Infotag
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Multidisciplinary Optimization using the Successive Response Surface Method

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Topics

- Introduction
- LS-OPT: Application of the Successive Response Surface Method (SRSM)
- Example: Multidisciplinary Optimization (MDO)

DYNA MORE

Introduction

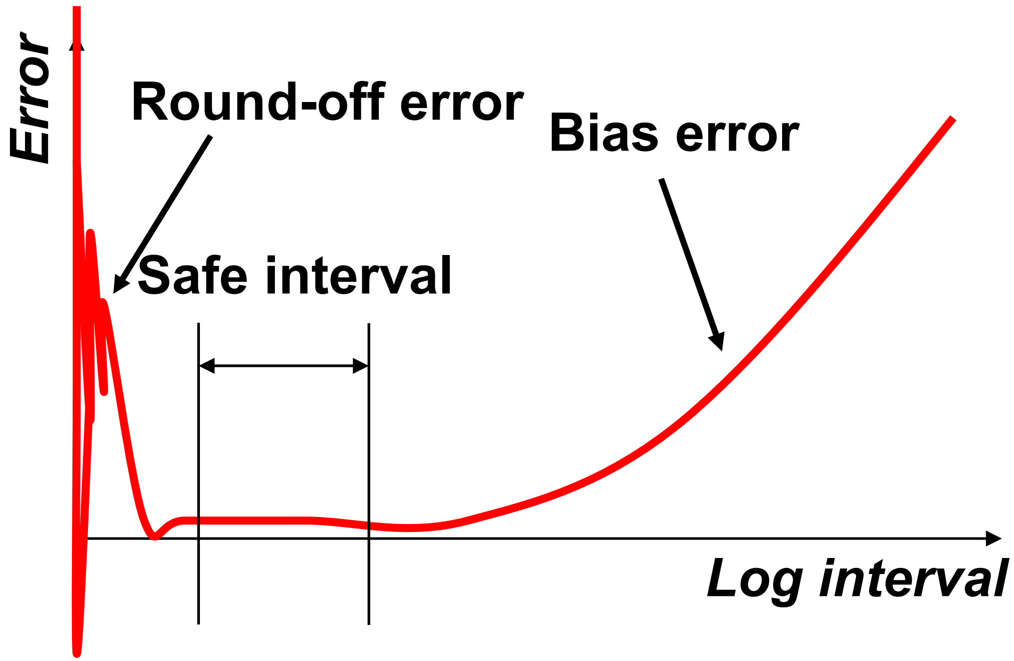
What is LS-OPT?

- **LS-OPT is an environment to explore automatically the design space and find an optimum design**
- **LS-OPT is a product of LSTC (Livermore Software Technology Corporation)**
- **LS-OPT is based on the Successive Response Surface Method (SRSM). Statistical approaches (Robustness Analysis) and genetic algorithms (Discrete Methods) will be implemented in near future**
- **LS-OPT provides a graphical user interface (GUI)**
- **LS-OPT can be linked to any simulation code, but it is perfect suitable in combination with LS-DYNA**

LS-OPT: Application of the SRSM

Why Response Surface Method and not Gradient Based Methods?

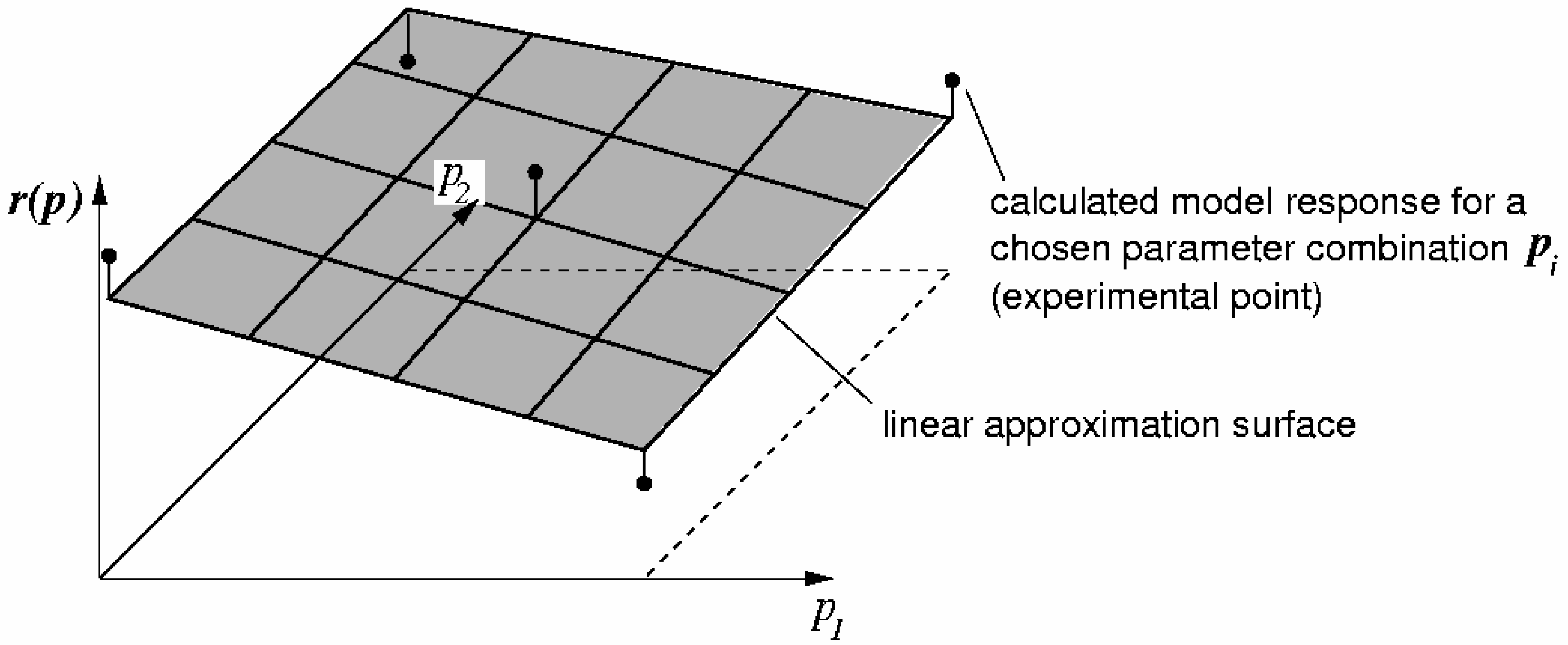
- **Highly Nonlinear Problems**
- **Local Sensitivities may lead to local optimums**
- **Difficulties by the Computation of Numerical Gradients**
  - **If the perturbation intervall is too large: loose accuracy**
  - **If the perturbation intervall is too small: find spurious gradients**



LS-OPT: Application of the SRSM

SRSM: How does it work?

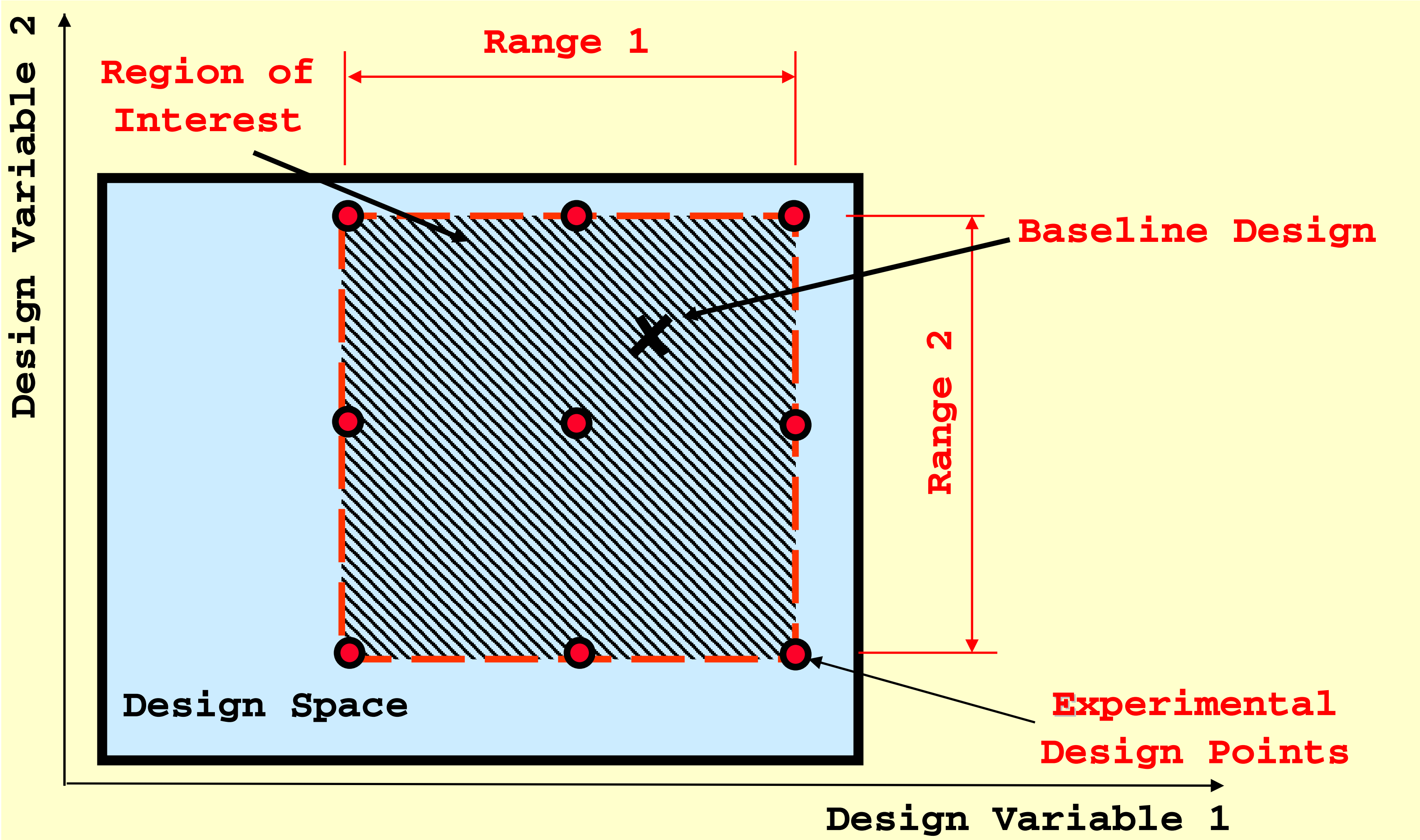
- **Design surfaces are fitted through points in the design space to form approximate optimization problem**



- **The idea is to find surfaces with the best predictive capability**

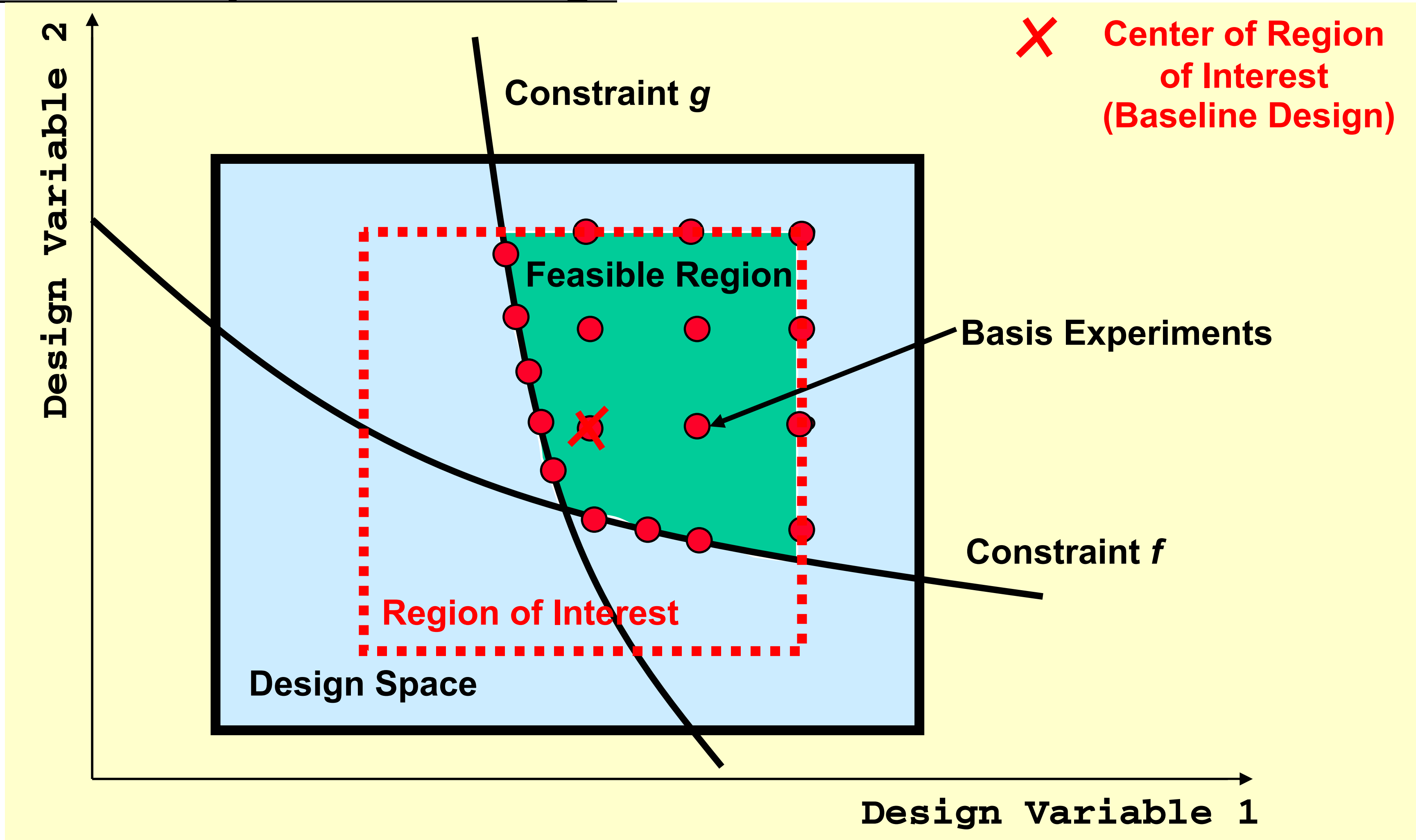
LS-OPT: Application of the SRSM

Design Space, Region of Interest & Experimental Design Points



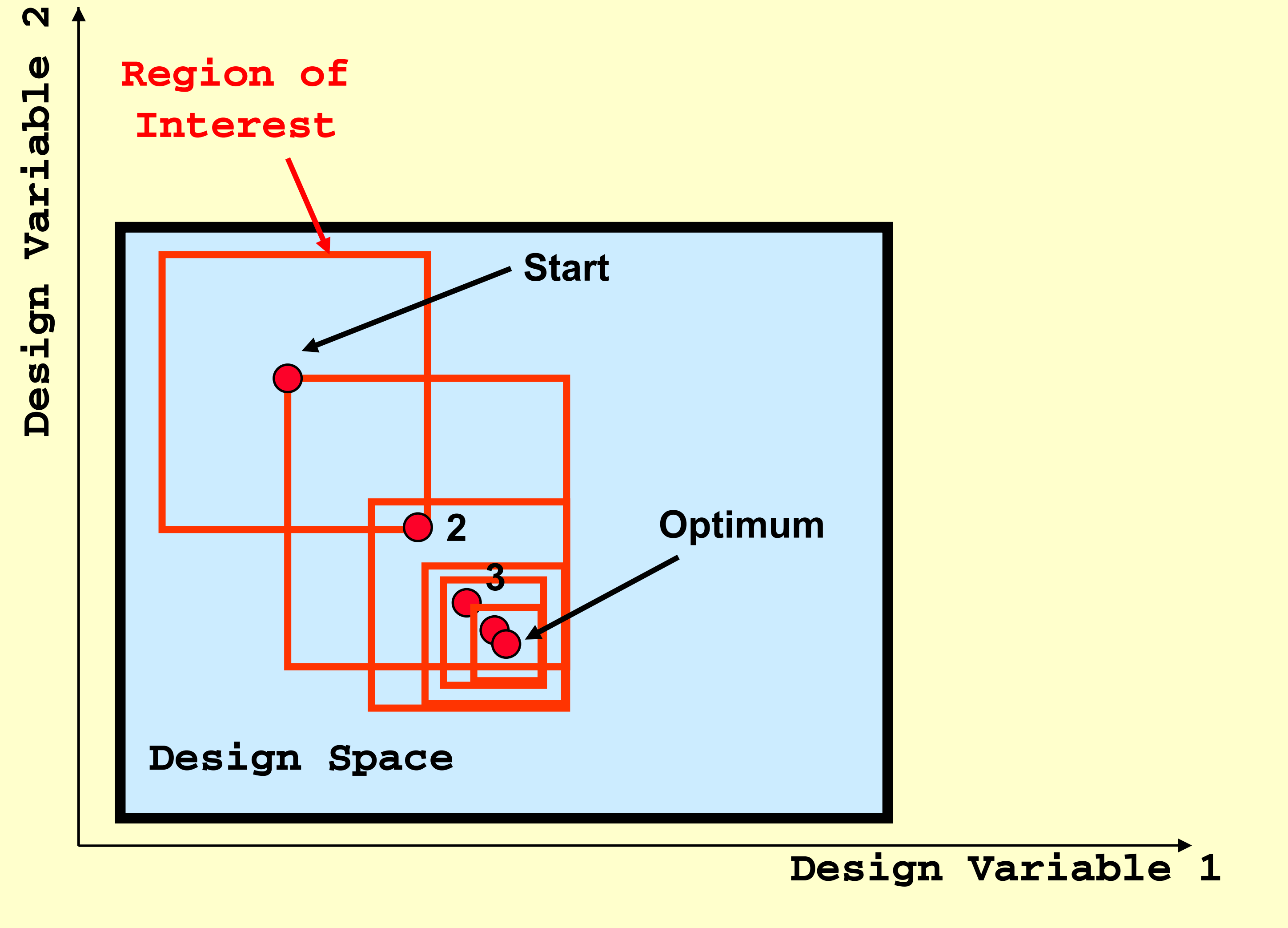
LS-OPT: Application of the SRSM

Feasible Experimental Design



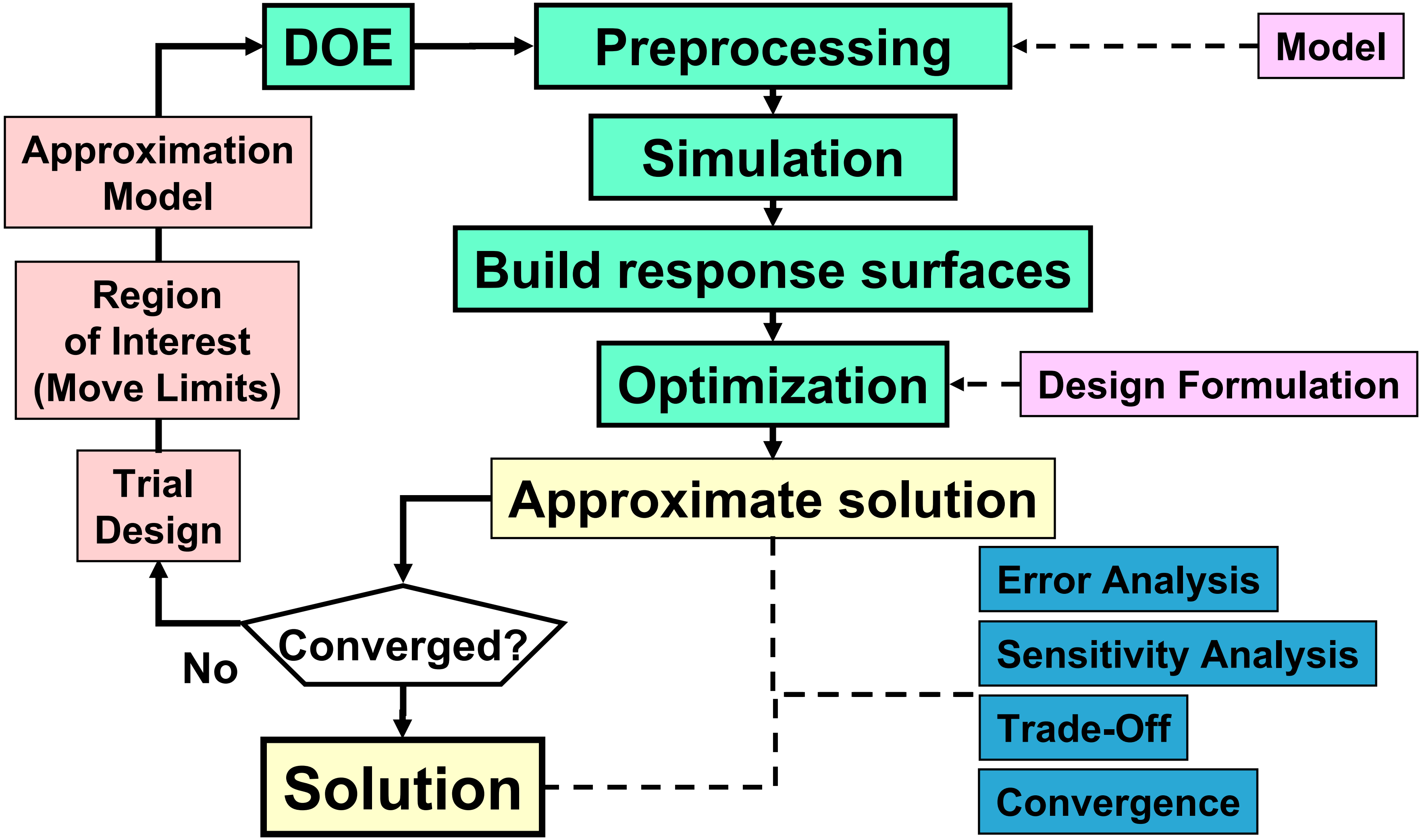
LS-OPT: Application of the SRSM

Successive Approximation Scheme



LS-OPT: Application of the SRSM

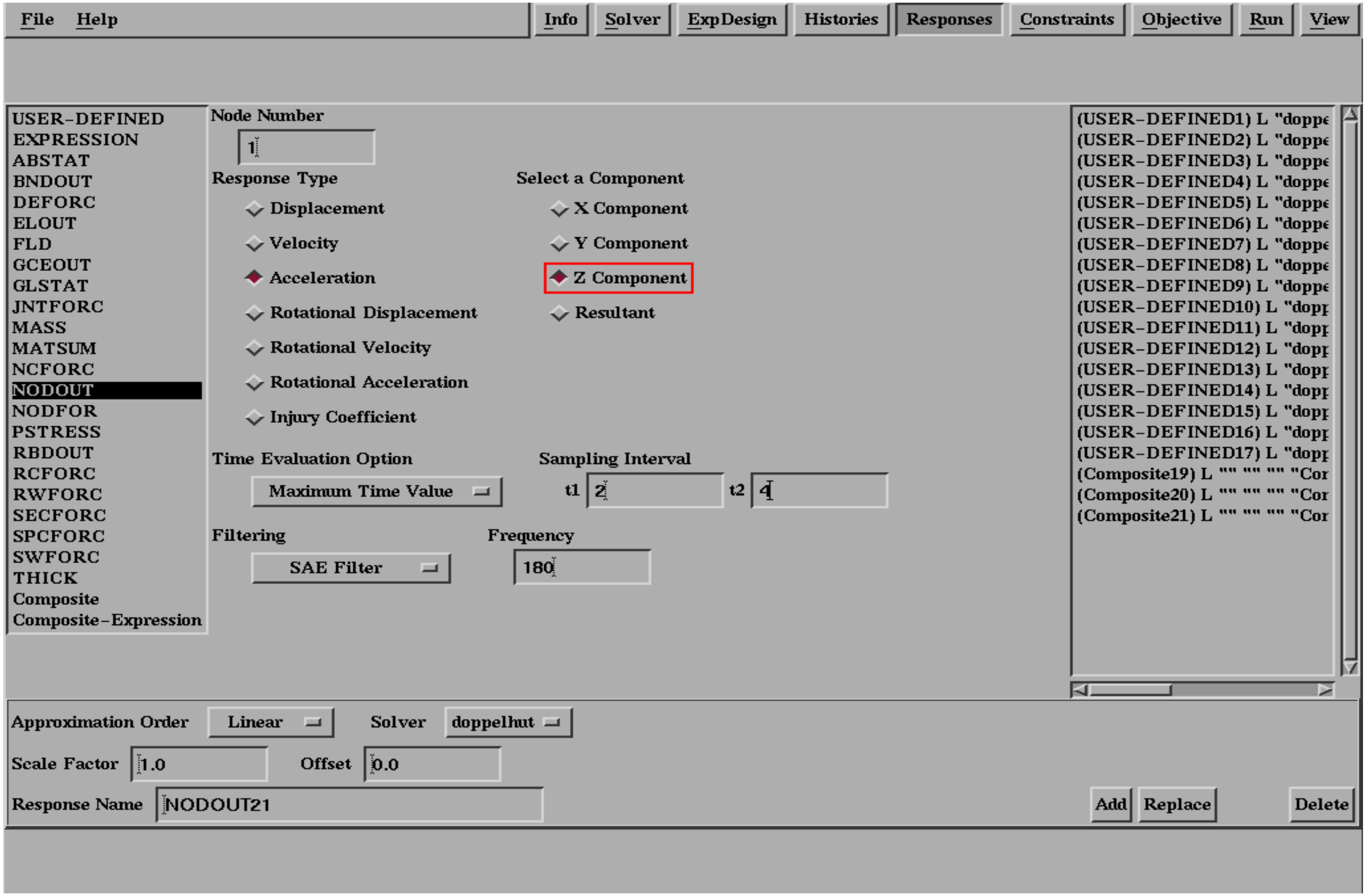
The Optimization Prozess



Graphical User Interface

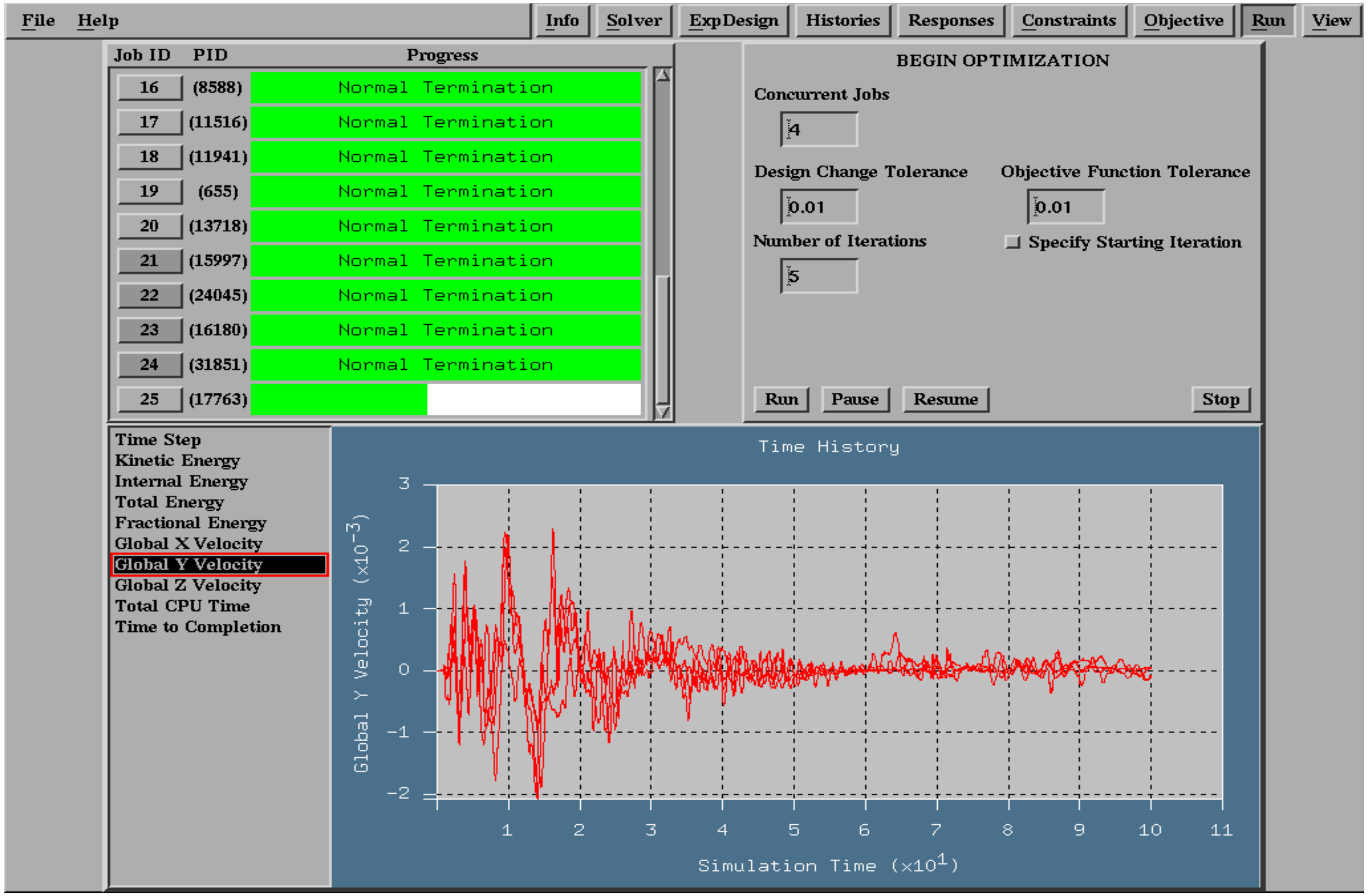
LS-OPT: Application of the SRSM

Graphical User Interface



LS-OPT: Application of the SRSM

Graphical User Interface



DYNA MORE

LS-OPT: Application of the SRSM

Advantages of the Method

- **Global Optimization:**

Response Surface have a tendency to capture globally optimal regions. Local minima caused by noisy response as well as the step-size dilemma for numerical gradients are avoided

- **Parallel Computation:**

Successive Response Surface scheme allows parallel (independent) computation of experimental points within one iteration

- **Flexible Design Exploration:**

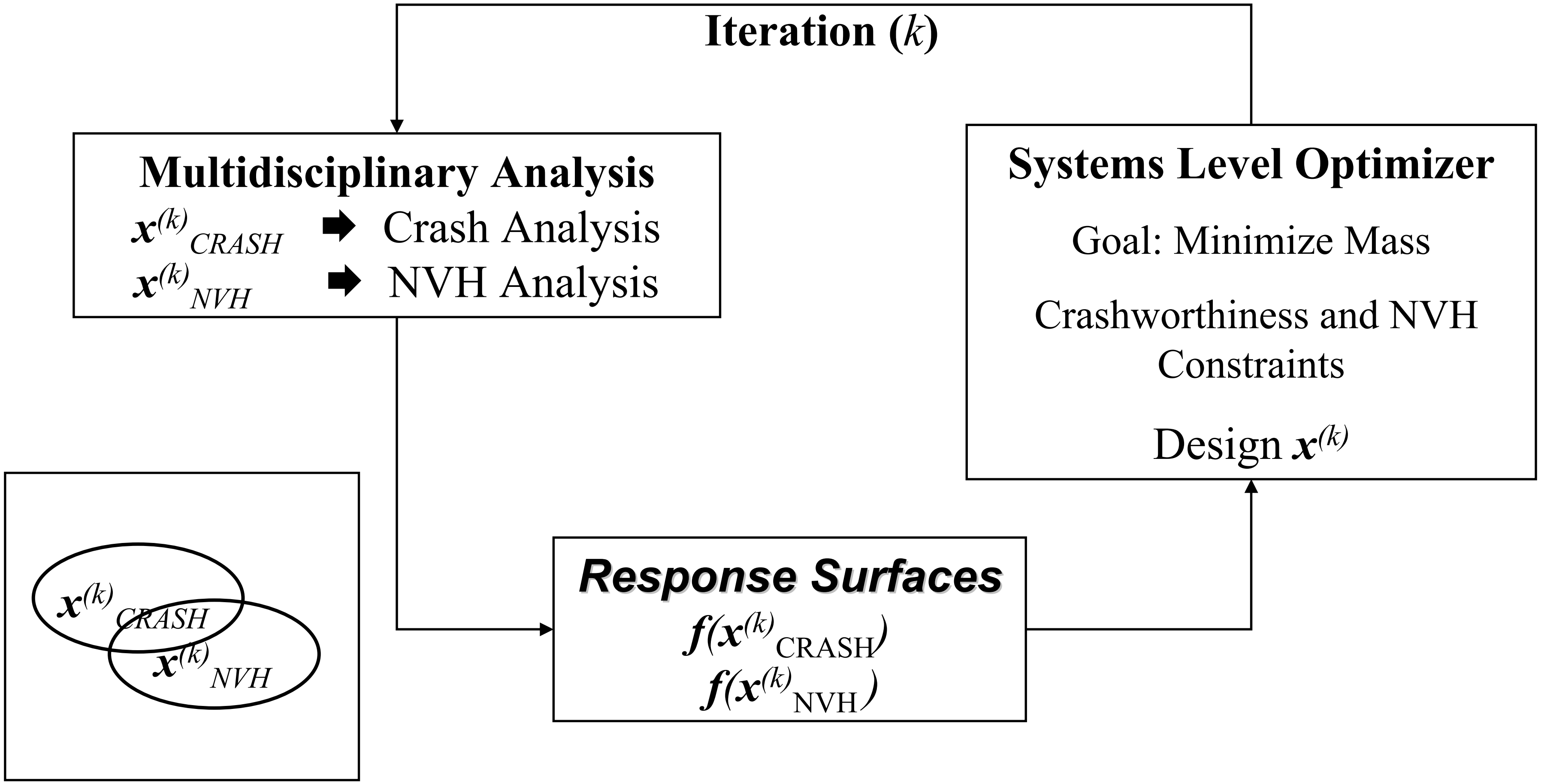
Design exploration can be changed within the optimization process. Thus, control of the computational time and the quality of the Response Surface is possible

- **Trade-Off Studies:**

Since the Response Surface is determined, easy examination of varying constraint bounds is possible (not reliable with linear approximations)

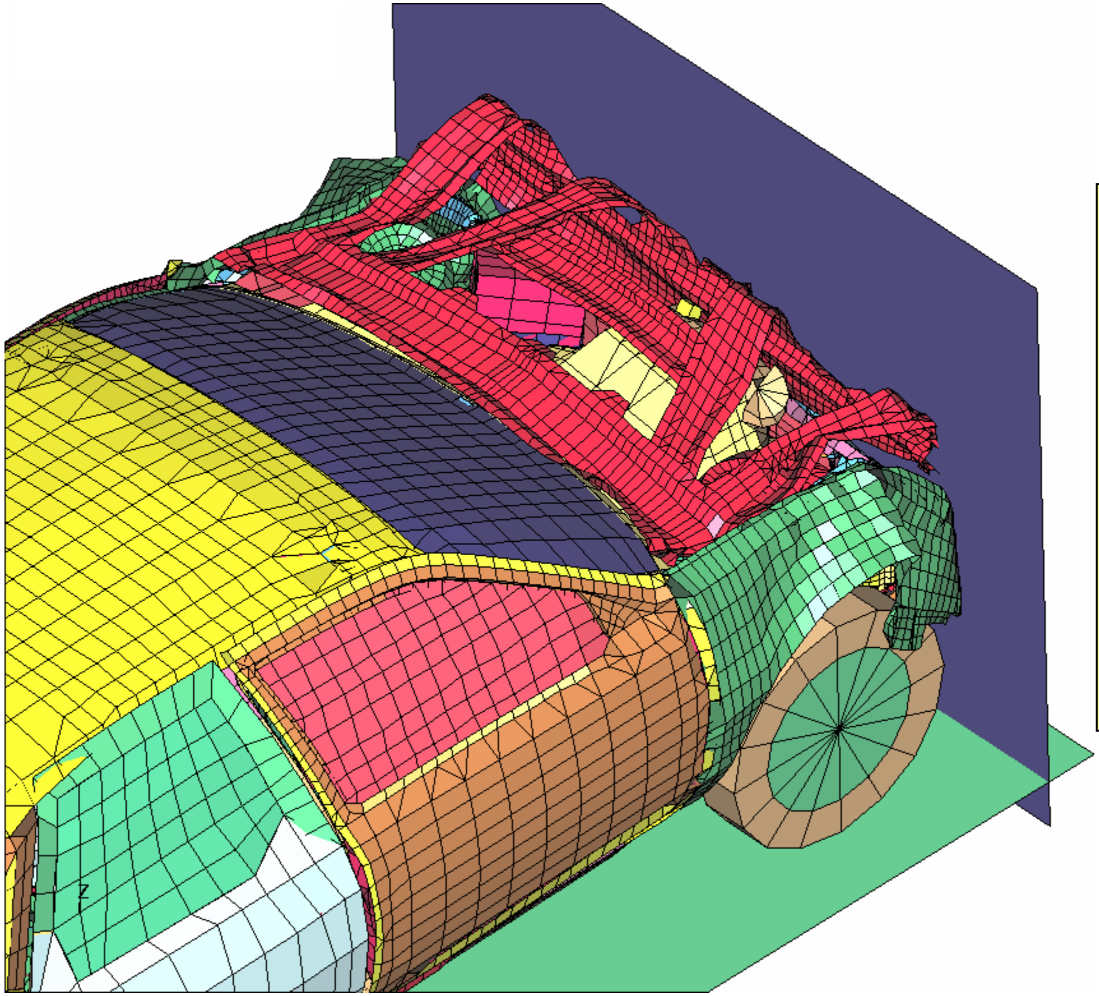
Example: Multidisciplinary Optimization (MDO)

Fully Integrated Optimization - Crash and NVH



Example: Multidisciplinary Optimization (MDO)

Full Vehicle – Crash Performance (LS-DYNA)

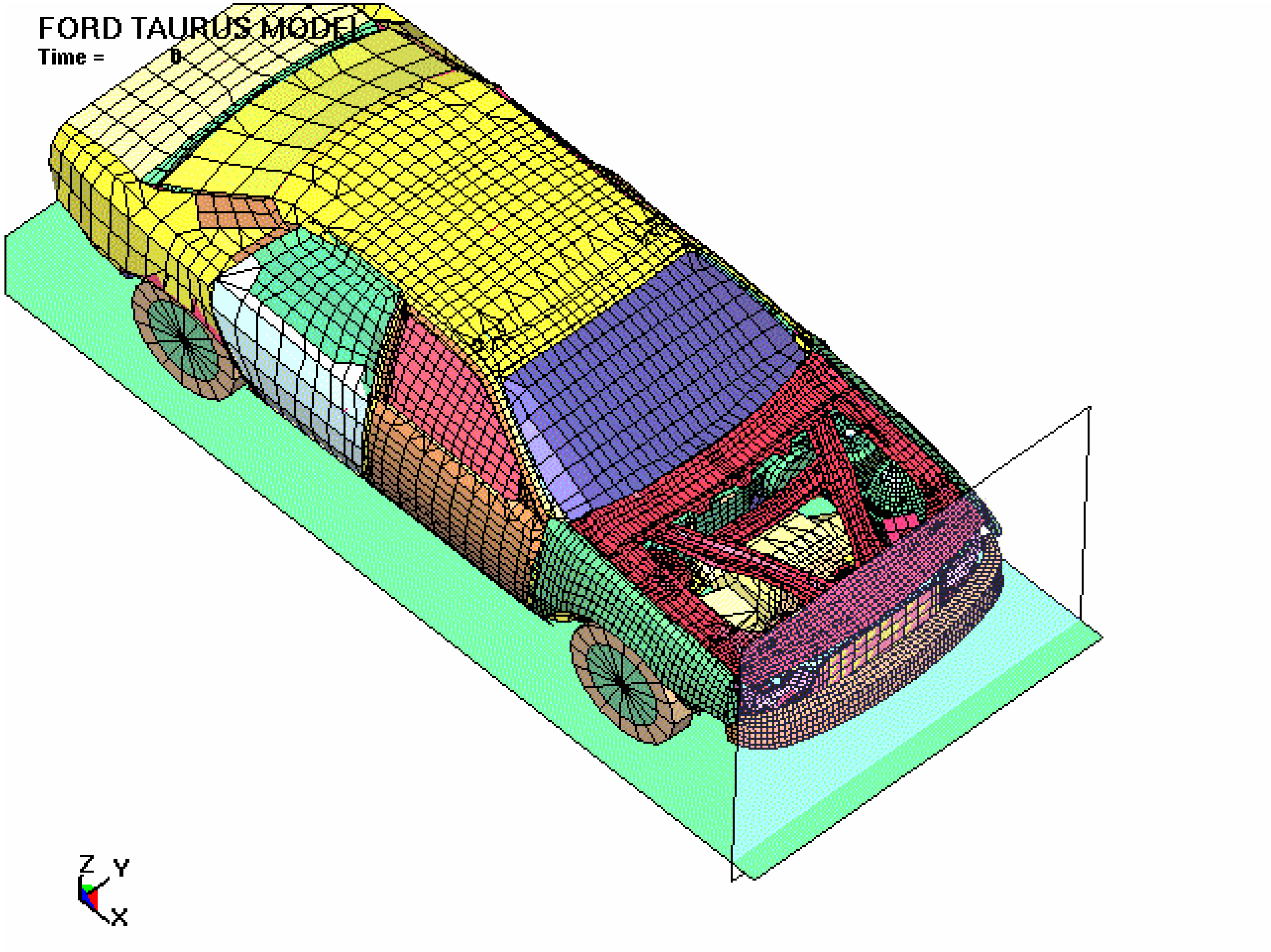


Baseline:

- **30 000 elements**
- **Displacement = 552mm**
- **Stage1Pulse = 14.34 g**
- **Stage2Pulse = 17.57 g**
- **Stage3Pulse = 20.76 g**

Example: Multidisciplinary Optimization (MDO)

Full Vehicle – Crash Performance (LS-DYNA)



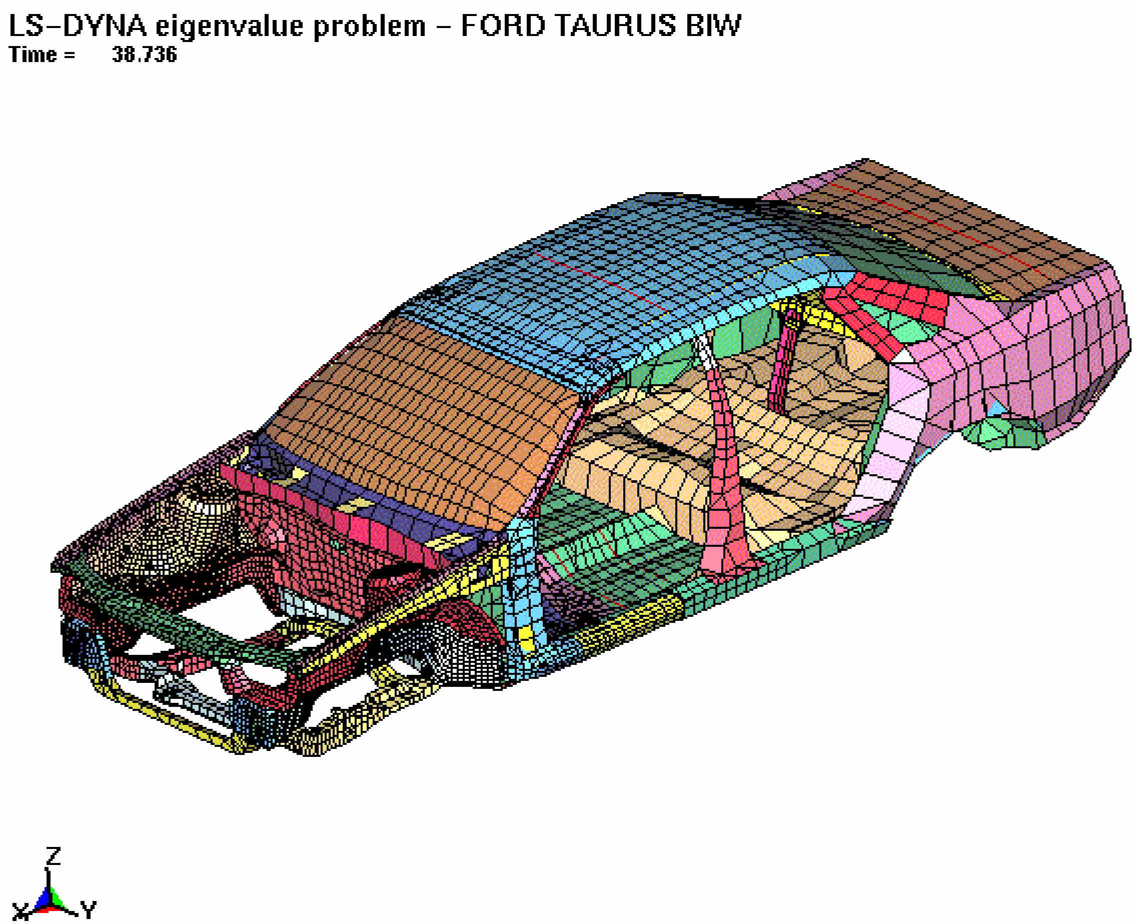
Example: Multidisciplinary Optimization (MDO)

BIW-Modell - NVH Performance (LS-DYNA)

Baseline:

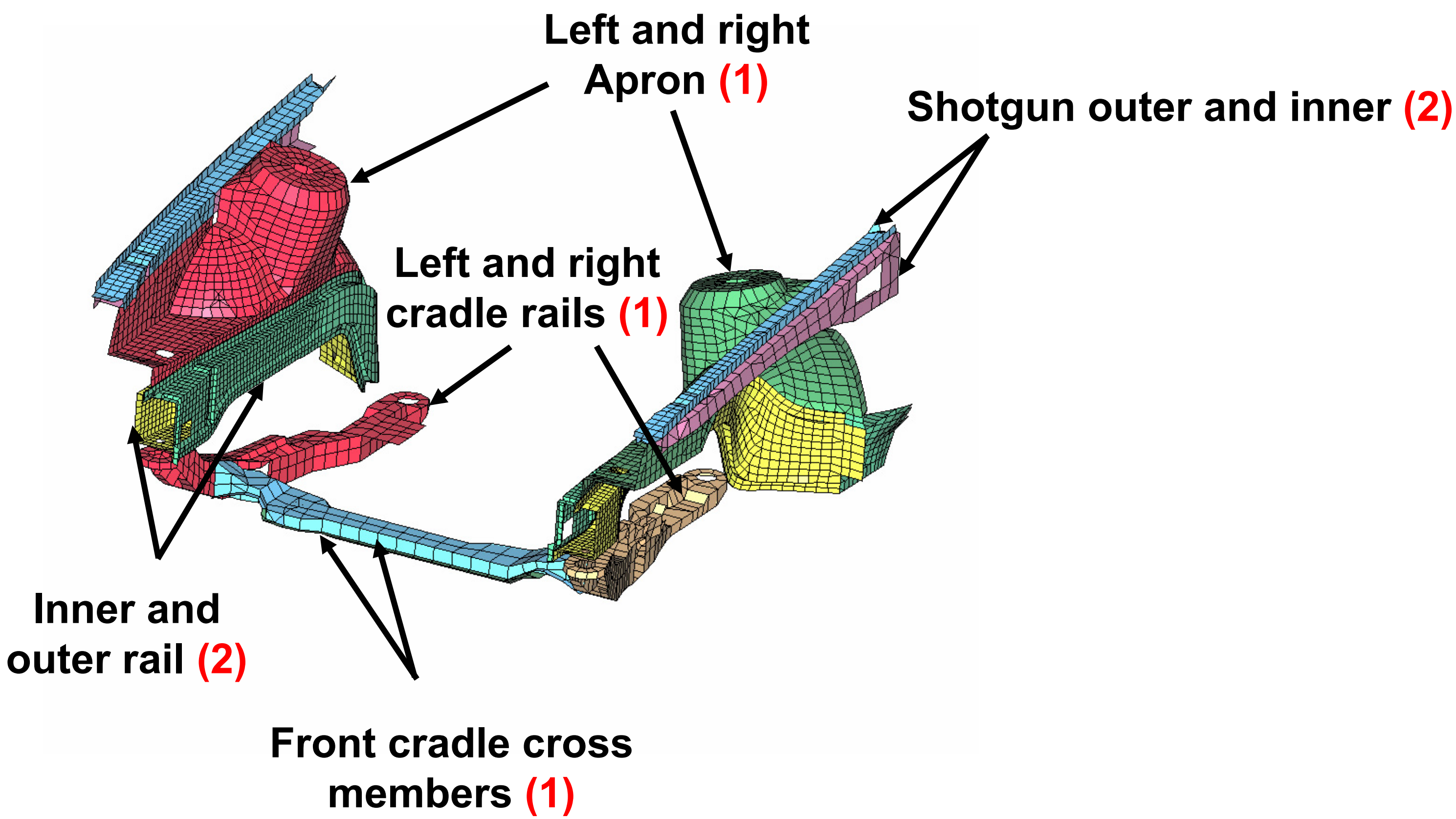
- **18 000 elements**
- **Torsional Mode 1**

  Frequency = 38.7 Hz



Example: Multidisciplinary Optimization (MDO)

Design Variables (Thickness)



Example: Multidisciplinary Optimization (MDO)

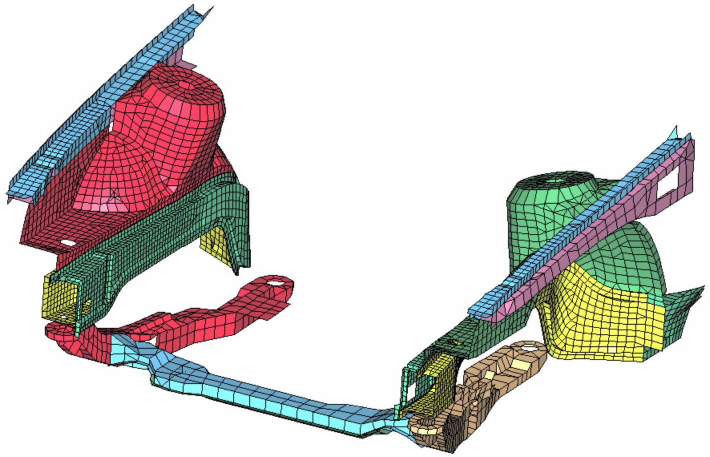
Design Formulation – FULLY SHARED VARIABLES

Design Objective:

- **Minimize (Mass of components)**

Design Constraints:

- **Displacement > 551.8mm**
- **37.77Hz < Torsional mode 1 frequency < 39.77Hz**
- **Stage1Pulse > 14.34g**
- **Stage2Pulse > 17.57g**
- **Stage3Pulse > 20.76g**



Thickness Design Variables Shared: 7

- **Rails (inner and outer),**
  Shotgun (inner and outer), Aprons,
  Cradle rails, cross member

Mode Tracking

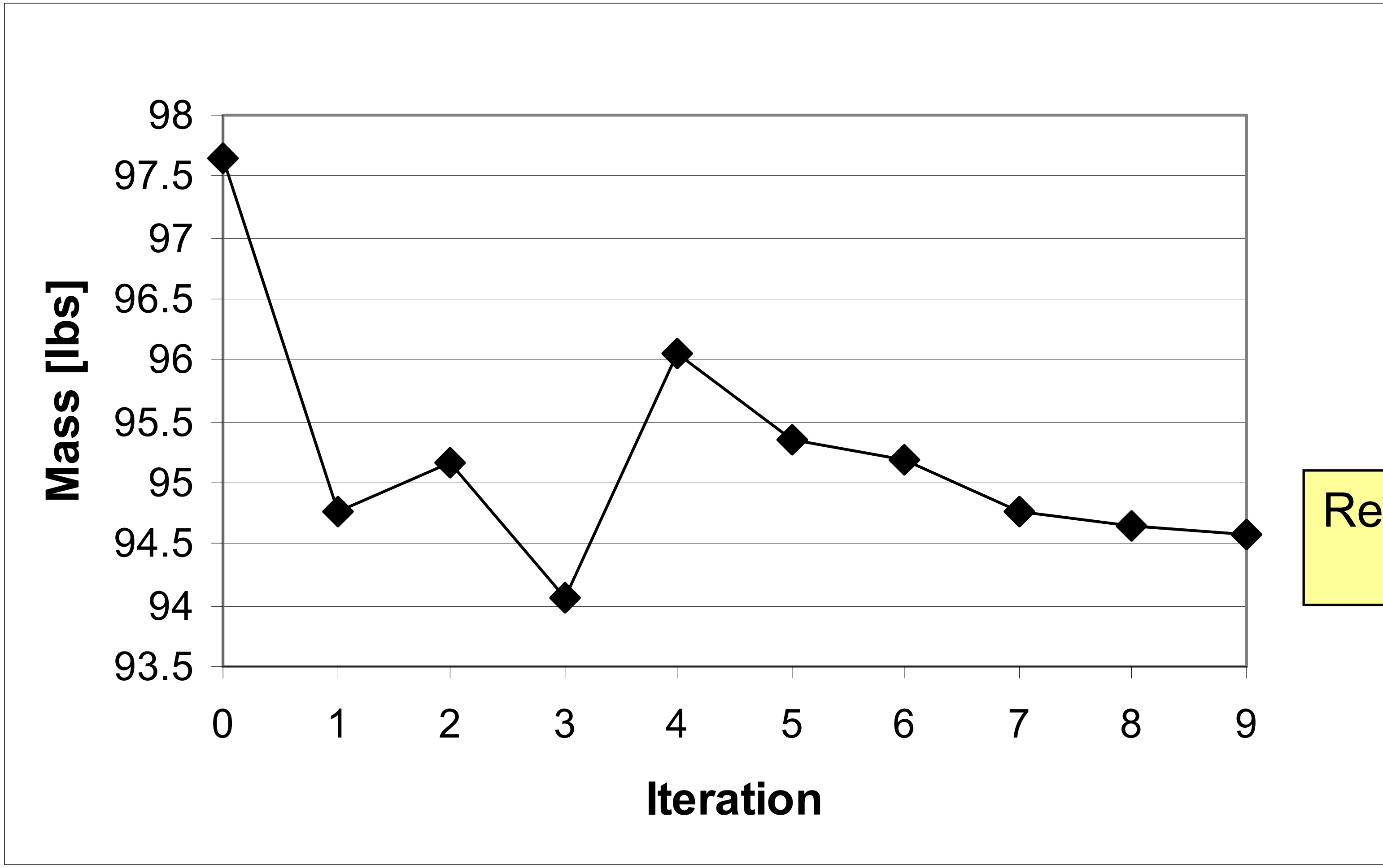
- **During NVH optimization necessary to track mode as mode switching can occur due to design changes**

- **Search for maximum scalar (dot) product between eigenvector of base mode and each solved mode:**

$$\max_j \left\{ \left(M_0^{\frac{1}{2}} \phi_0 \right)^T \left(M_j^{\frac{1}{2}} \phi_j \right) \right\}$$

Example: Multidisciplinary Optimization (MDO)

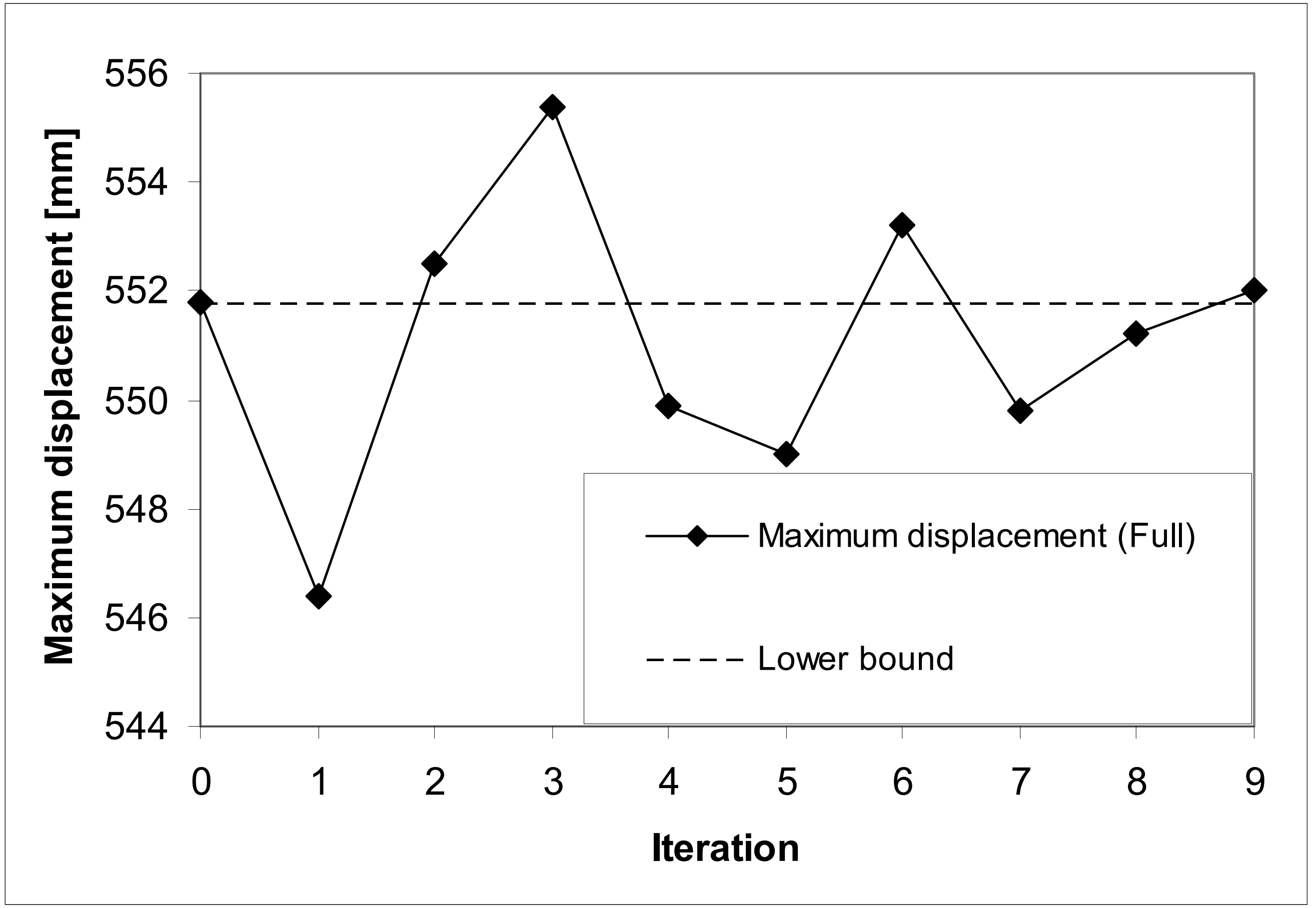
Optimization History: Mass (Objective) – FULLY SHARED VARIABLES



Reduction:
-3%

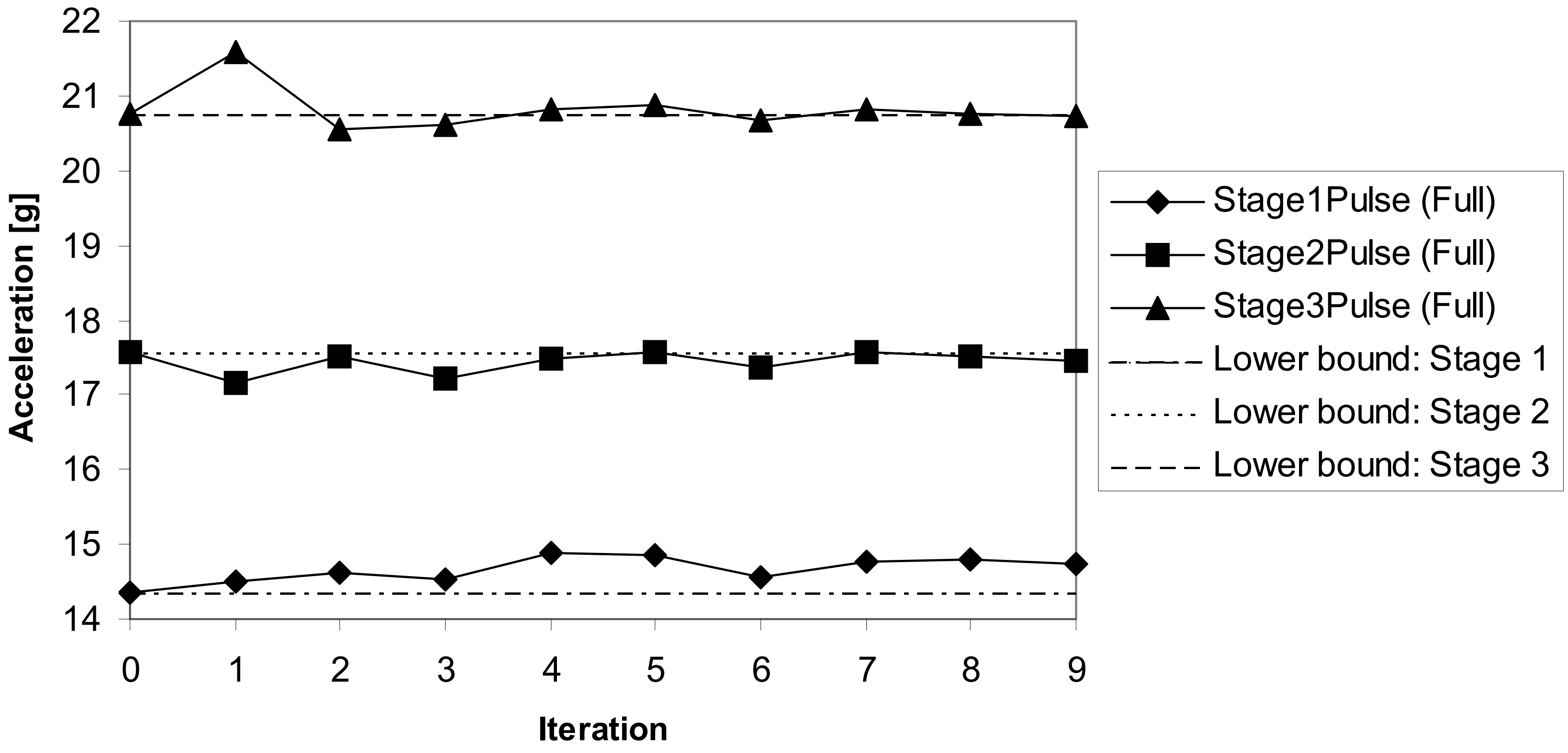
Example: Multidisciplinary Optimization (MDO)

Optimization History: Maximum Displacement – FULLY SHARED VARIABLES



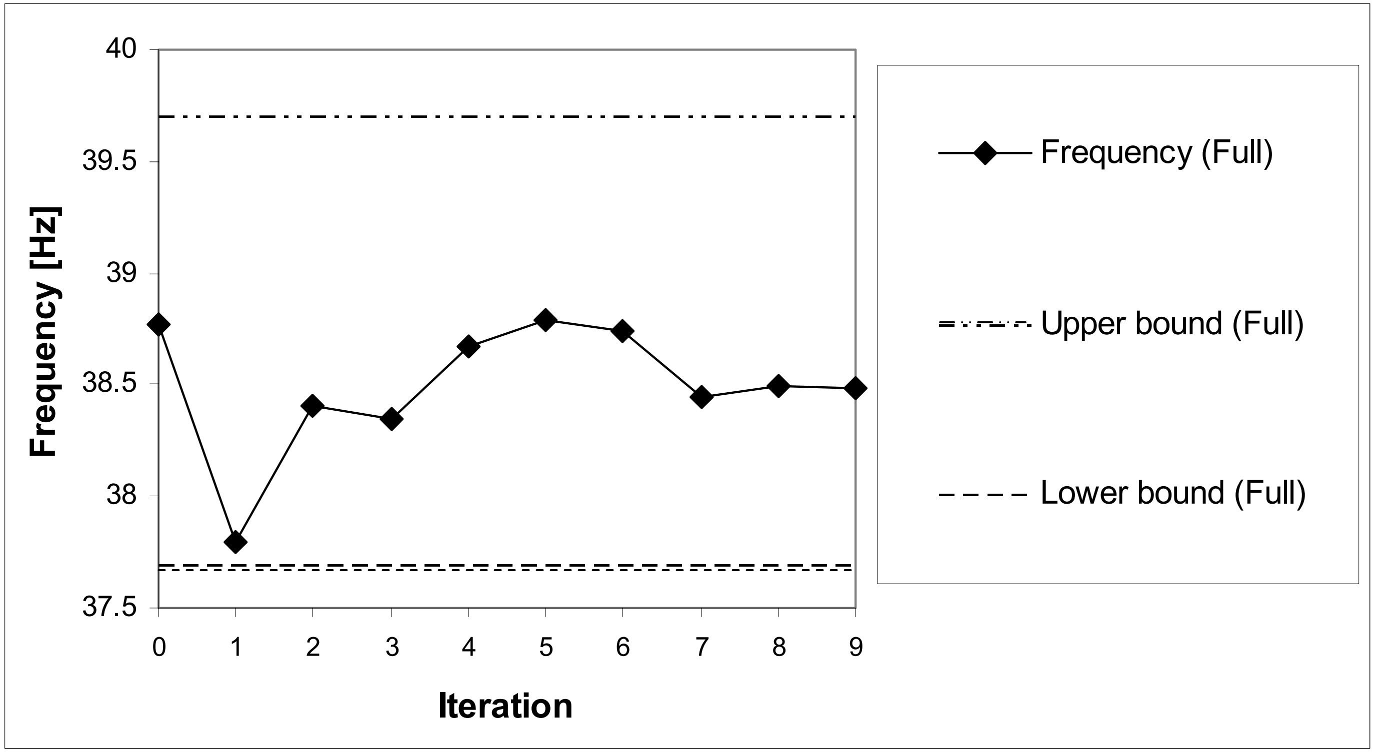
Example: Multidisciplinary Optimization (MDO)

Optimization History: Stage Pulses – FULLY SHARED VARIABLES



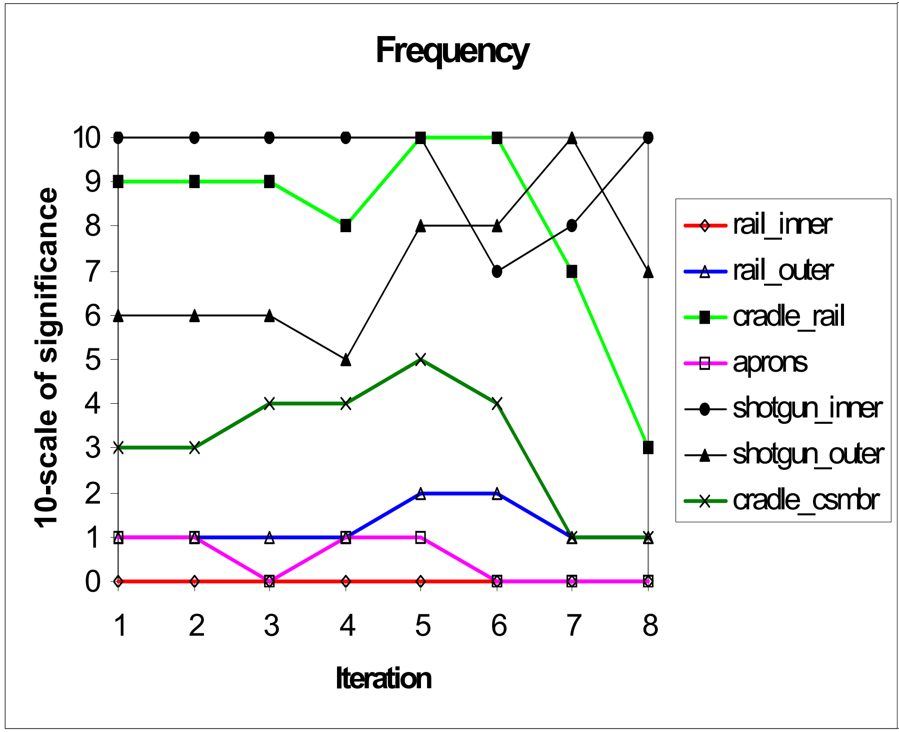
Example: Multidisciplinary Optimization (MDO)

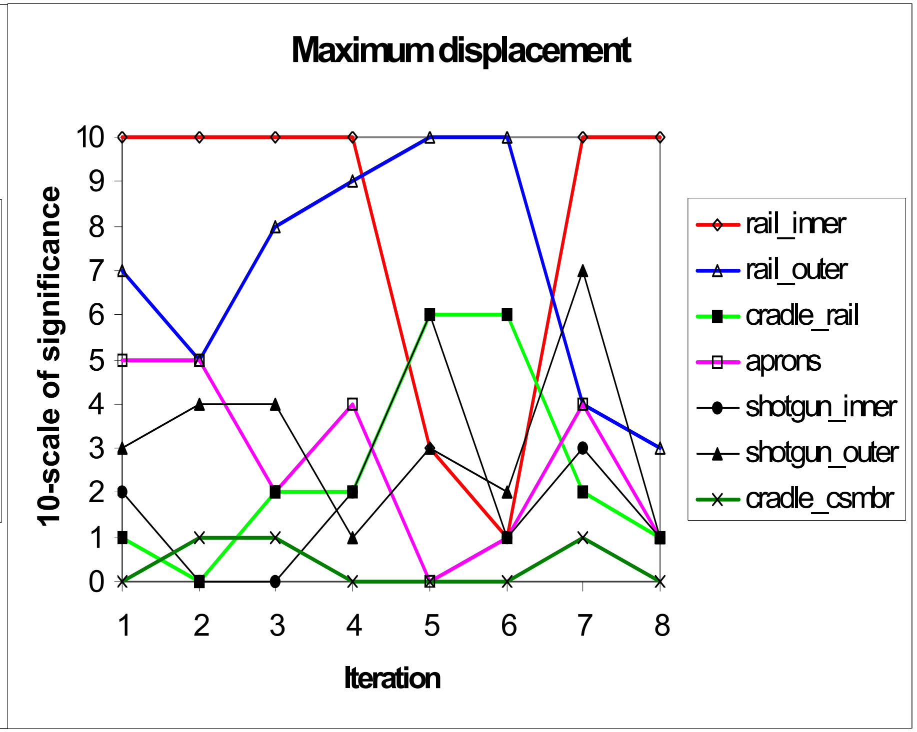
Optimization History: Torsional Mode Frequency – FULLY SHARED VARIABLES



Example: Multidisciplinary Optimization (MDO)

Variable Screening



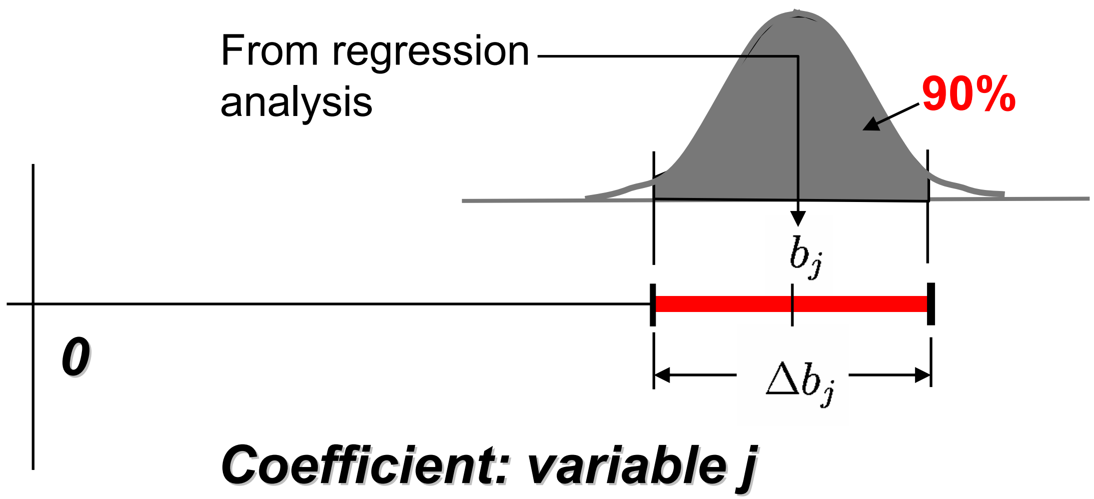


- **Goal: Remove of less significant variables**

Example: Multidisciplinary Optimization (MDO)

Variable Screening

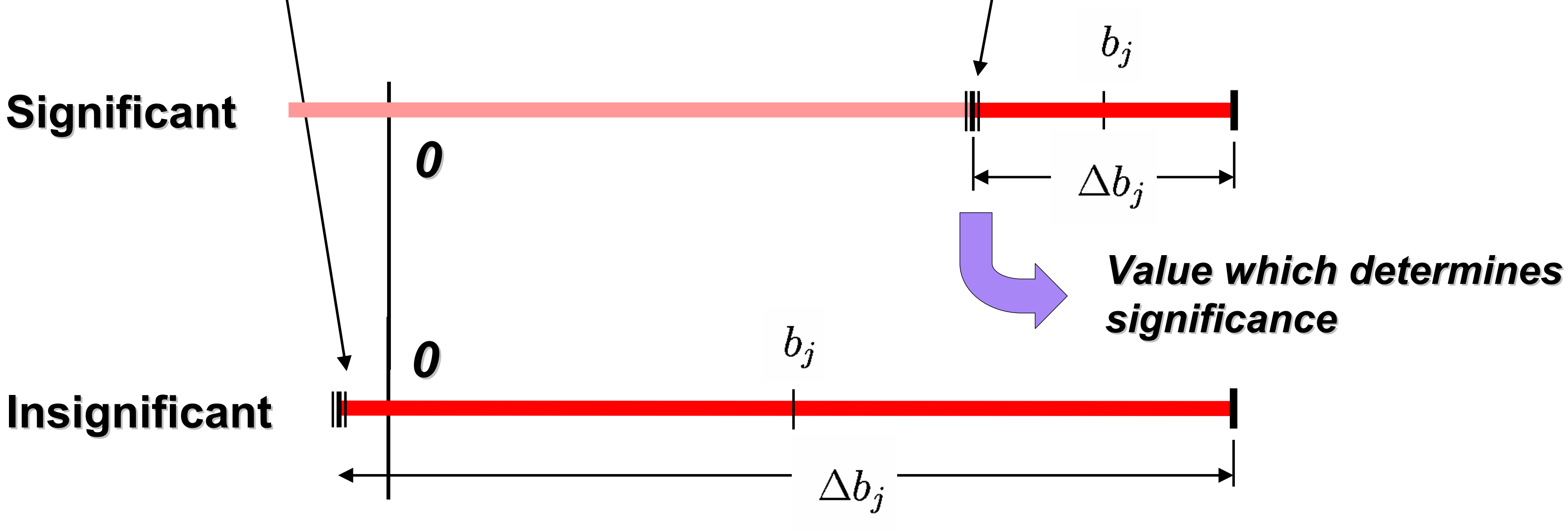
- **Methodology: ANOVA (ANalysis Of VAriance)**
- Δb_j **depends on the variance of the simulation points**
- **Use a 90% confidence level and determine the lower bound**



Example: Multidisciplinary Optimization (MDO)

Variable Screening

- **Variables are ranked according to lower bound**
- **If the lower bound < 0, regression coefficient is insignificant**
- **In a linear approximation, a variable can be removed if its coefficient is insignificant**



Example: Multidisciplinary Optimization (MDO)

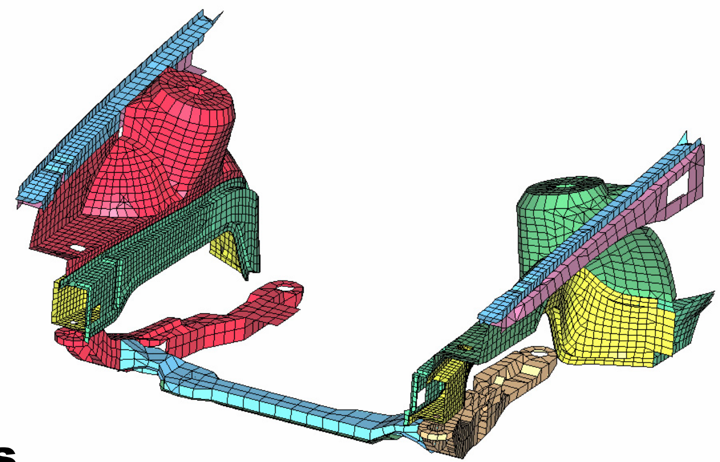
Design Formulation – PARTIALLY SHARED VARIABLES

Design Objective:
- **Minimize (Mass of Components)**

Design Constraints:
- **Displacement > 551.8mm**
- **38.27Hz < Torsional Mode 1 frequency < 39.27Hz**
- **Stage1Pulse > 14.34g**
- **Stage2Pulse > 17.57g**
- **Stage3Pulse > 20.76g**

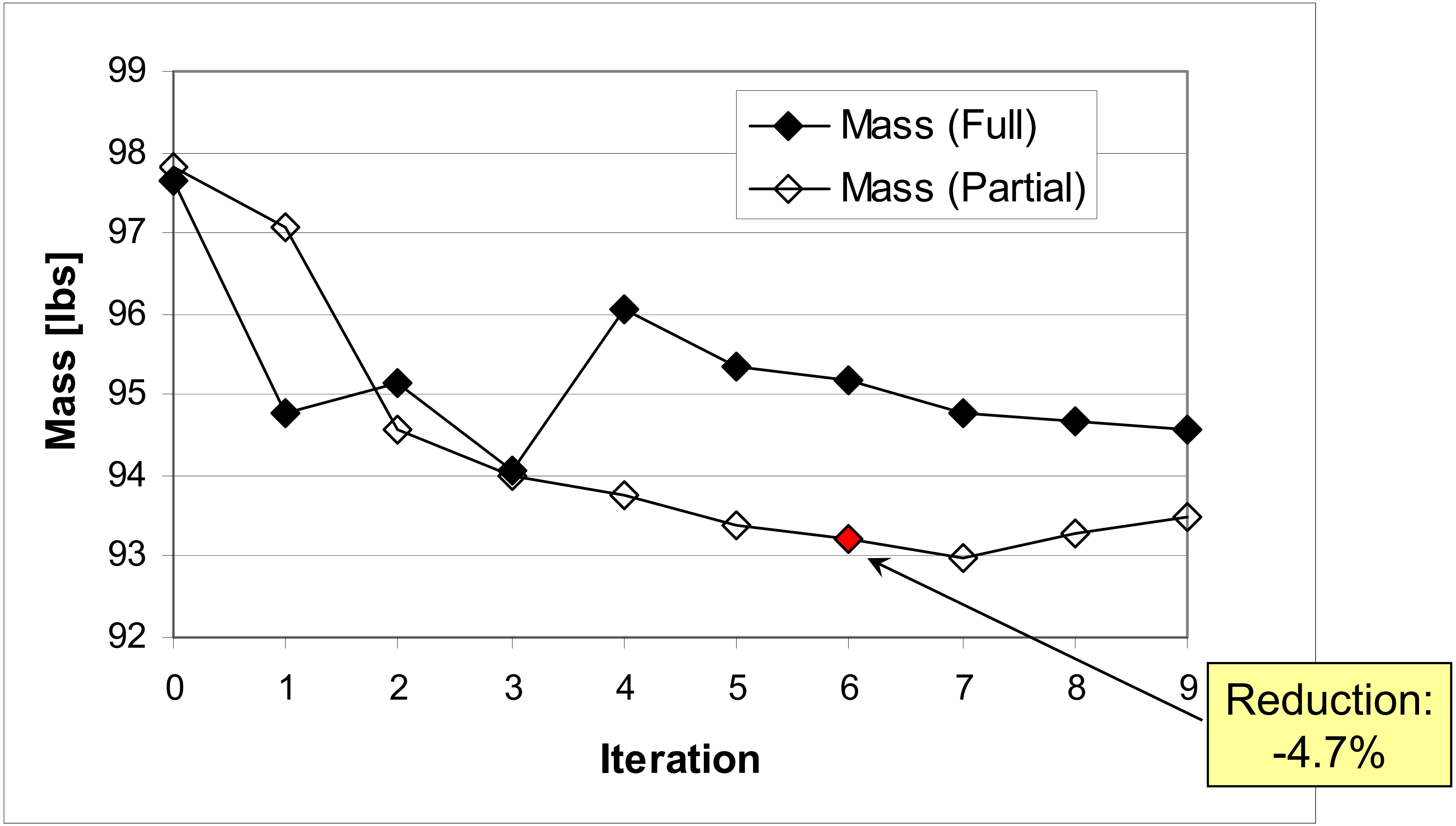
Crashworthiness Design Variables: 6
- **Rails (inner and outer), Shotgun (inner and outer), Aprons, Cradle Rails**

NVH Design Variables: 4
- **Shotgun (inner and outer), Cradle Rails, Cross Member**



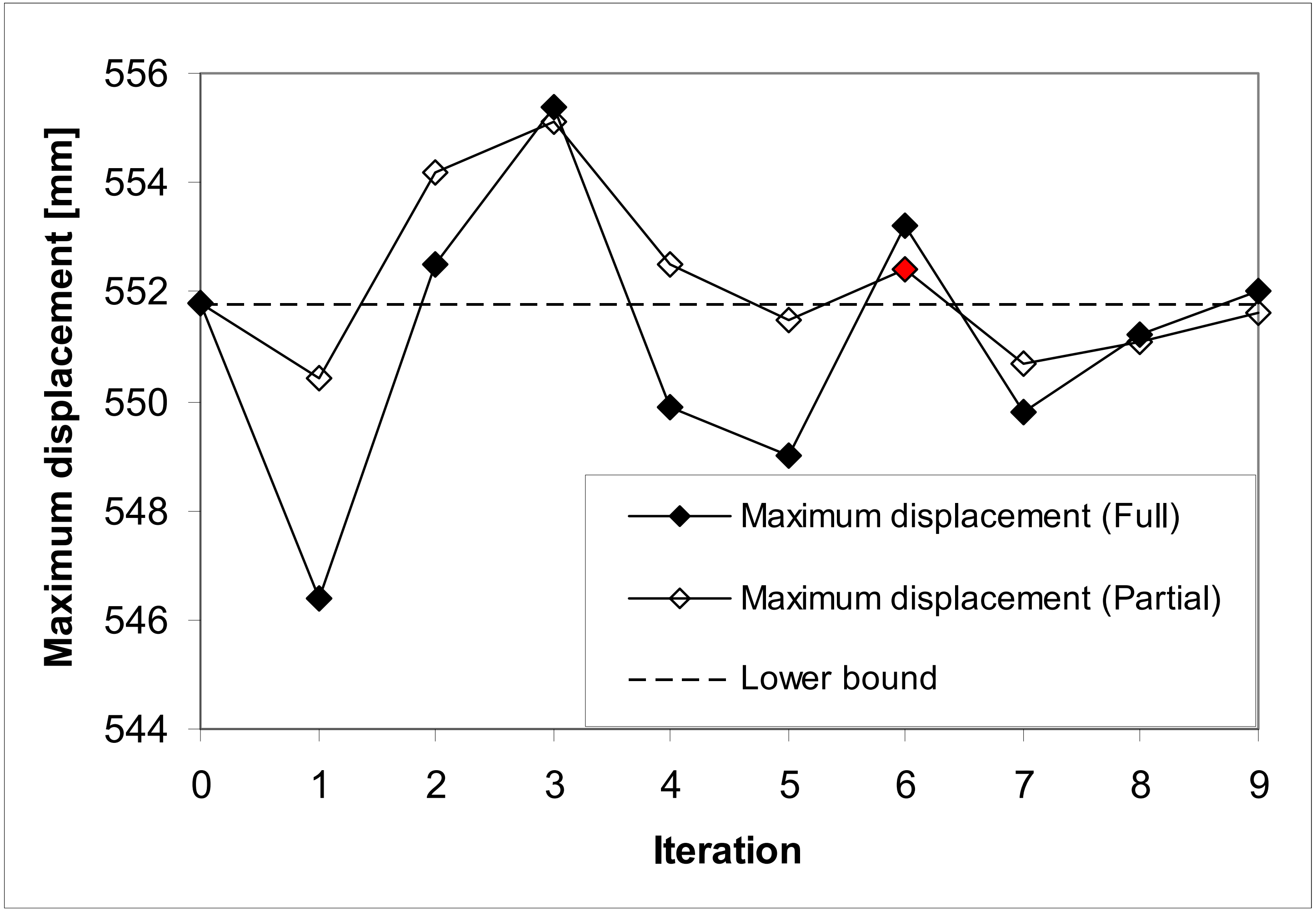
Example: Multidisciplinary Optimization (MDO)

Optimization History: Mass (Objective)



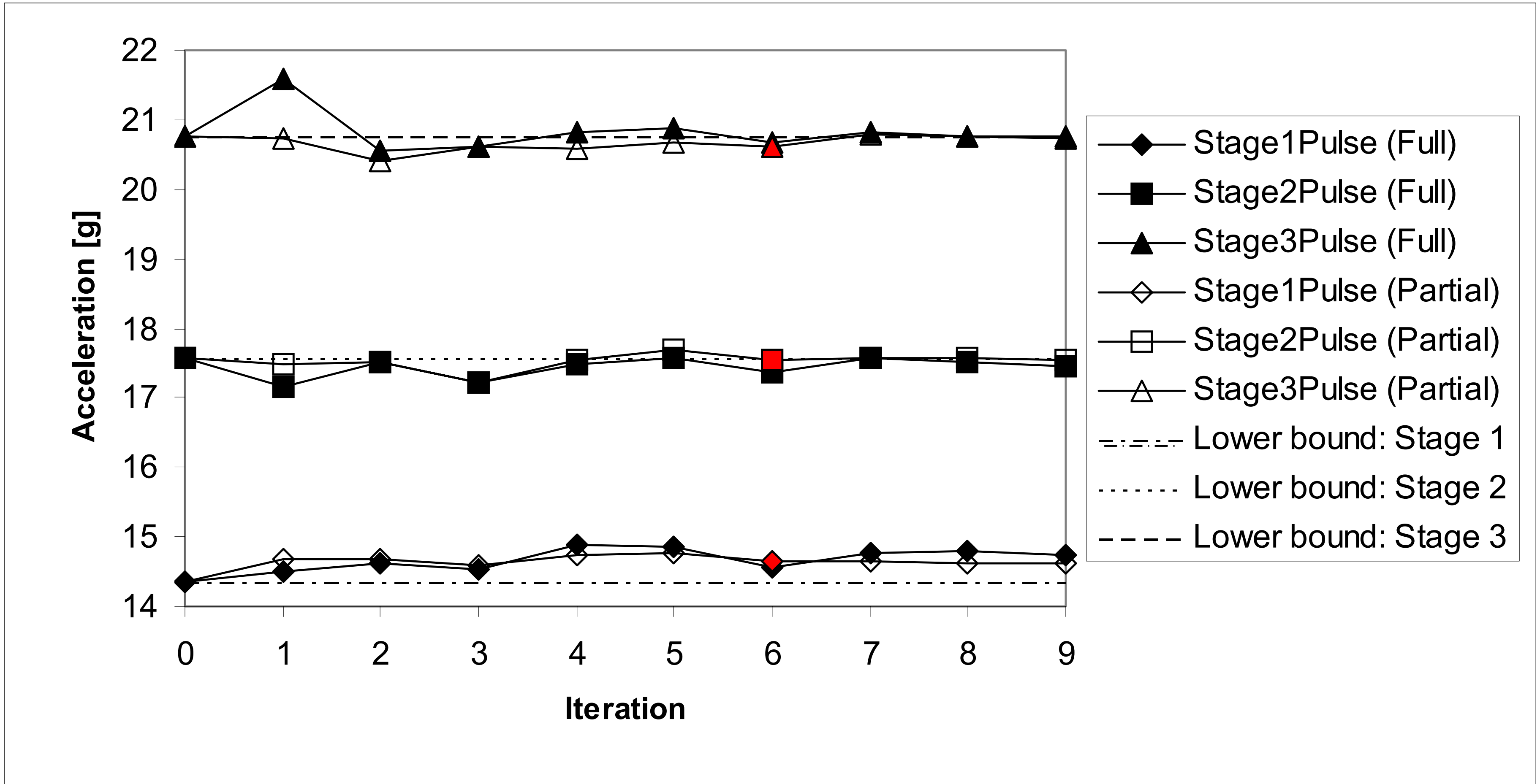
Example: Multidisciplinary Optimization (MDO)

Optimization History: Maximum Displacement



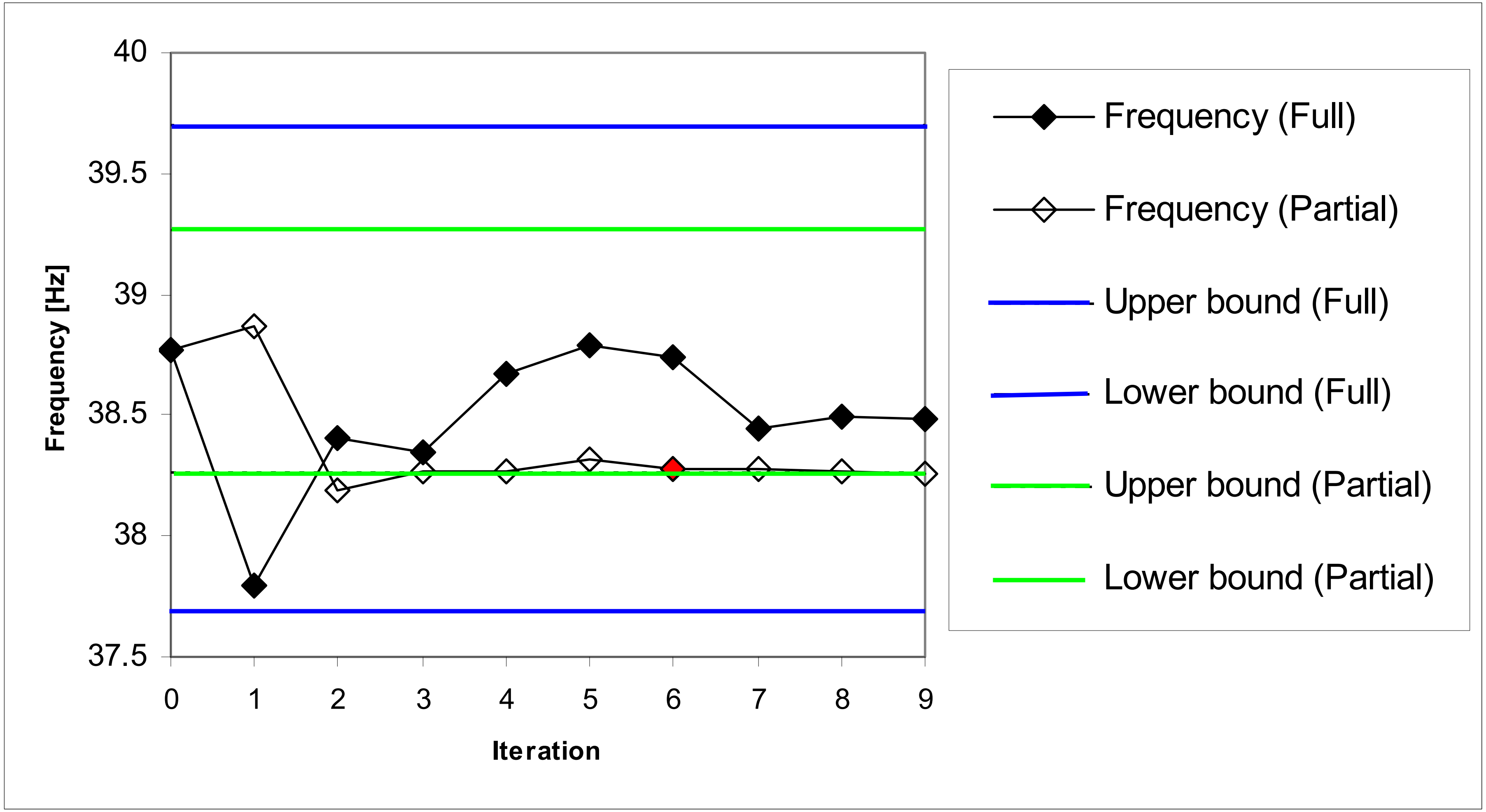
Example: Multidisciplinary Optimization (MDO)

Optimization History: Stage Pulses



Example: Multidisciplinary Optimization (MDO)

Optimization History: Torsional Frequency



Example: Multidisciplinary Optimization (MDO)

Run Statistics

Run Statistics – Fully Shared MDO

13 experimental points per iteration per discipline

- **7 hours per crash simulation**
- **10 minutes per NVH simulation (700MB memory each)**
- **9 iterations to converge**
- **117 crash simulations and 117 NVH simulations**

Run Statistics – Partially Shared MDO

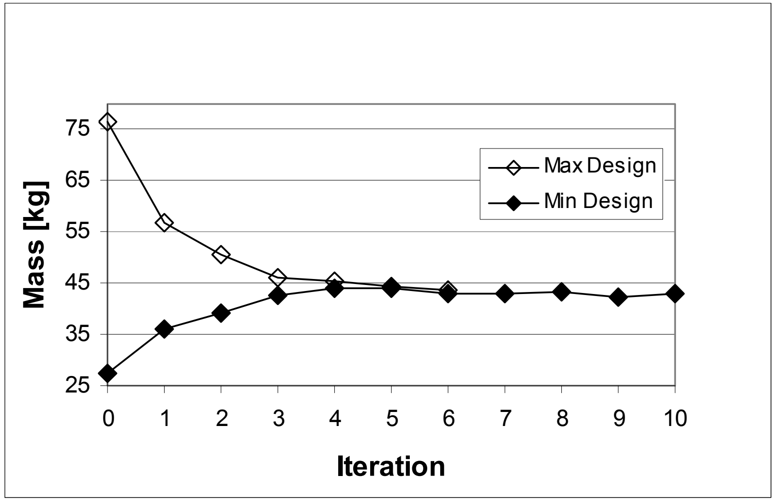
11 experimental points per iteration for crash

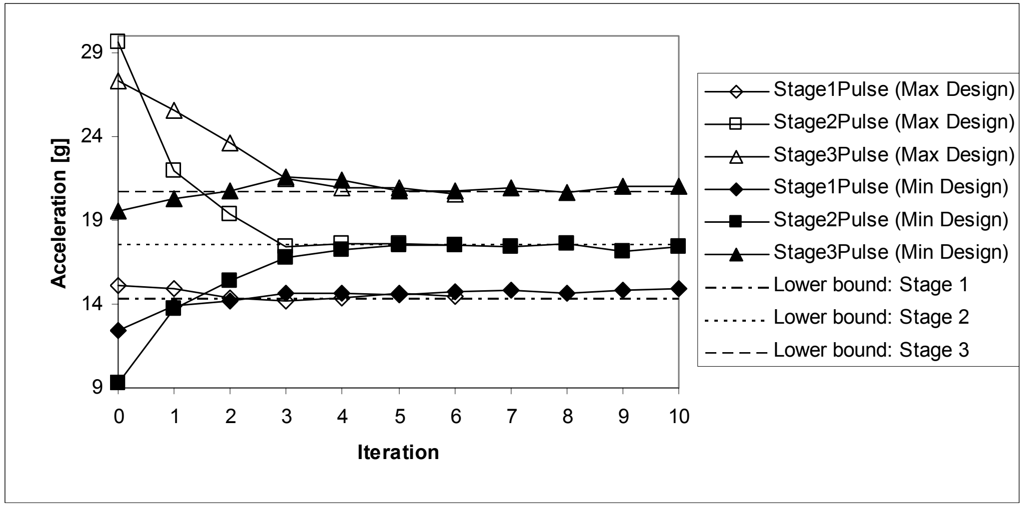
8 experimental points per iteration for NVH

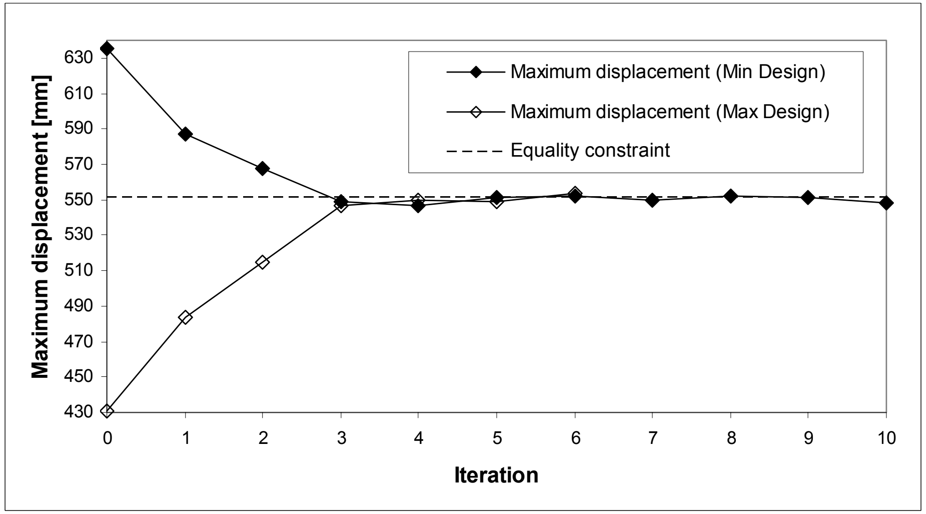
- **6 iterations for good compromised solution**
- **66 crash simulations and 48 NVH simulations**
- **More flexibility in using resources (processors and memory)**

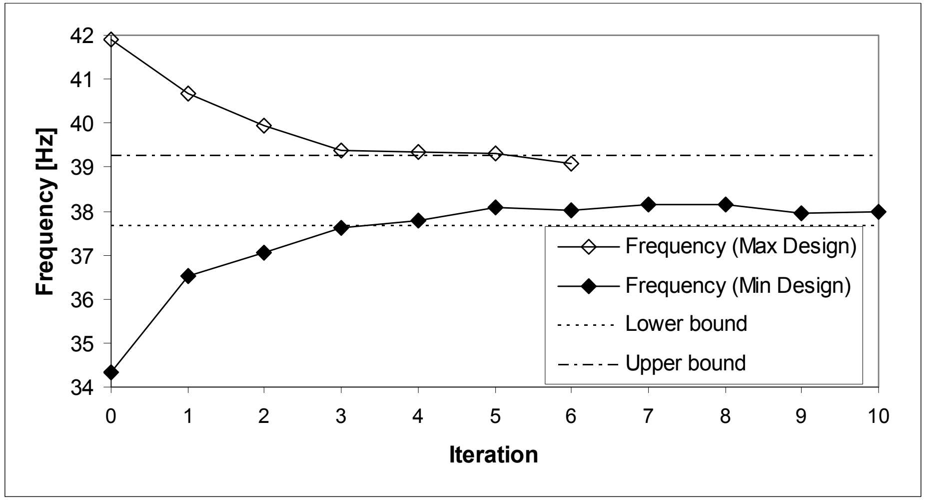
Example: Multidisciplinary Optimization (MDO)

Starting from Ligthest and Heaviest Design









Conclusions MDO-Example

Conclusions / Outlook / Remarks

- **Multidisciplinary feasible optimization of a full vehicle model considering crashworthiness and NVH design criteria is described**
- **Almost 5% mass reduction is achieved while maintaining or improving of the design criteria of the baseline design**
- **Variable Screening allows the detection of unsignificant design variables**
- **The capability of partially or non shared variables for MDO may reduce the computational effort dramatically**

Conclusions MDO-Example

Conclusions / Outlook / Remarks

- **Optimization with current full vehicle crash models (500000-1000000 Elements) is still very time consuming and requires huge hardware resources**
- **Gradients of the linear implizit discipline (NVH) may be used for the calculation of the according Response Surface approximation**
- **Discrete Methodologies for sheet thickness optimization**
- **A two-stage approach with stochastic and deterministic methods, may be very efficient for crash**