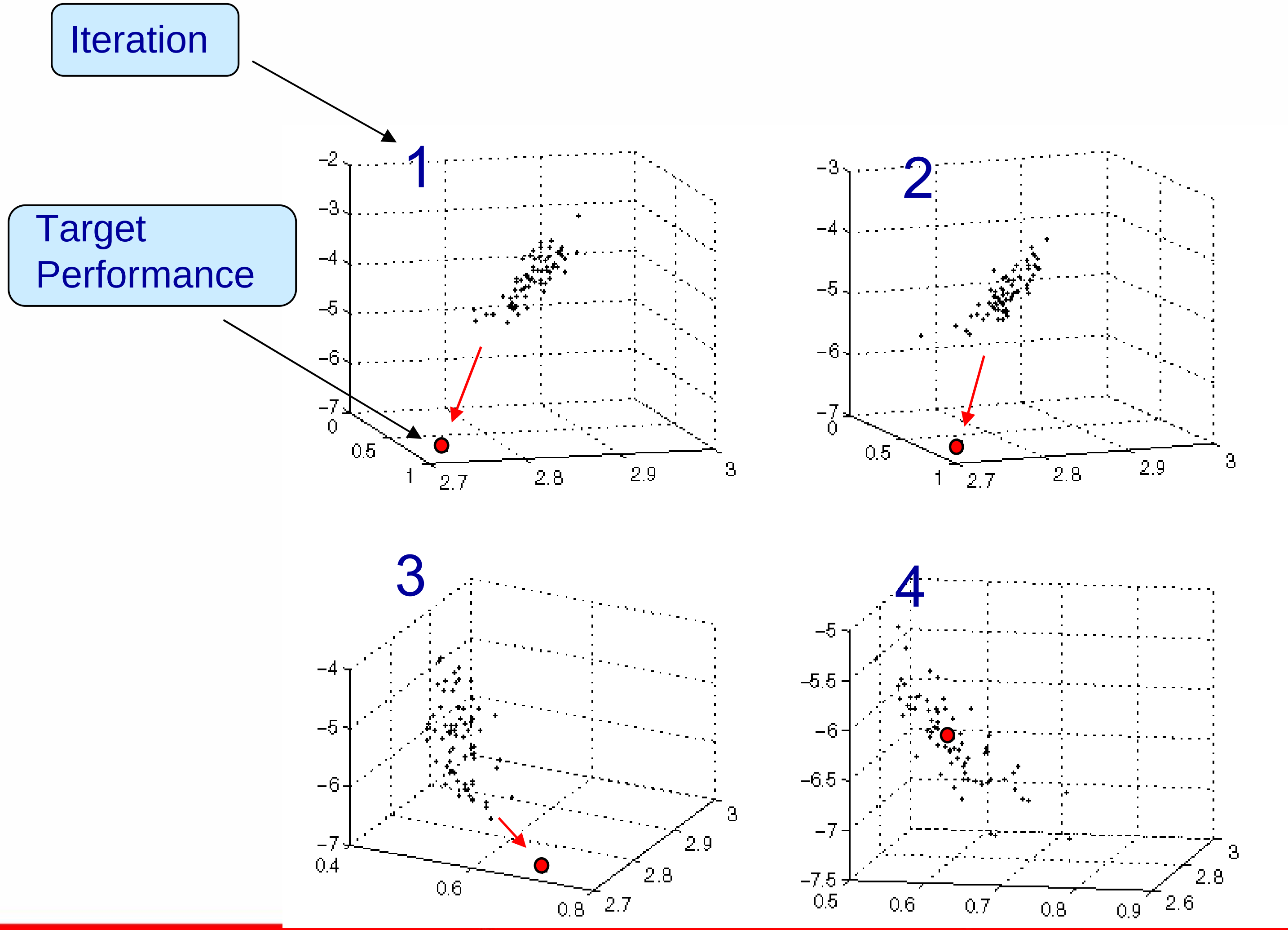
Outlier Identification



Outliers: may be dangerous:
- System Failure
- Mission Failure

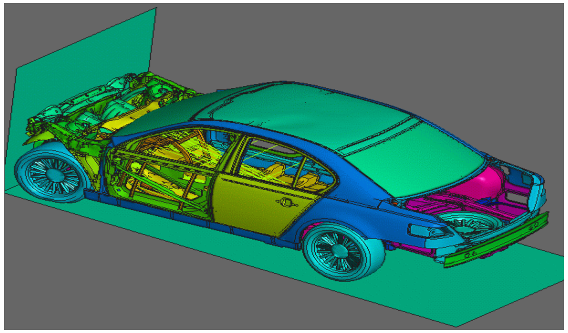
Most likely behavior

Design Improvement Process

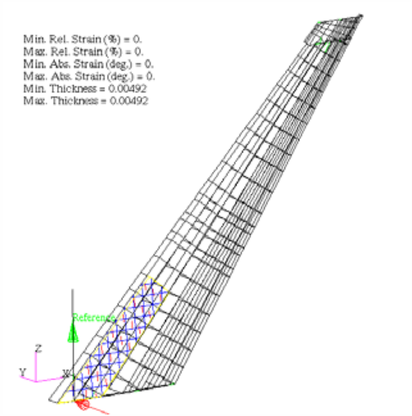


APPLICATIONS

- Automotive and Aerospace companies have continued to expand use of process since 1997
- BMW, Audi, Toyota, Mecedes, Nissan and Jaguar have expanded Computer Clusters for Stochastic Car Crash Simulation taking 10's of pounds from car model designs.
- Aerospace companies applying to improve aerospace designs. Alenia reduced weight of new commercial airliner tail by 6%.



Courtesy of BMW AG



Courtesy, Alenia Aeronautica

Process for Decision Support

- Model a multi-disciplinary design-analysis process
- Randomize the process model
- Run Monte Carlo simulation of the model
- Process Results
  - Correlation Maps showing Cause and Effect
  - Outlier identification showing anomalies
  - Direction for Design Improvement

Correlation Maps - Filter Complexity while Modeling Reality

- Identify what influences functionality
- Address Uncertainty and Variation
  - Provides credibility in modeling & simulation
  - Results clouds represent what is possible
- Easy to use
  - No methods or algorithms to learn
- Reduces risk through better engineering
  - Takes all inputs into account vice using initial assumptions
- Changing the general engineering process