Empowering Engineers to Generate Six-Sigma Quality Designs

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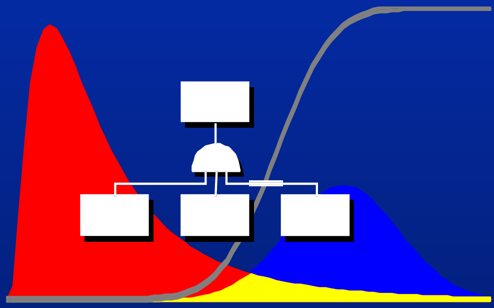

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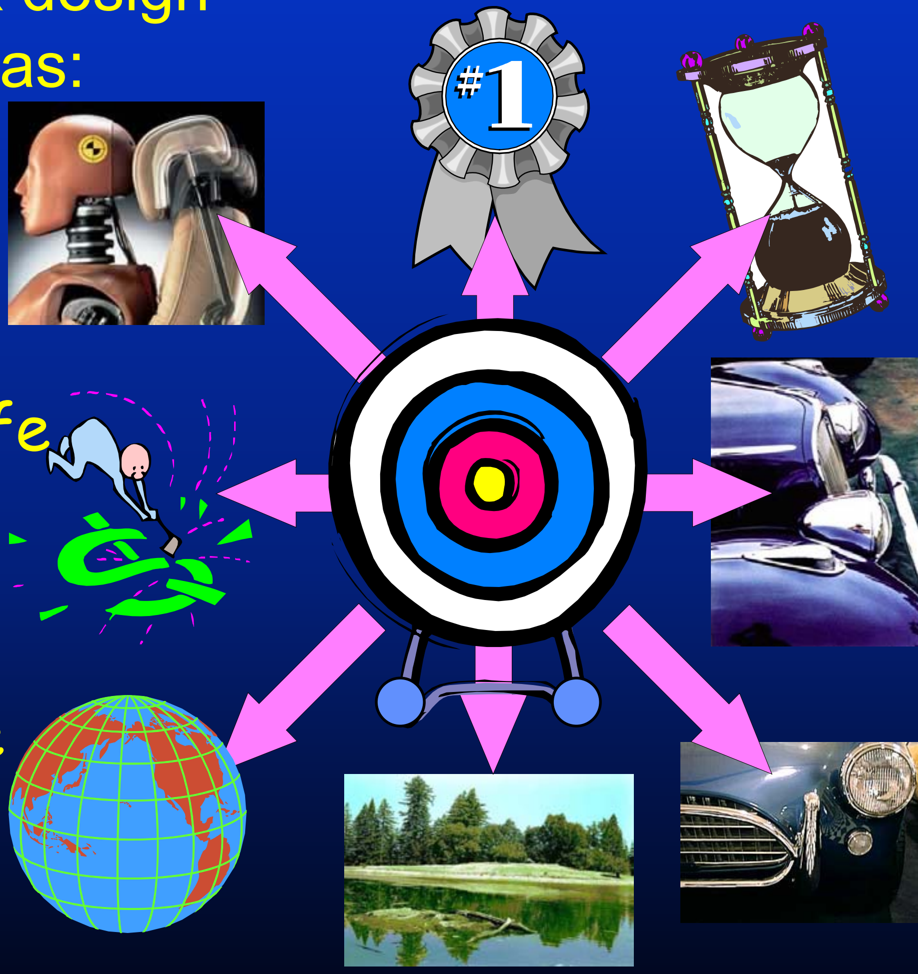
Contradicting Design Requirements

The need for innovative tools is apparent now more than ever as more complex design requirements are surfacing such as:

- Cost
- Performance & safety
- Quality
- Time to market & short life cycle
- Environmental impacts
- Aesthetics (wow, lust for the product, I got to have it ...)
- Major Changes in Industry's Business Model



Quality - Robust Design

- **Definition** of **Robust Design**:
  Deliver customer expectations at profitable cost regardless of:
  - customer usage
  - variation in manufacturing
  - variation in supplier
  - variation in distribution, delivery & installation
  - degradation over product life

- **Goals** of Robust Design (shift and squeeze)
  - Shift performance mean to the target value
  - Reduce product's performance variability

Statistical Design Performance Simulation?

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" You 've got to be passionate lunatics about the quality issue …"

Jack Welch

"U.S. autos fight poor quality reputation …"

Joe Miller / The Detroit News

" Product quality requires managerial, technological and statistical concepts throughout all the major functions of the organization …"

Josheph M. Juran

Variation (thickness, properties, surface finish, loads, etc.) is … *THE ENEMY*

DOE, Six Sigma, Statistical FEA, Behavioral Modeling … *THE DEFENCE*

Improved Quality reduced Total Cost

Cost of Defect or Failure

- Lost Customers
- Liability (R&D)
- Recalls (production)
- Rework

Examples:

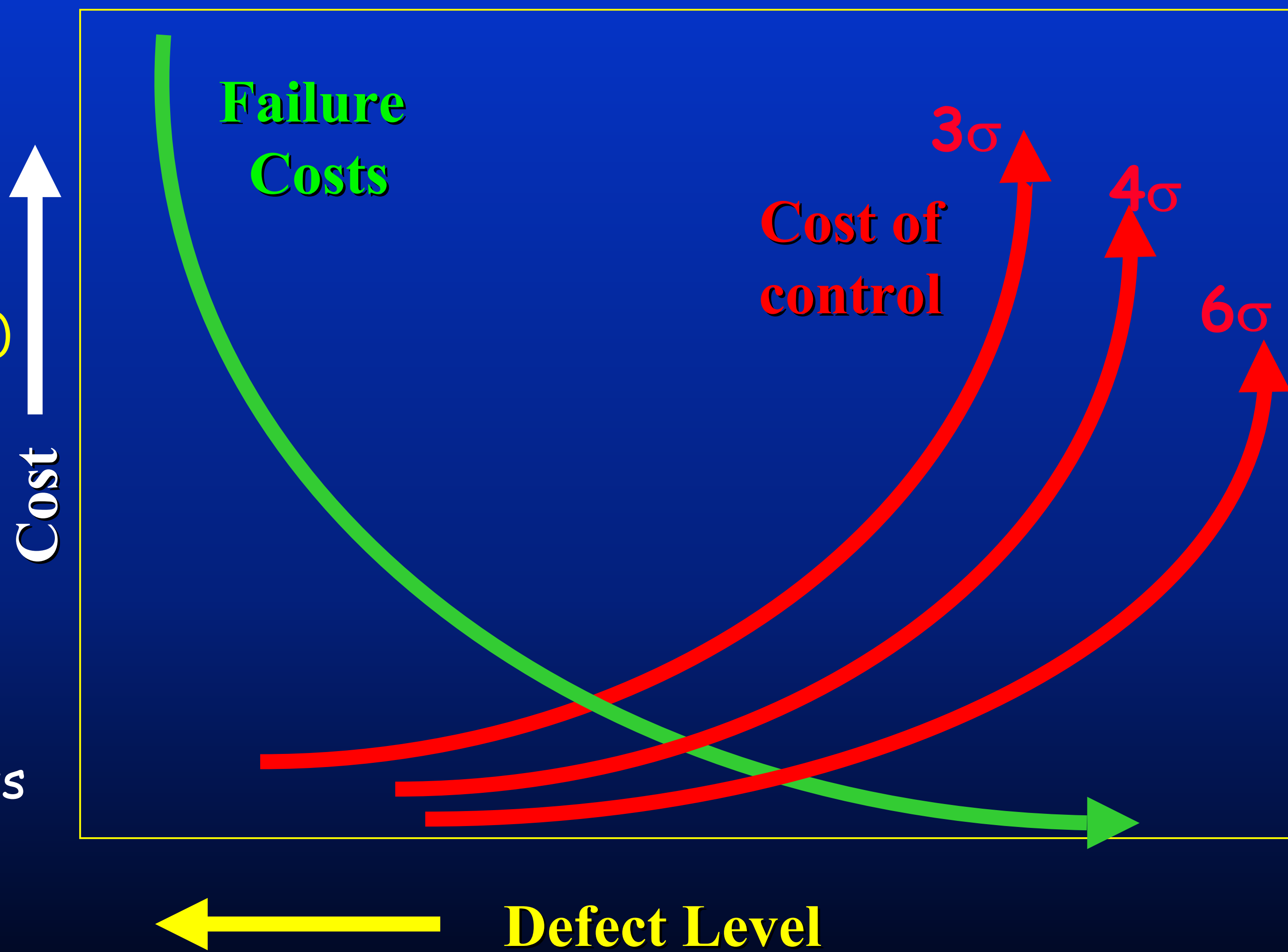
Titanic

Asbestos

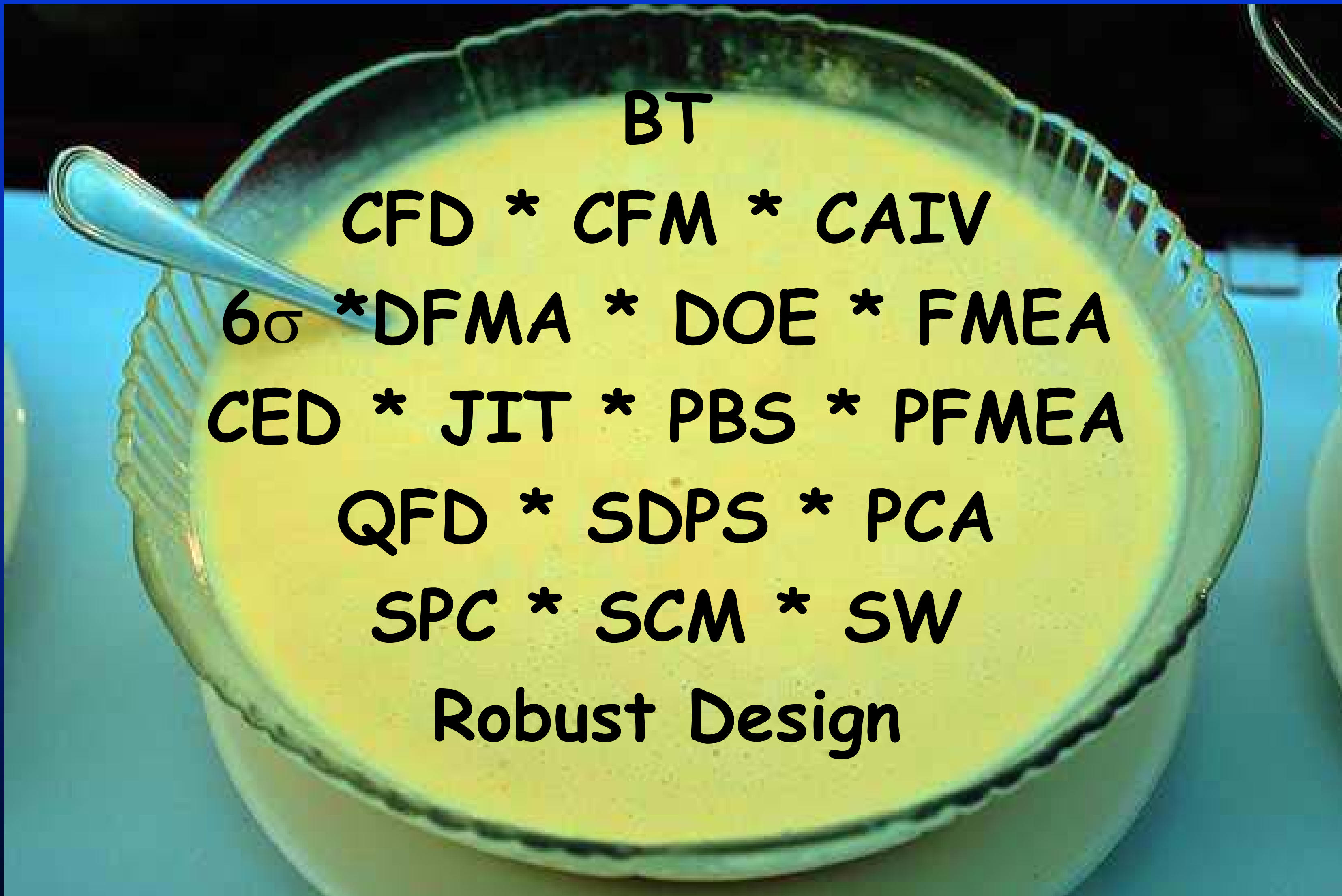
Breast Implants

Bhopal, India

...



Elements of Quality Process: The alphabet soup

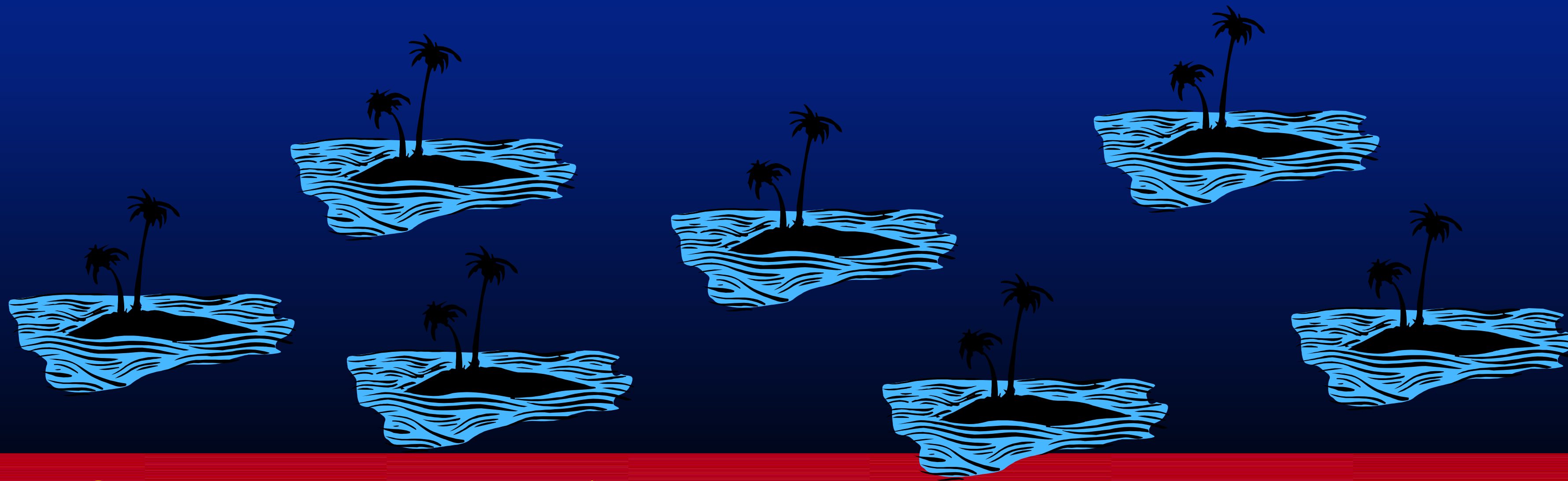


Elements of Quality Management Process

- Agile Improvement Process
- Axiomatic Design *
- Benchmarking & Bench-trending
- Catch-ball
- Cellular Manufacturing
- Continuous Flow Development
- Continuous Flow Manufacturing
- Cycle Time Management
- Defect Reduction
- Design for Manufacturing and Assembly
- Design of Experiments
- Failure Modes effects Analysis
- Cause and Effect Diagrams
- Just In Time
- Performance Based Specifications Process
- Failure Mode Effects Analysis
- Quality Function Deployment
- Robust Design
- Self-Directed Work Teams
- Statistical Design Performance Simulation
- Process Capability Analysis
- Statistical Process Control
- Supply Chain Management
- Synchronous Workshops
- Theory of Constraints *
- Thinking Process Reality Trees
- Total Productive Maintenance

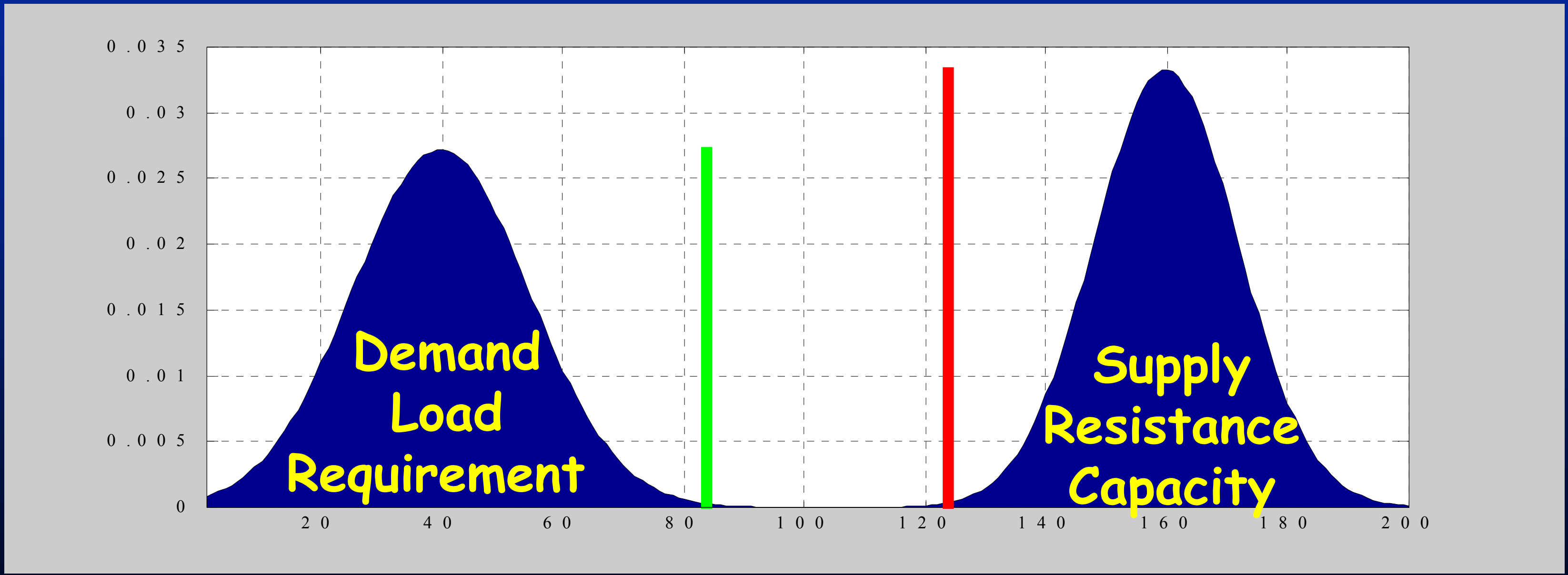
Elements of Quality Management Process

- Although all the elements of quality management process are closely connected they remain apart because they have been developed independently from each other
- Integration of these tools is critical to the organization and necessary for successful federation and robust optimization efforts



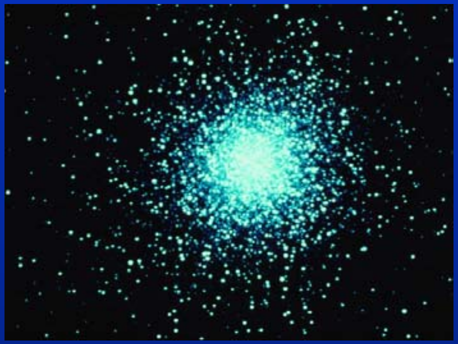
Traditional Deterministic Approach

- Accounts for uncertainties through the use of empirical Safety factors:
  - Are derived based on past experience
  - Do not guarantee safety or satisfactory performance
  - Do not provide sufficient information to achieve optimal use of available resources



Noise & Control Parameters

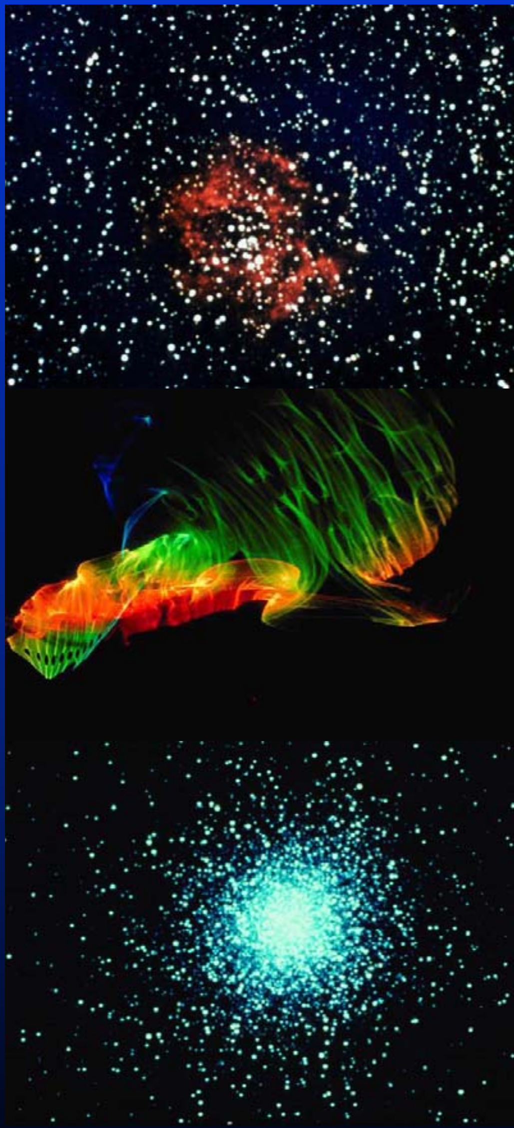
- Noise parameters:
  Factors that are beyond the control of the designer or too expensive to control or change
  - material property variability
  - manufacturing process limitations
  - environment temperature & humidity
  - component degradation with time
  - ...



- Control Parameters:
  Factors that the designer can control
  - geometric design variables
  - material selections
  - design configurations
  - manufacturing process settings
  - ...

Tools for Robust Design

- Design Of Experiments
  - Exploits nonlinearities and interactions between noise & control parameters to reduce product performance variability
  - full factorial, fractional factorial, Monte-Carlo, LHC
- Response Surface Methods
  - Central Composite Design
  - Box-Behnken Design
- 6-sigma design
  - Identifying & qualifying causes of variation
  - Centering performance on specification target
  - Achieving Six Sigma level robustness on the key product performance characteristics with respect to the quantified variation



Shift and Squeeze

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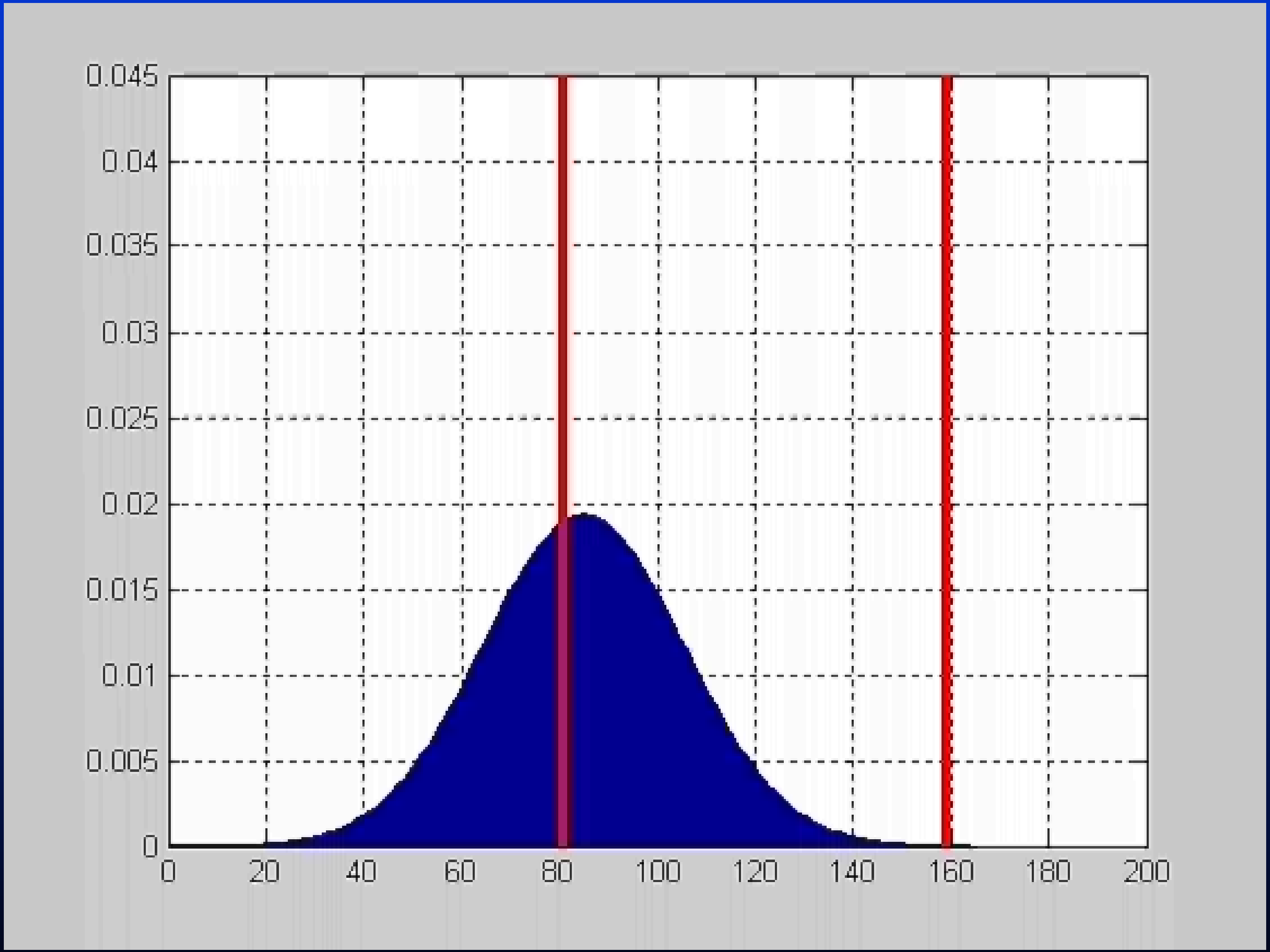
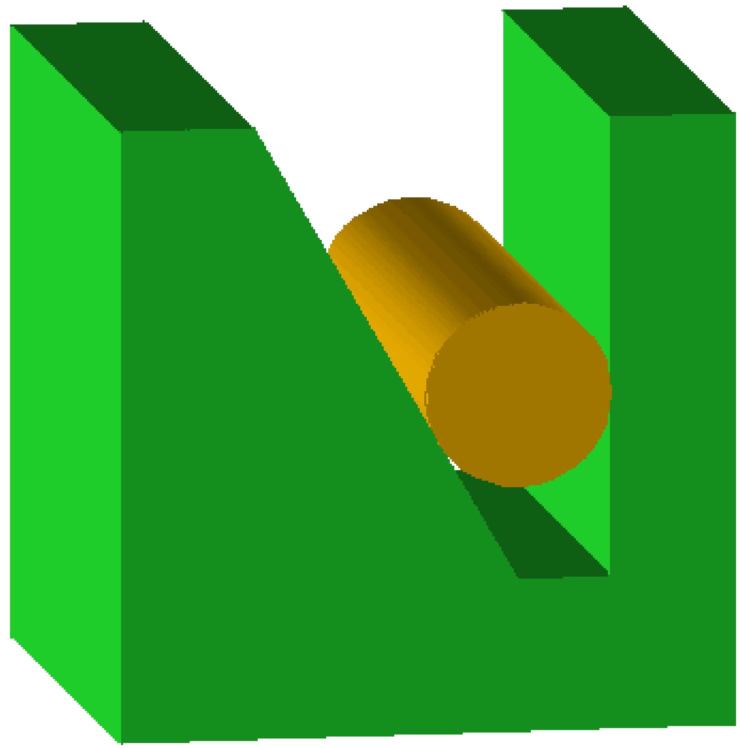


Sources of Assembly Variation: Part Dimensions

Size variations in parts result in location variations in assembled features

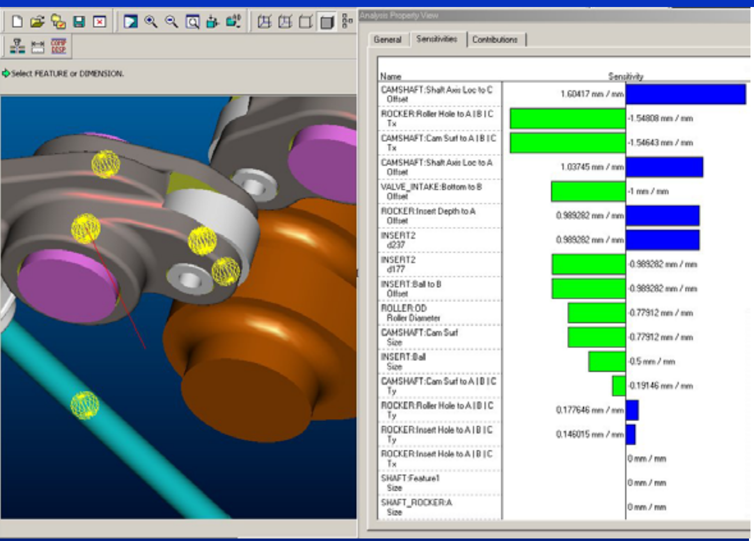
CETOL 6σ

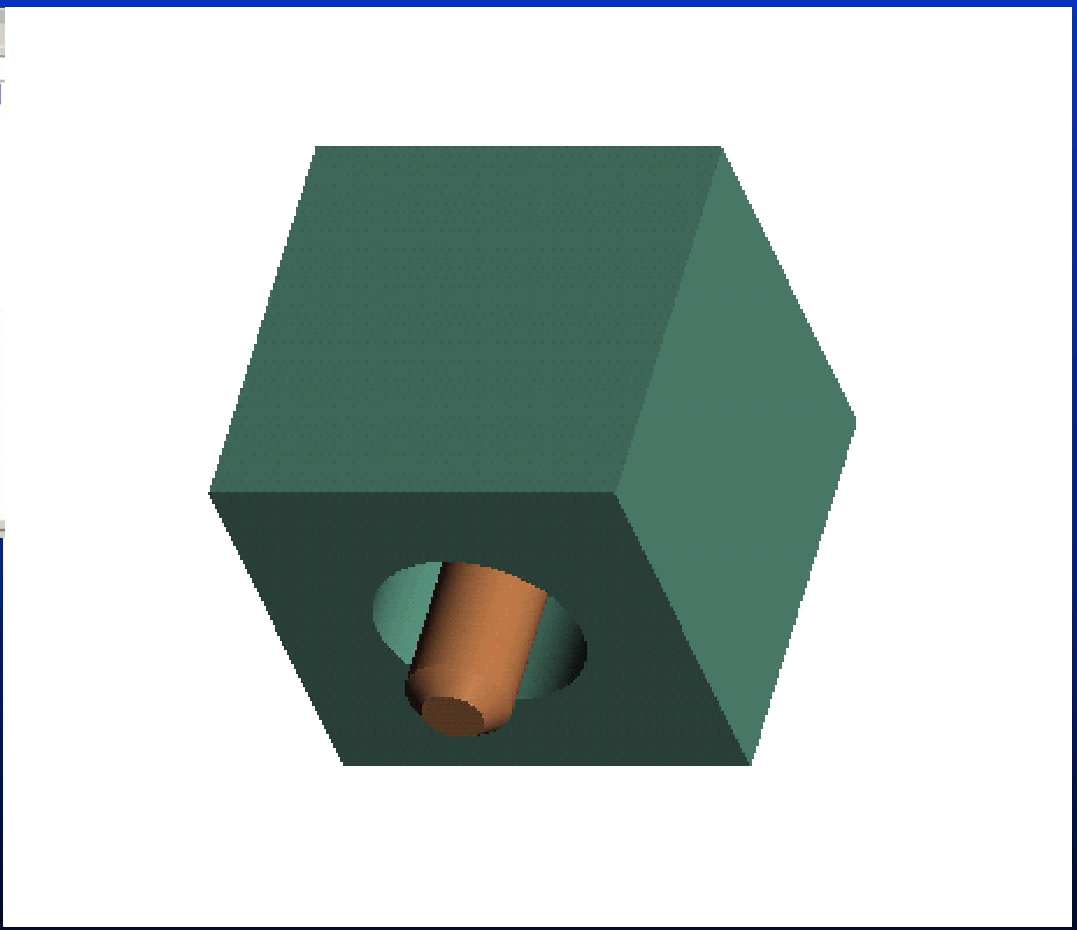
- Mechanical Variation Management System
- 3D Tolerance Analysis / Allocation Software
- Sensitivity and Statistical Analysis
- Leverages Mfg Process Capability Data
- Optimized for DFSS Experts and Pro/E Users



Sources of Assembly Variation: Multiple Configurations of Assembly

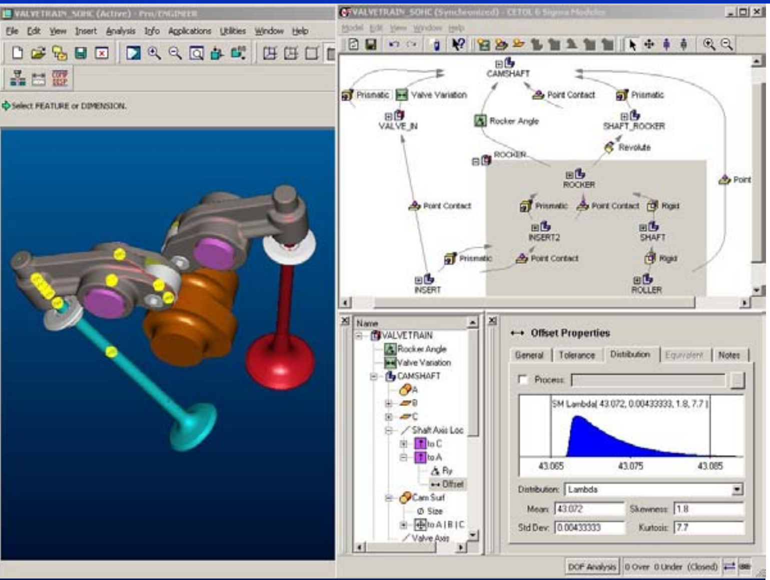
Tools like CE/TOL addresses the issue that one assembly constraint in Pro/E can have many configurations affecting variation

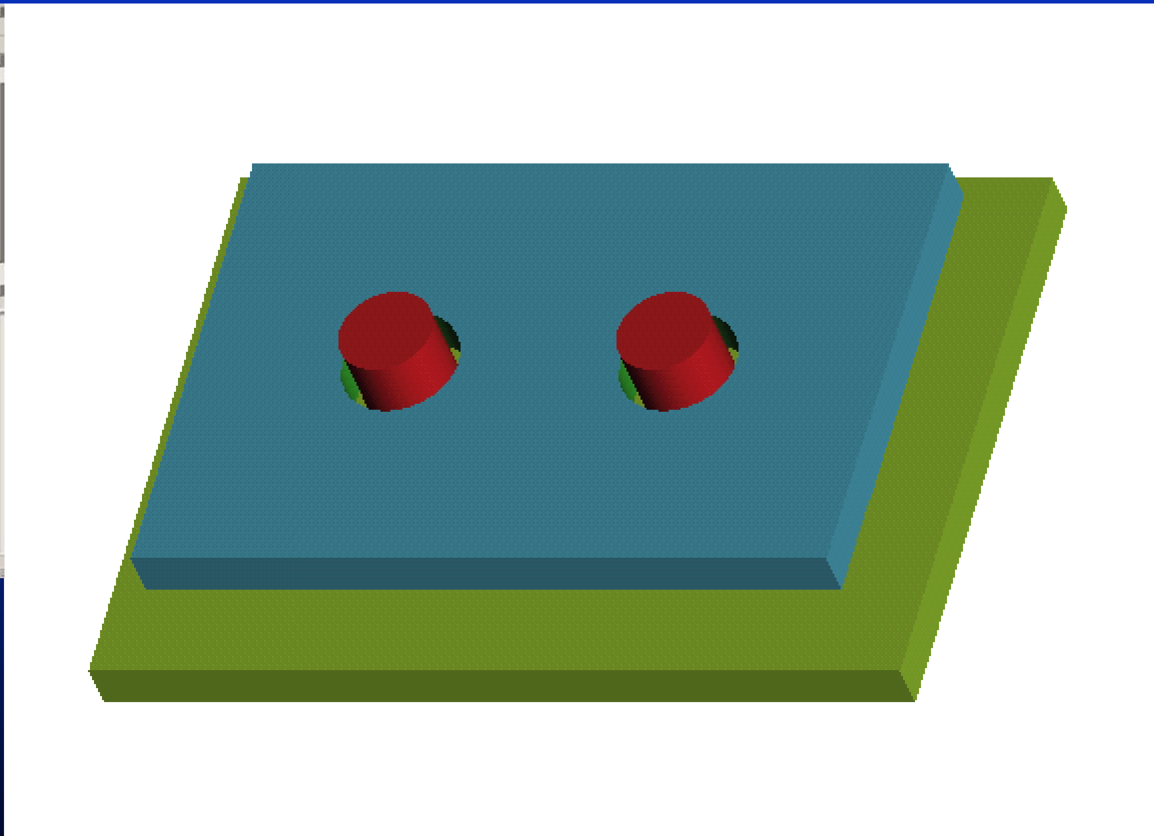




Sources of Assembly Variation: Fastened Interface Variation

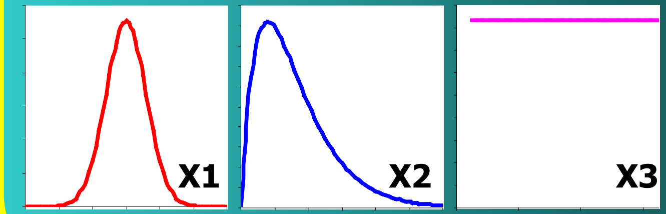
- Higher level assembly constraints require unique representation
- CETOL recognizes full range of configurations





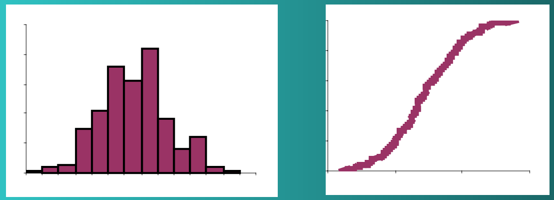
Statistical Design Performance Simulation

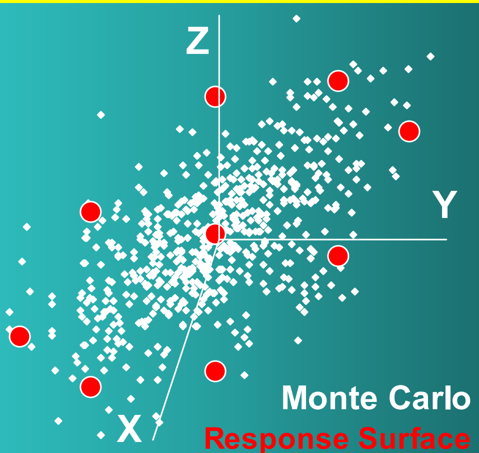
Simulation of input parameters (material, thickness, spot welds, …)



PDS

Statistical analysis of output parameters (stress, fatigue life, …)





- **Over-design is avoided** (not "as planned", "as is" or the "worst design")
- **Weight Reduction**
- **Six sigma quality**

Reliability Based Optimization within CAD

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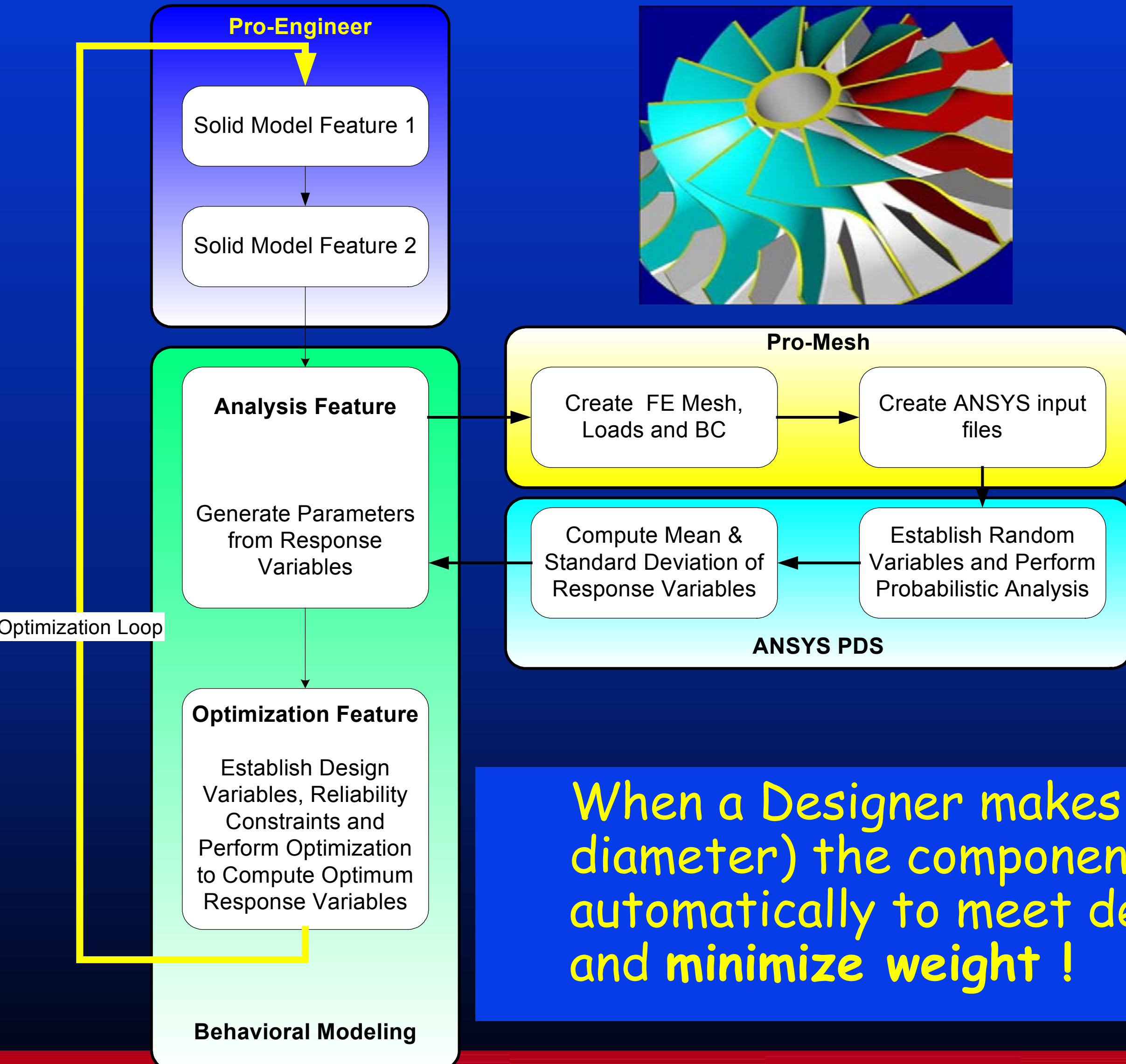
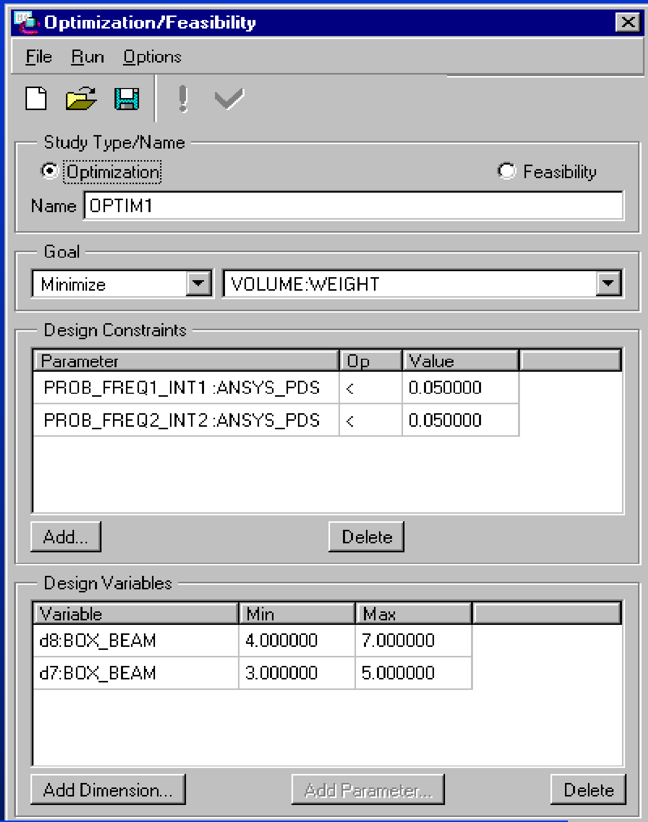
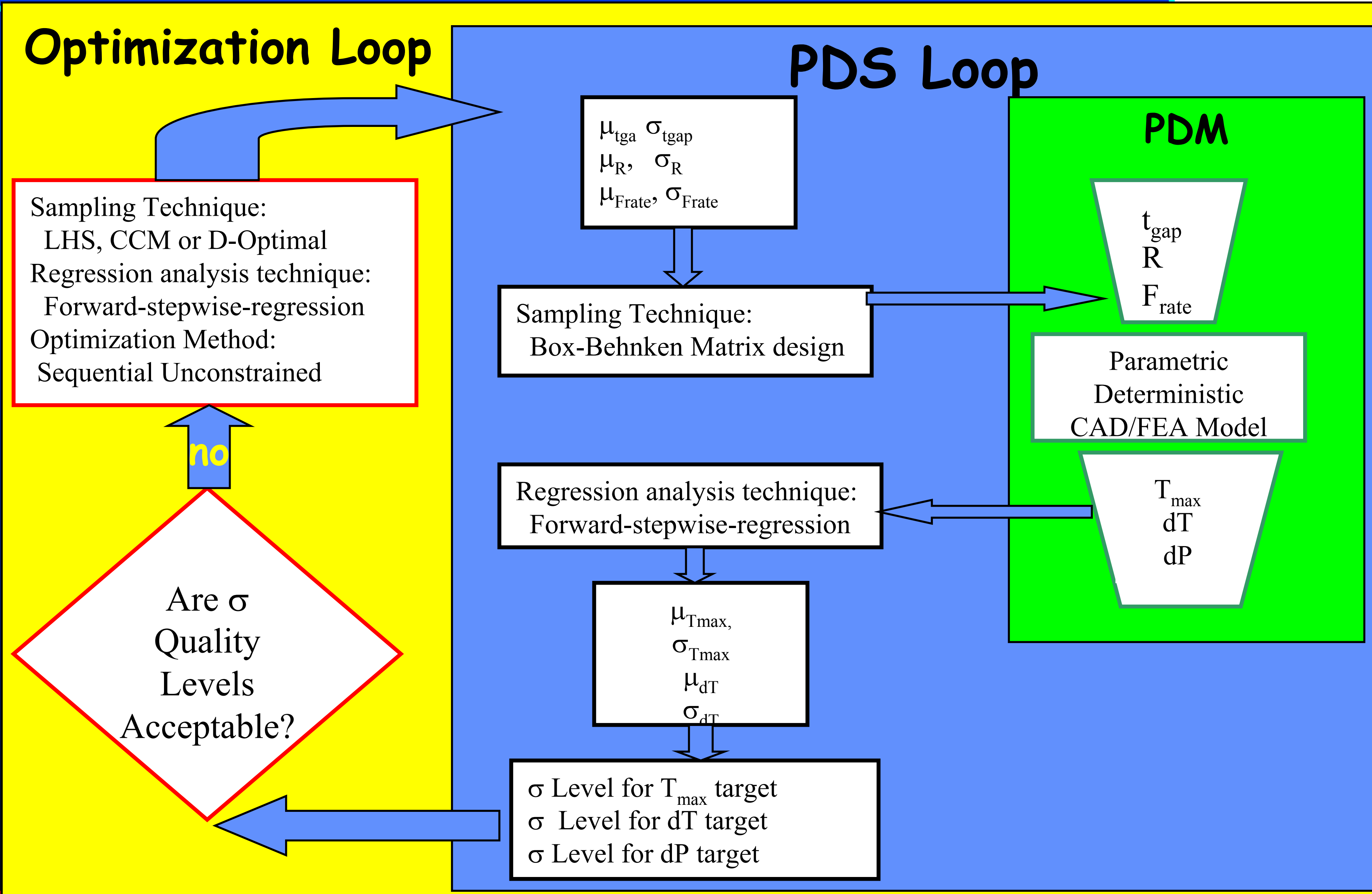




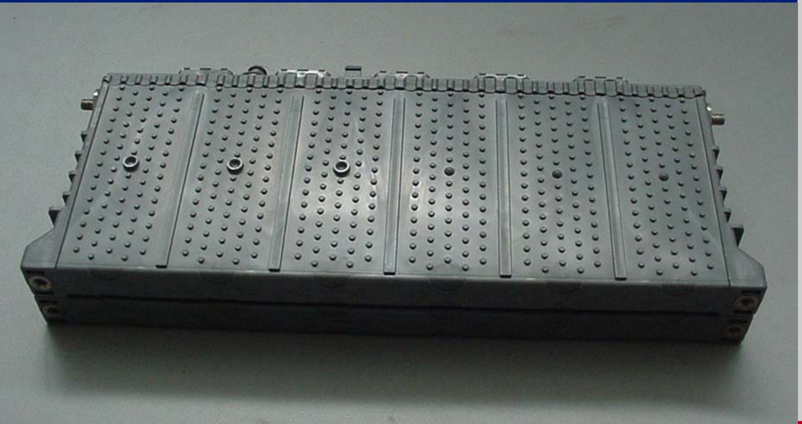
When a Designer makes a change (i.e. hole diameter) the component thickness updates automatically to meet desired quality criteria and **minimize weight !**

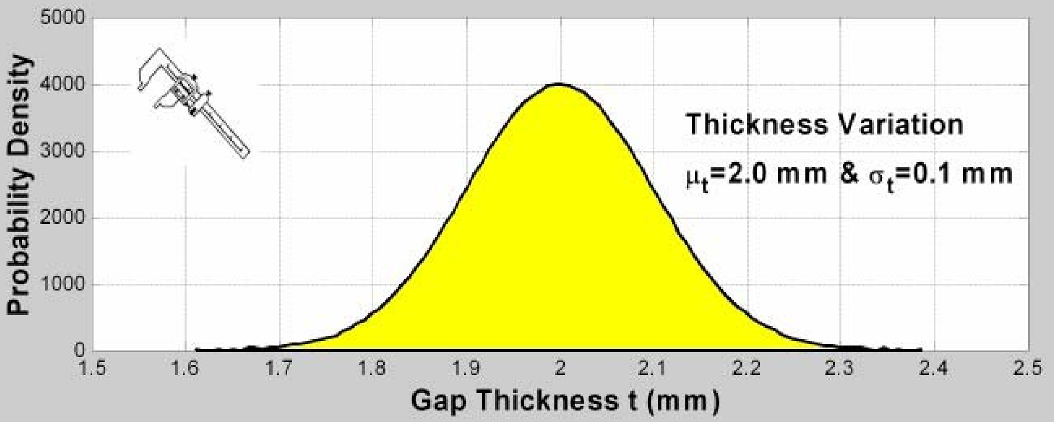
Reusable Workflow

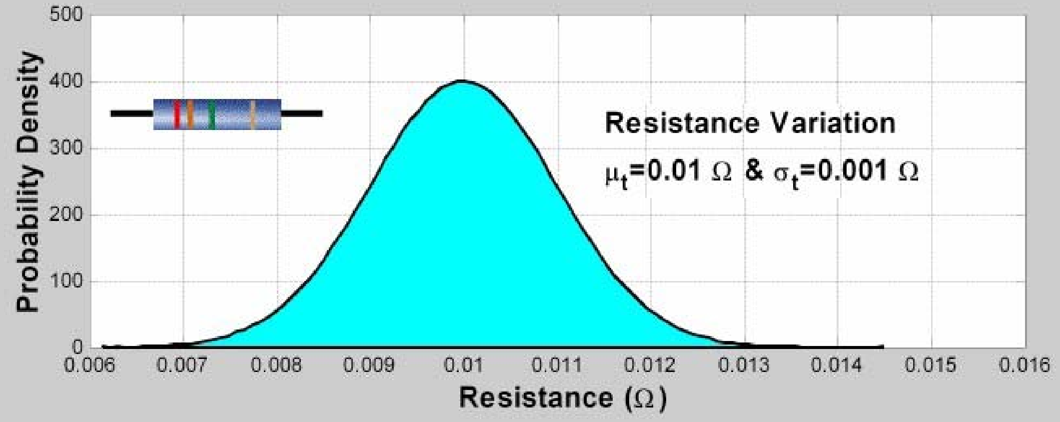


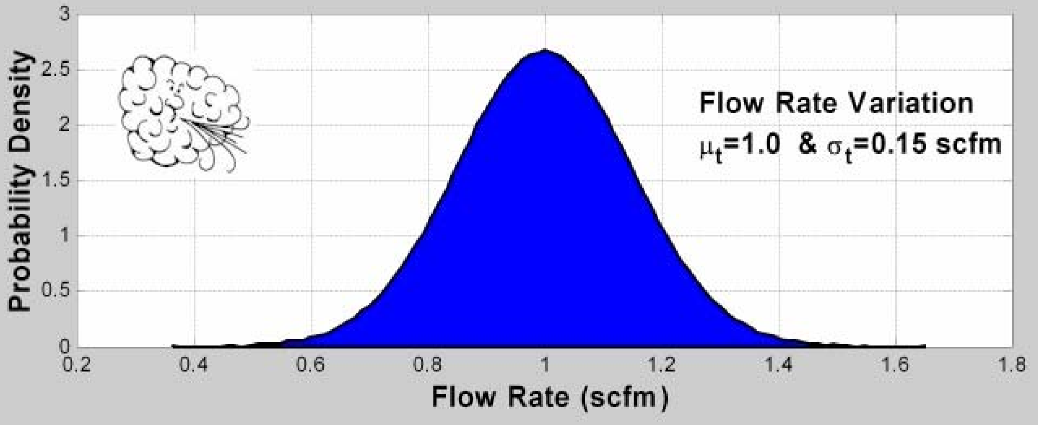
Inputs with Variation

- Gap Thickness
- Cell Resistance
- Flow Rate
- Six input parameters:
  1. μ_{tgap}
  2. σ_{tgap}
  3. μ_R
  4. σ_R
  5. μ_{Frate}
  6. σ_{Frate}



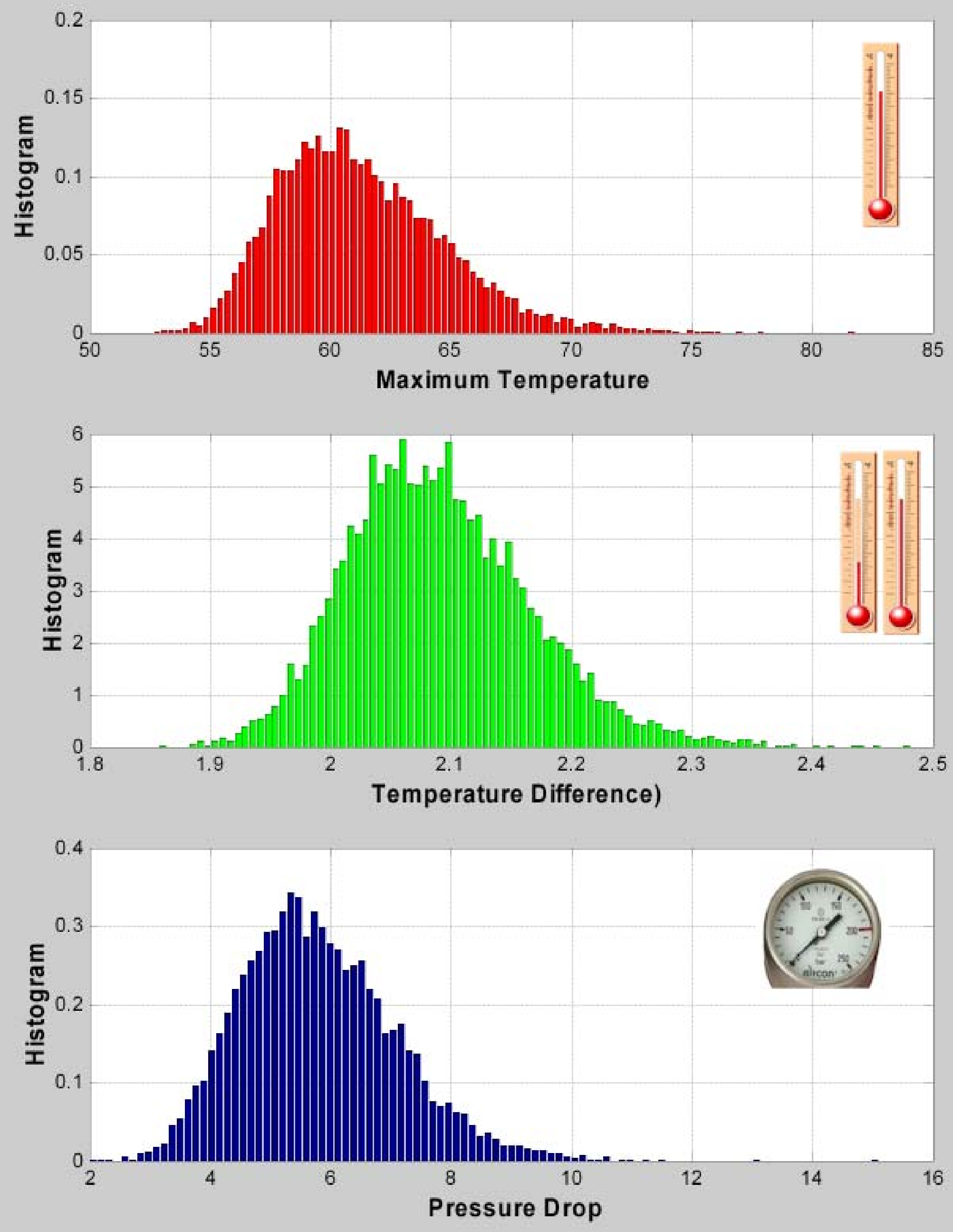






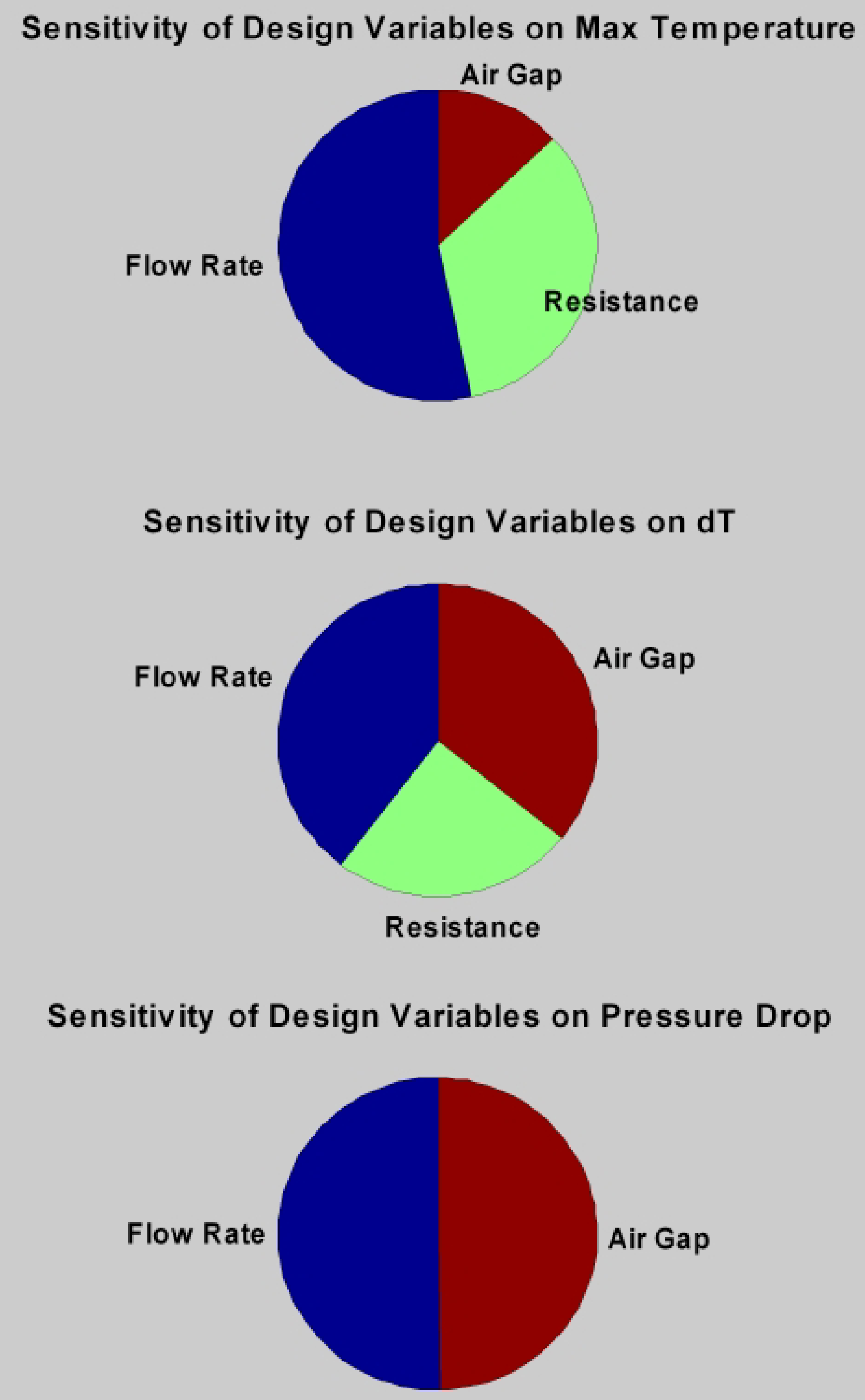
Outputs

- SMART Attributes
  - Simple
  - Measurable
  - Agree to
  - Reasonable
  - Time-based
- Outputs – variation
  - max temperature
  - differential temperature
  - pressure drop
- Six input parameters:
  - $\mu_{Tmax}, \mu_{dT}, \mu_{dP}$
  - $\sigma_{Tmax}, \sigma_{dT}, \sigma_{dP}$

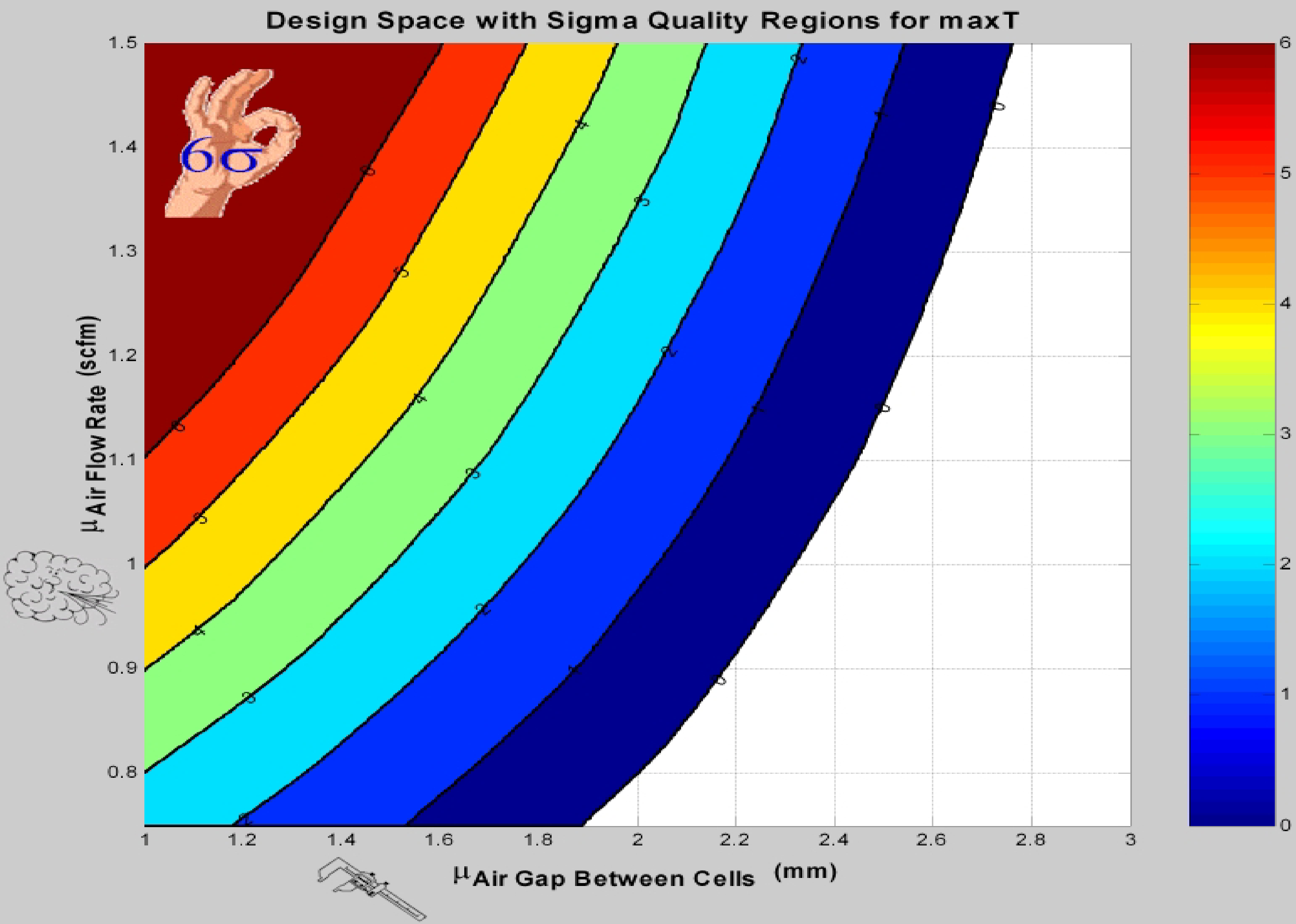


Sensitivity Analysis

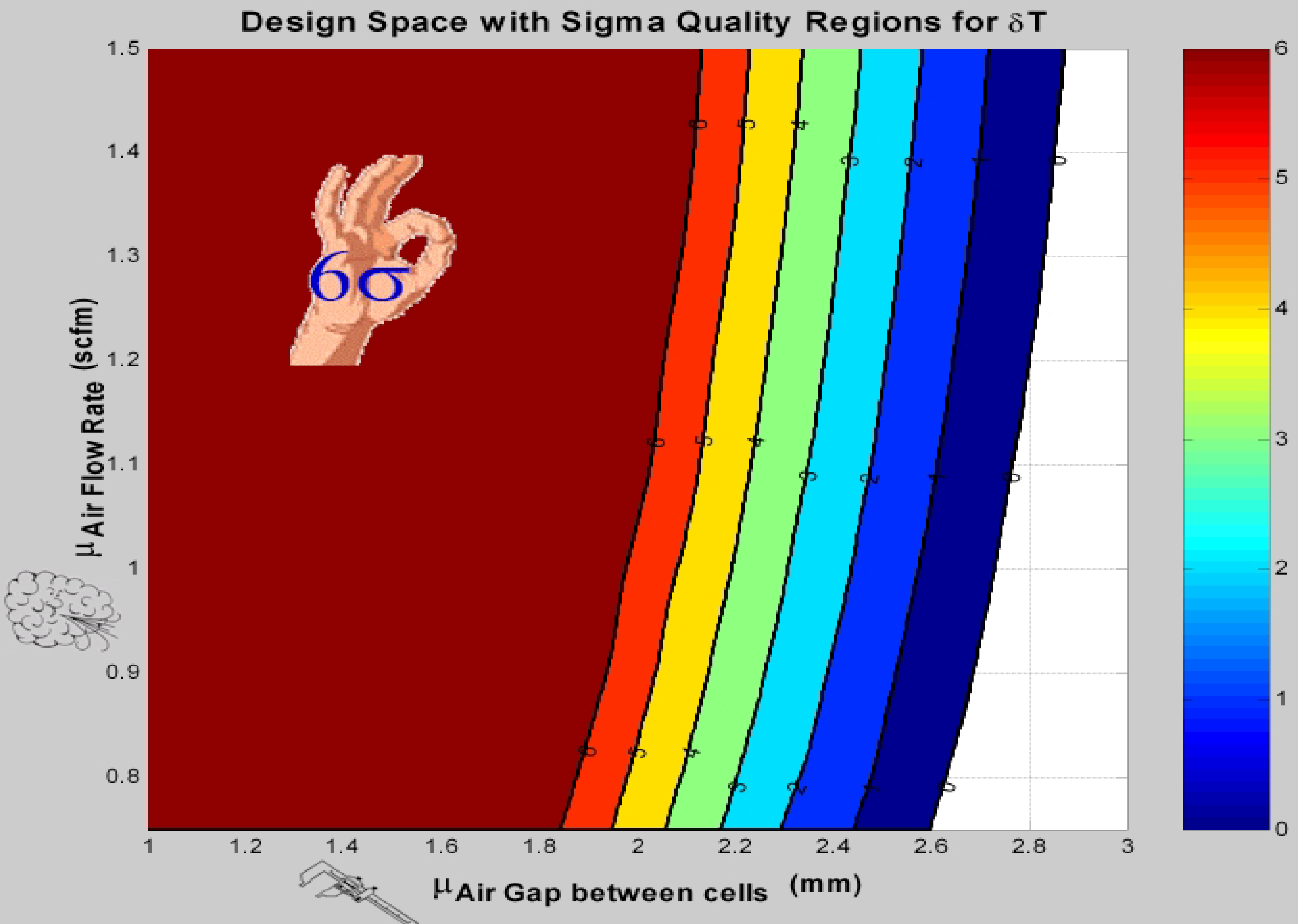
- Sensitivity of the design variables on the response attributes
  - The flow rate has the most impact on the maximum temperature
  - All three input design variables have about equal effect on the temperature differential
  - The internal battery resistance has no effect on the pressure drop.



Design Space with σ Quality Regions T_{max}



Design Space with σ Quality Regions dT



Design Space with σ Quality Regions dP

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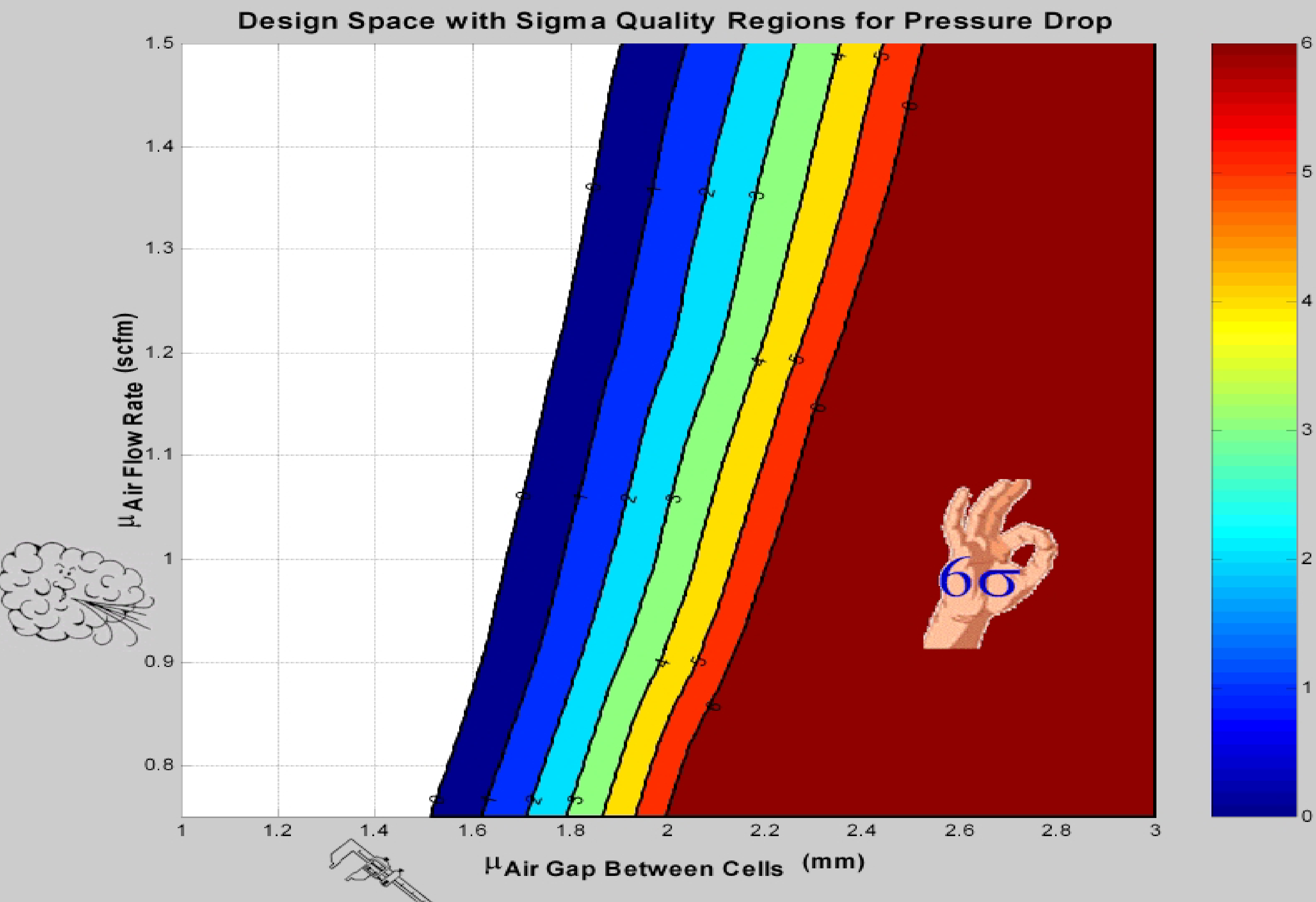
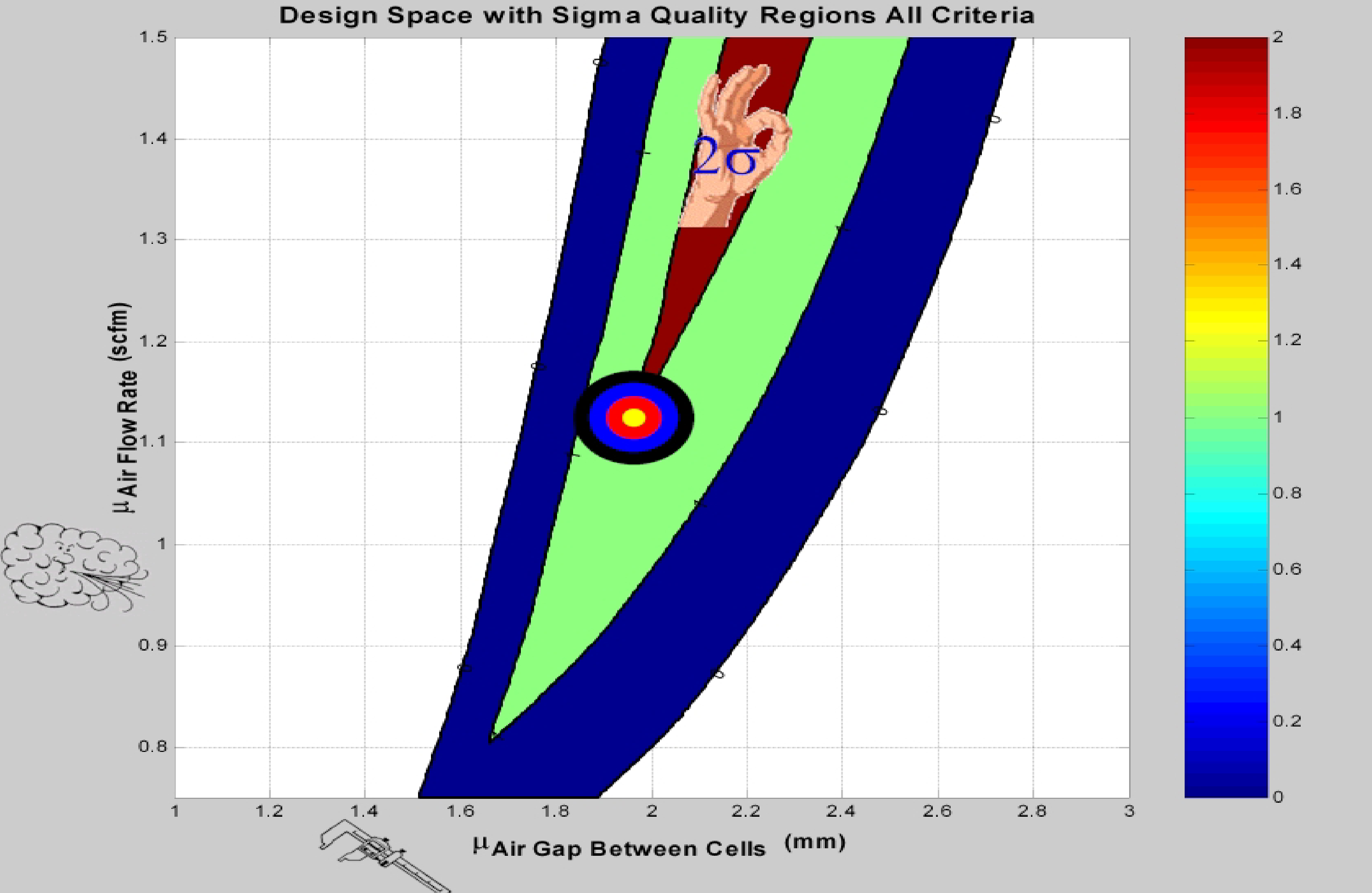


Design Space with σ Quality Regions All



Implementation Challenges

- Technical challenges
  - Design process remains unstructured or unplanned
  - Insufficient number of experts for product design & attribute prediction
  - Product attributes have not been formalized and managed early enough
  - CAD / CAE toolset is not tailored to design environment
  - Data not readily available to feed analysis

Implementation Challenges

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- Organizational challenges
  - Lack of clear metrics and success stories
  - Achieving consensus on methods to be used and on integration of product development environment with PDM software
  - Developing and implementing custom capabilities with commercially available software
    - BMX
    - Visual DOC
    - iSIGHT,
    - AI*workbench
    - CO,…)
  - Organization's commitment to product development excellence

Overcoming Challenges

1. Identify the right organization
   - Committed to product development
   - Willing to change
   - Able to make decisions
   - Willing to bypass consensus where needed

2. Identify the right project
   - Repetitive and measurable
   - High value added
   - Bottle neck, short duration (3-6 months)
   - Non trivial, expertise required
   - Mainly with objective requirements

Overcoming Challenges

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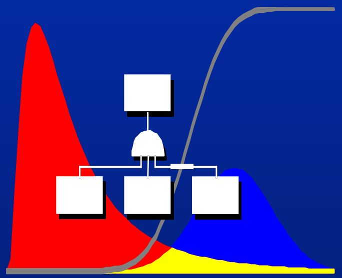
3. Implement the following Solution Strategies

- Clarify and document the desired design decision process
- Establish the cost & time of the current state
- Create a design environment tailored to the desired design process; workflow management
- Develop a repository of design & manufacturing rules to govern the design process
- Augment the experts by automating large portions of the design process (BMX)
- Simplify and automate tool usage for standard analyses
- Improve attribute prediction as knowledge increases
- Automate data integration and allow for new methods

Conclusions

- This Design Process enables engineers to quantify uncertainty and improve quality
- The Information Architecture and the Design Process can provide productivity improvements up to 90% but must be crystal clear so you always know:



  - Where you are
  - How you got there
  - How to get home
  - Where you can go
  - How to get help
- Greater Utilization of Engineering Talent
  - Drudgery of multiple simulation runs passed onto computer
  - Greater portion of the engineer's time spent on fundamental engineering
  - More time to understand customer requirements and focus on design constraint definition

Create a Vision,

Adopt it,

Adapt to Achieve it