

Tolerance Optimization Using LS-OPT

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Outline

- Motivation
 - Deterministic vs tolerance-based design optimization

- Tolerance Optimization Methodology
 - Multilevel LS-OPT setup

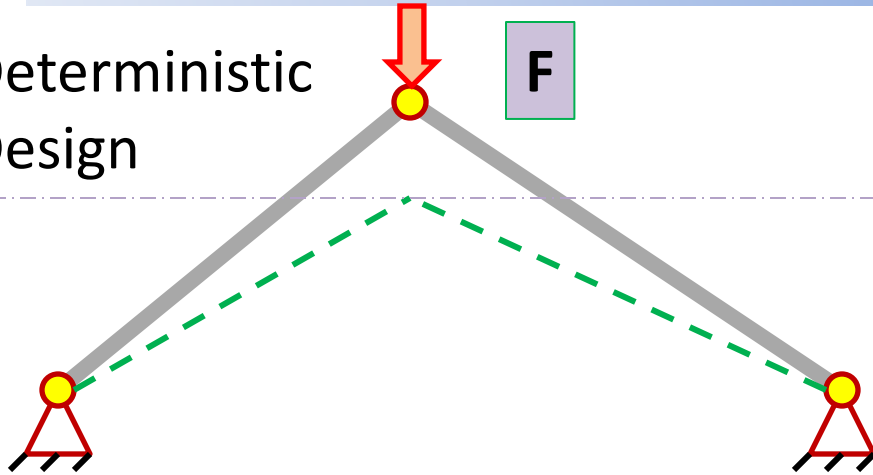
 - Parameterization of LS-OPT attributes

 - Extraction of failure probability as response

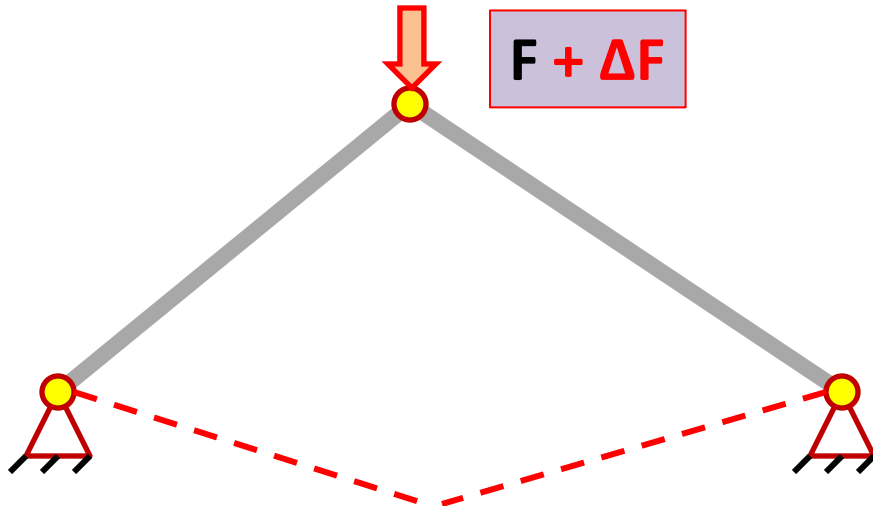
- Example
 - Chevrolet Truck Impact

Deterministic vs Robust Design

Deterministic
Design

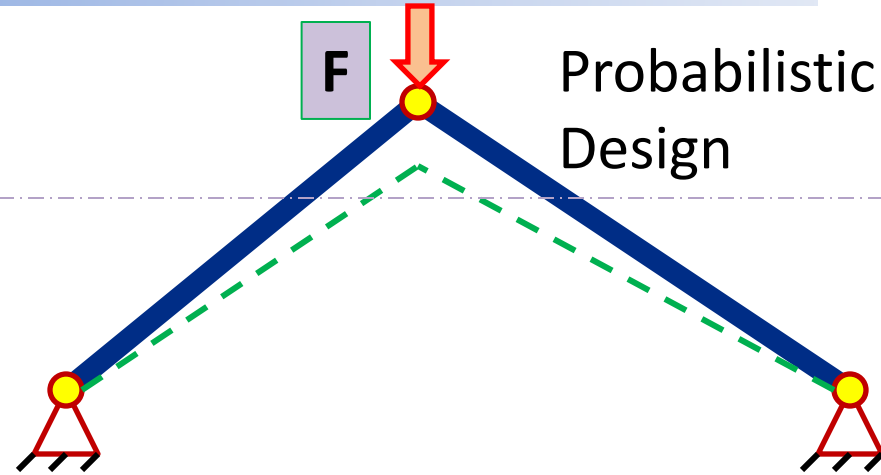


No uncertainty consideration
- Feasible mean (deterministic) behavior

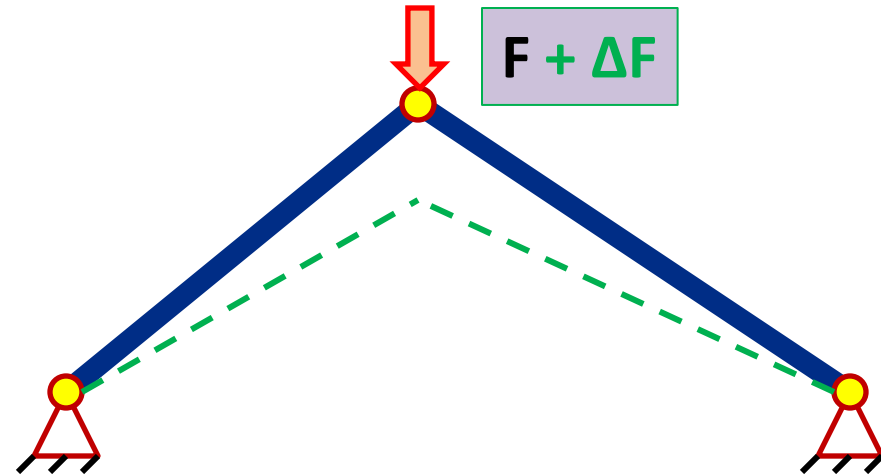


Infeasible perturbed behavior

Probabilistic
Design



Feasible nominal behavior



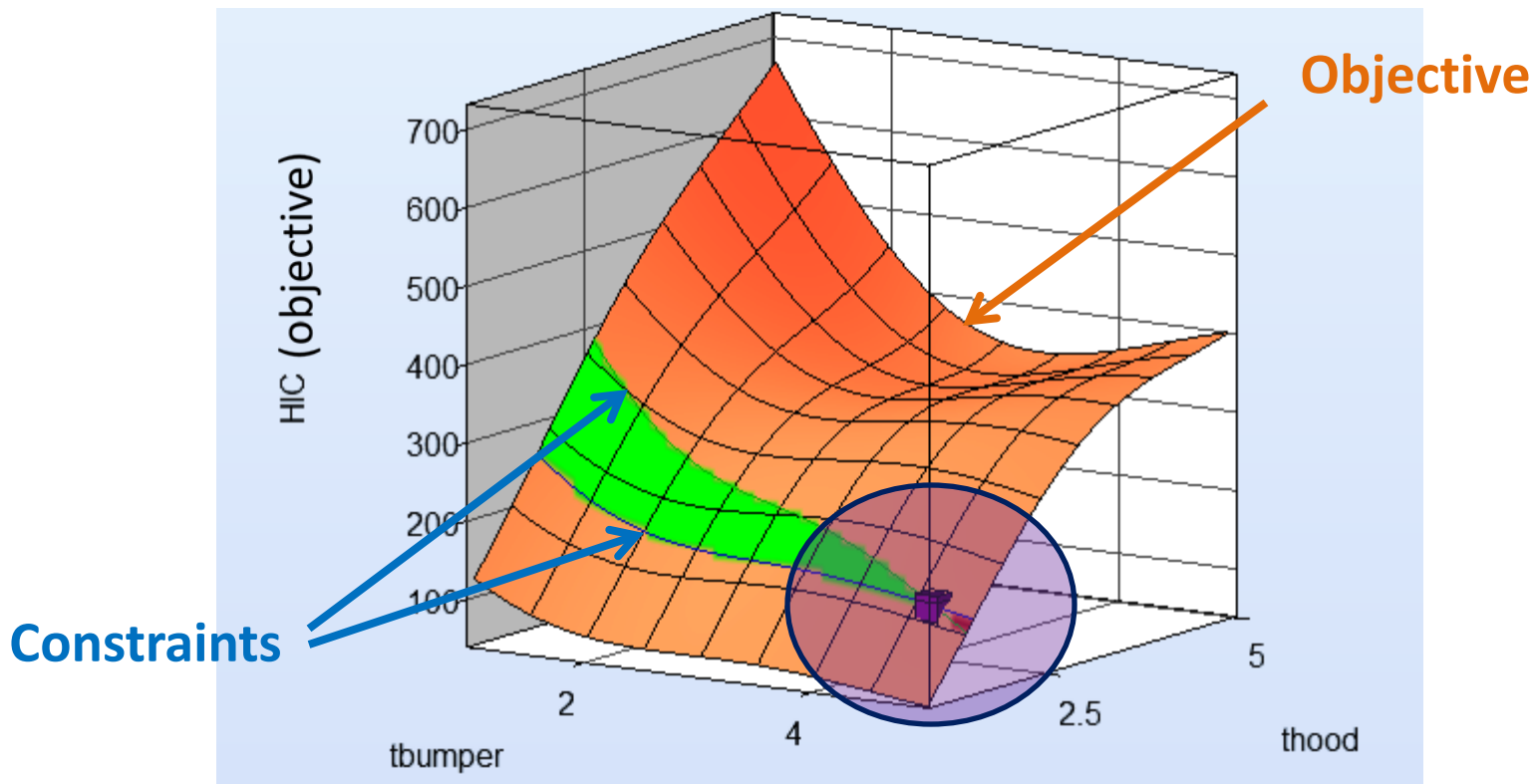
Feasible perturbed behavior

Optimization vs Robustness/Reliability

Deterministic Optimization:

Minimize Objective Function subject to Constraints

Optimum very often lies on the constraint boundary



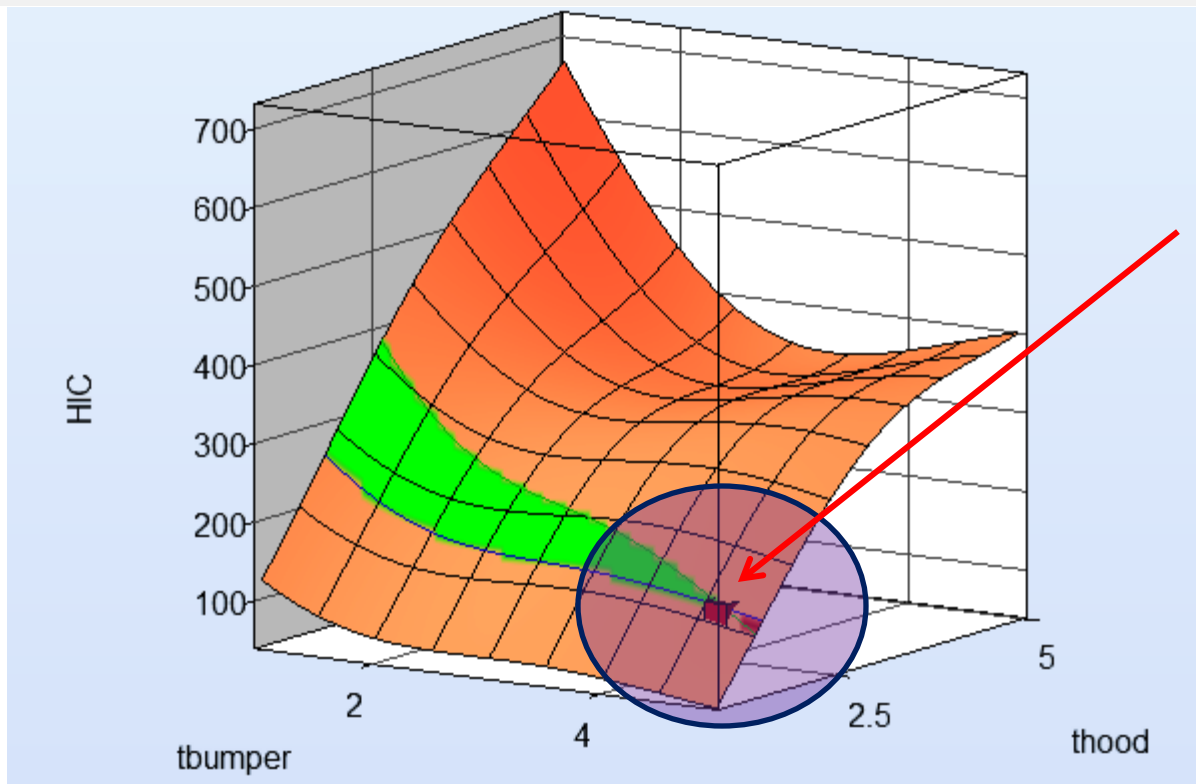
Optimization vs Robustness/Reliability

Is the Optimum Robust??

Sources of uncertainty:

Manufacturing imperfections, Load variations, Environment variations

Approximation/Metamodeling Error, Optimization Error, Analysis Error



Improving Robustness of Optimum

- Reliability-based design optimization (RBDO)
 - Optimize objective function at nominal design
 - Low failure probability target
- Robust design
 - Minimize variance of the objective
- Tolerance-based design
 - Optimize nominal design variables **and tolerances**
 - Maximize tolerance
 - No failure within tolerance

Available
as LS-OPT
Tasks

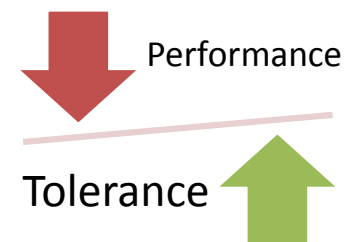
Tolerance Optimization vs RBDO

RBDO:

- Variables associated with distribution
- Mean variable values (distribution means) are optimized

Tolerance Optimization:

- Variables associated with tolerance values - fixing the tolerance value similar to RBDO with truncated PDF
- *Tolerances (i.e. distribution shape) also optimized*
- Set up as a *multilevel problem with parameterized inner level distribution*



Setup for Tolerance Optimization

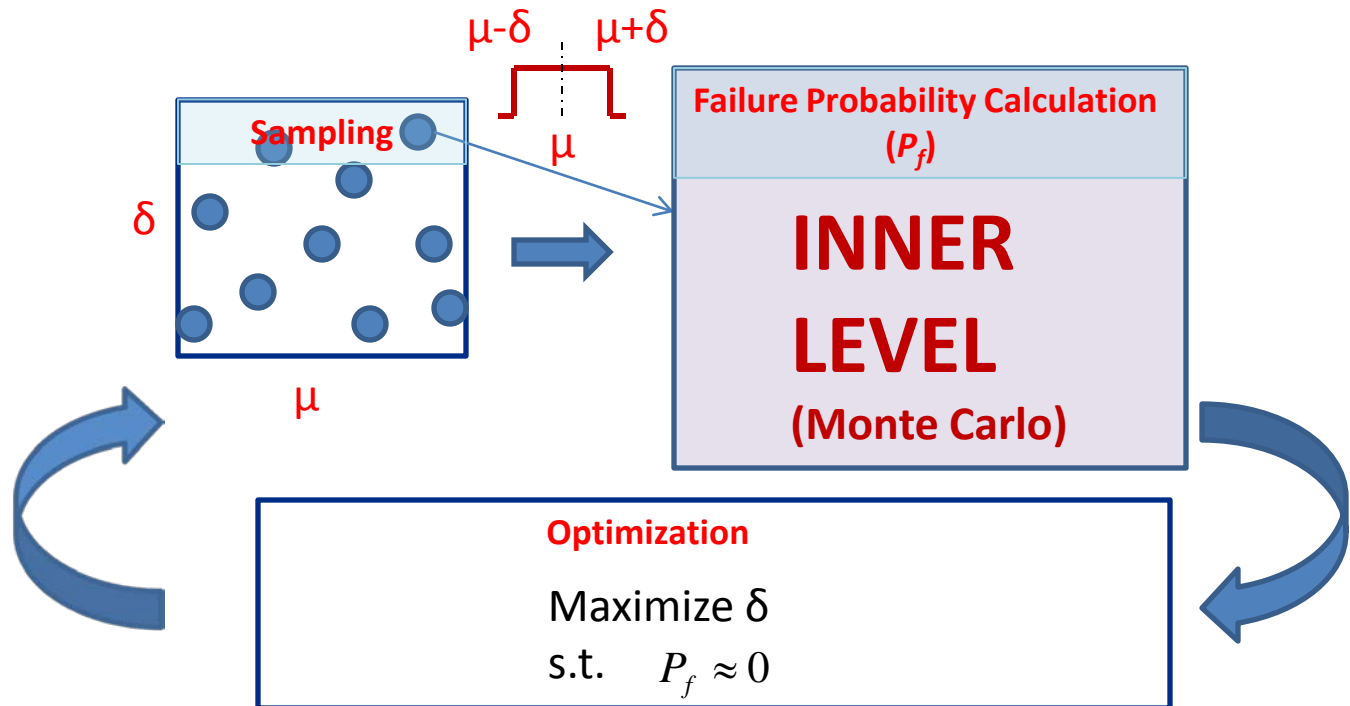
Multilevel (Two level) Setup:

OUTER LEVEL (Direct Optimization):

Variables: Nominal design variables, Tolerance (μ, δ)

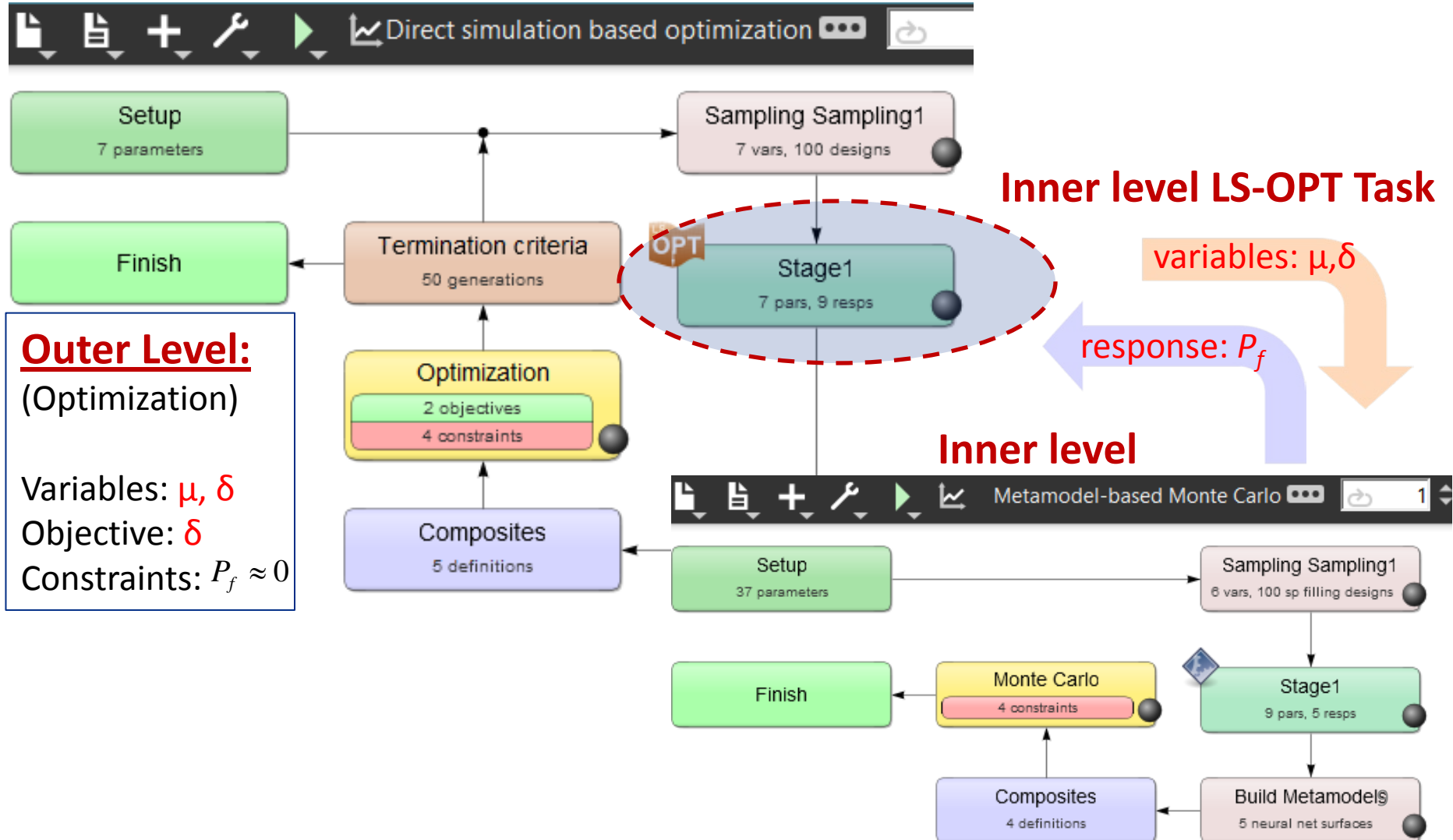
Maximize Tolerance

s.t. Zero failure within tolerance interval, i.e. Failure Probability = 0



Setup for Tolerance Optimization

Multilevel (Two level) Setup:



Inner Level – distribution parameterization

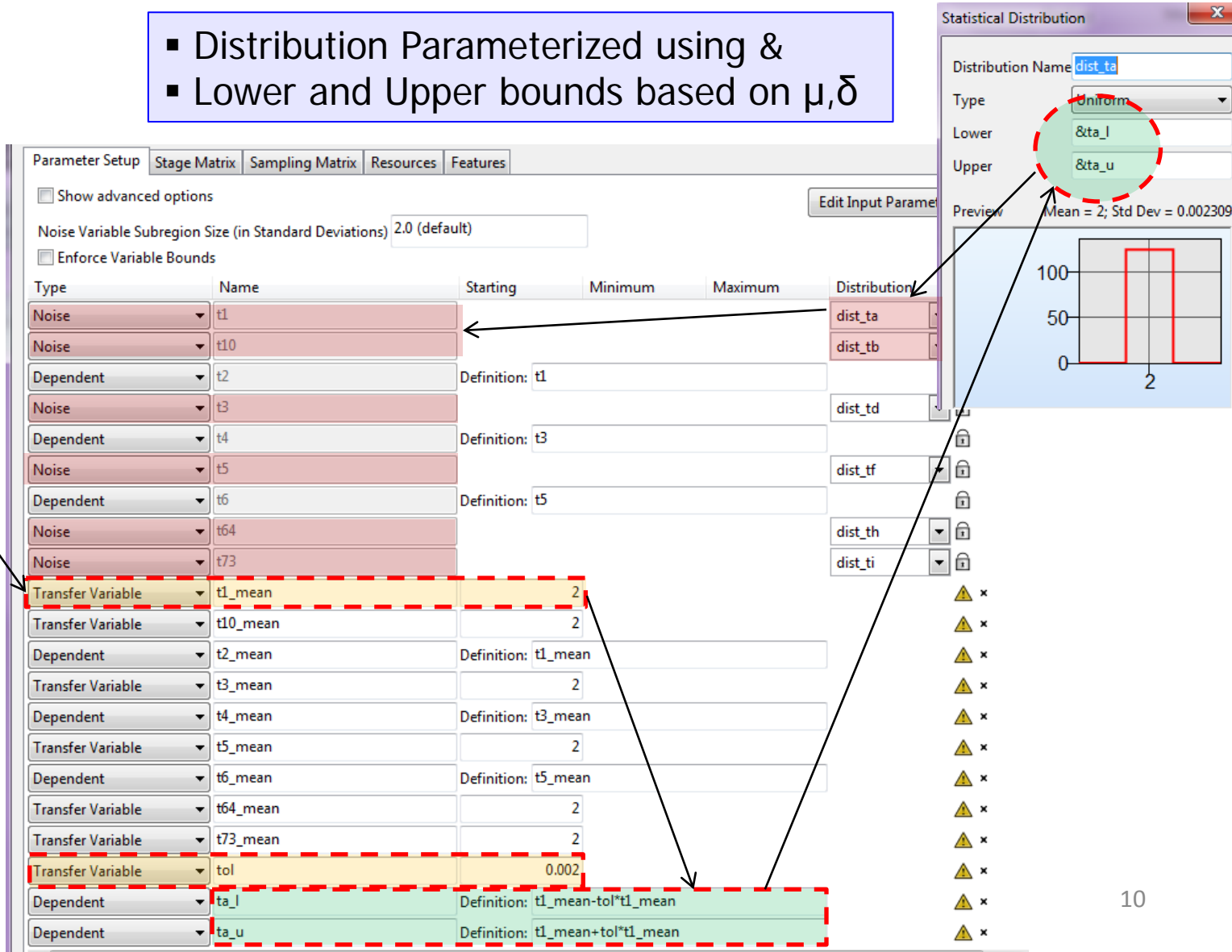
Inner Level:
(Monte Carlo)

Noise Variables:

$$X(\mu, \delta)$$

From
Outer level

- Distribution Parameterized using μ &
- Lower and Upper bounds based on μ, δ

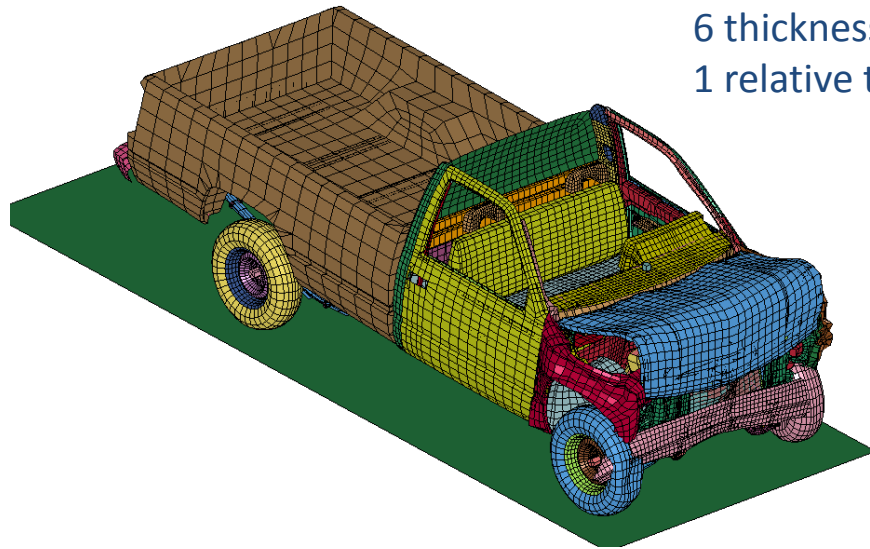


The screenshot shows the 'Parameter Setup' window with tabs for 'Stage Matrix', 'Sampling Matrix', 'Resources', and 'Features'. The 'Noise Variable Subregion Size (in Standard Deviations)' is set to 2.0. A table lists various parameters:

Type	Name	Starting	Minimum	Maximum	Distribution
Noise	t1				dist_ta
Noise	t10				dist_tb
Dependent	t2	Definition: t1			
Noise	t3				dist_td
Dependent	t4	Definition: t3			
Noise	t5				dist_tf
Dependent	t6	Definition: t5			
Noise	t64				dist_th
Noise	t73				dist_ti
Transfer Variable	t1_mean		2		
Transfer Variable	t10_mean		2		
Dependent	t2_mean	Definition: t1_mean			
Transfer Variable	t3_mean		2		
Dependent	t4_mean	Definition: t3_mean			
Transfer Variable	t5_mean		2		
Dependent	t6_mean	Definition: t5_mean			
Transfer Variable	t64_mean		2		
Transfer Variable	t73_mean		2		
Transfer Variable	tol		0.002		
Dependent	ta_l	Definition: t1_mean - tol * t1_mean			
Dependent	ta_u	Definition: t1_mean + tol * t1_mean			

The 'Statistical Distribution' window is open, showing 'Distribution Name' as 'dist_ta', 'Type' as 'Uniform', 'Lower' as '&ta_l', and 'Upper' as '&ta_u'. A preview graph shows a uniform distribution with a mean of 2 and a standard deviation of 0.002309.

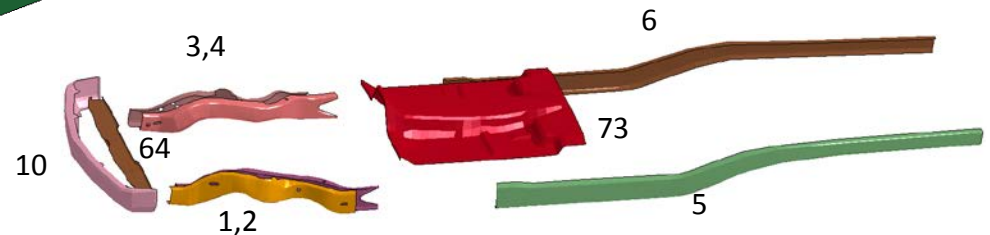
Tolerance Optimization: Example



6 thickness design parameters
1 relative tolerance (%) parameter

Objectives:

1. Minimize Mass
2. Maximize Tolerance (robust)



Expensive Analysis – Tolerance Optimization requires repeated calls!!

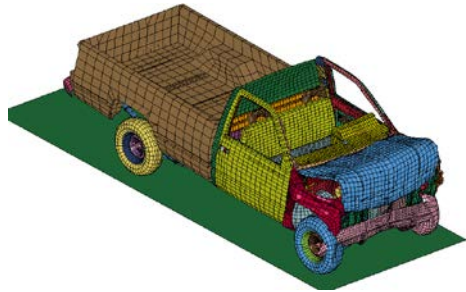
Two Step Solution:

Step 1: LS-DYNA Analysis + Metamodel Construction

Step 2: Only Metamodel Evaluation

Example

Step 1 (Deterministic)



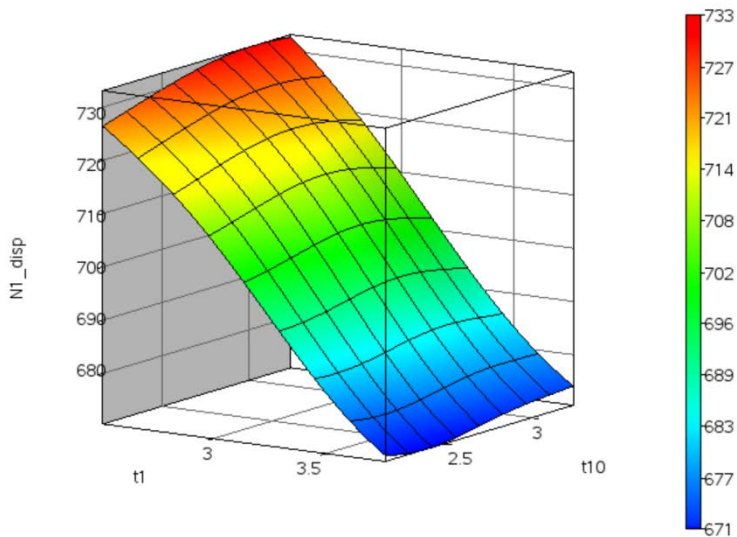
6 thickness design parameters

Objective: Minimize Mass

$$\min_{\bar{t}_1, \bar{t}_2, \bar{t}_3, \bar{t}_4, \bar{t}_5, \bar{t}_6} \text{scaled_mass}$$

$$s.t. \quad \begin{aligned} \text{scaled_stage1_pulse}(\bar{t}_1, \bar{t}_2, \bar{t}_3, \bar{t}_4, \bar{t}_5, \bar{t}_6) &\leq 1 \\ \text{scaled_stage1_pulse}(\bar{t}_1, \bar{t}_2, \bar{t}_3, \bar{t}_4, \bar{t}_5, \bar{t}_6) &\leq 1 \\ \text{scaled_disp}(\bar{t}_1, \bar{t}_2, \bar{t}_3, \bar{t}_4, \bar{t}_5, \bar{t}_6) &\leq 1 \end{aligned}$$

Baseline Scaled Mass: 1



Optimum Scaled Mass: 0.832

Metamodels with 1000 samples (LS-DYNA)

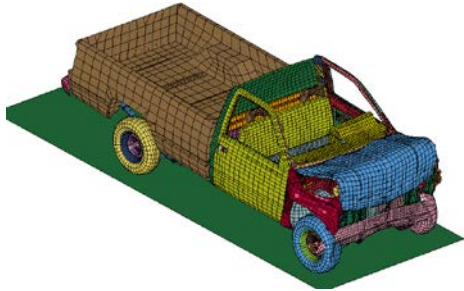
Analytical formula saved to file

Example

Step 2 (Non-Deterministic)

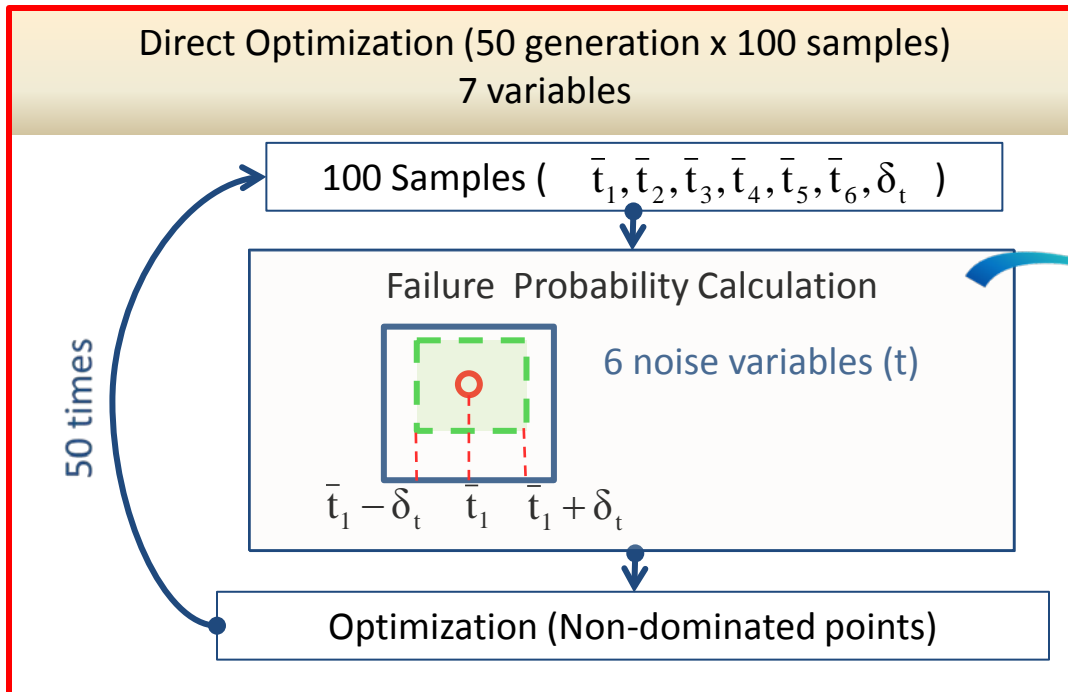
6 thickness design parameters

1 relative tolerance (%) parameter



Objective Functions:

1. Nominal Scaled Mass (minimize)
2. Tolerance (maximize)



$$\max_{\bar{t}, \delta_t} \quad \{\delta_t, -scaled_mass(\bar{t})\} \quad \text{Ensure min performance}$$

$$s.t. \quad P(scaled_mass(\mathbf{t}) > 0.9) \leq P_{target}$$

$$P(scaled_stage1_pulse(\mathbf{t}) > 1) \leq P_{target}$$

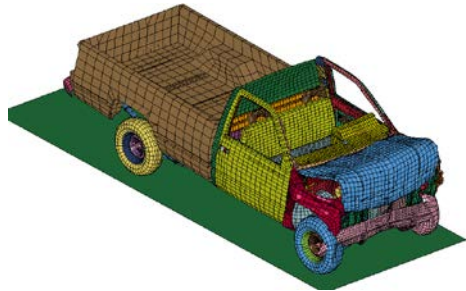
$$P(scaled_stage2_pulse(\mathbf{t}) > 1) \leq P_{target}$$

$$P(scaled_disp(\mathbf{t}) > 1) \leq P_{target}$$

$$P_{target} \approx 0$$

Inner Level
Metamodel-based Monte Carlo
100 samples

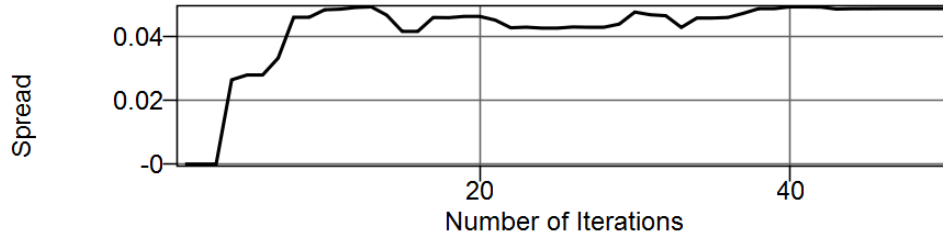
Pareto Front



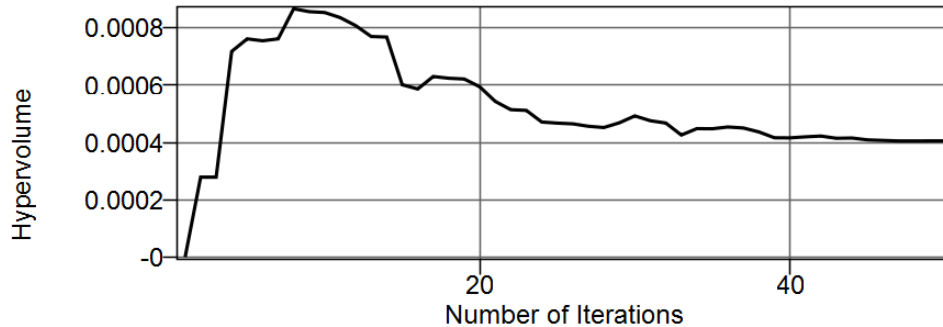
7 variables:
6 thickness design parameters
1 relative tolerance (%) parameter

2 objectives:
Minimize nominal mass
Maximize tolerance

Convergence Performance Metrics

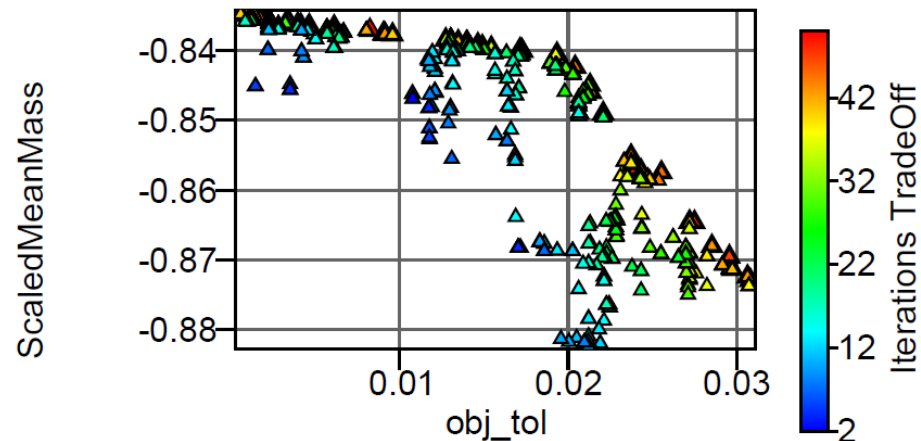


Convergence Performance Metrics

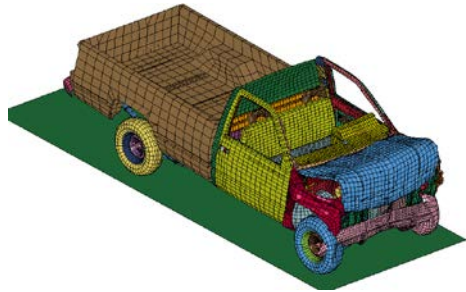


Tradeoff Plot

Objective "obj_tol" vs. Objective "ScaledMeanMass"
(Results of All Iterations)



Pareto Front



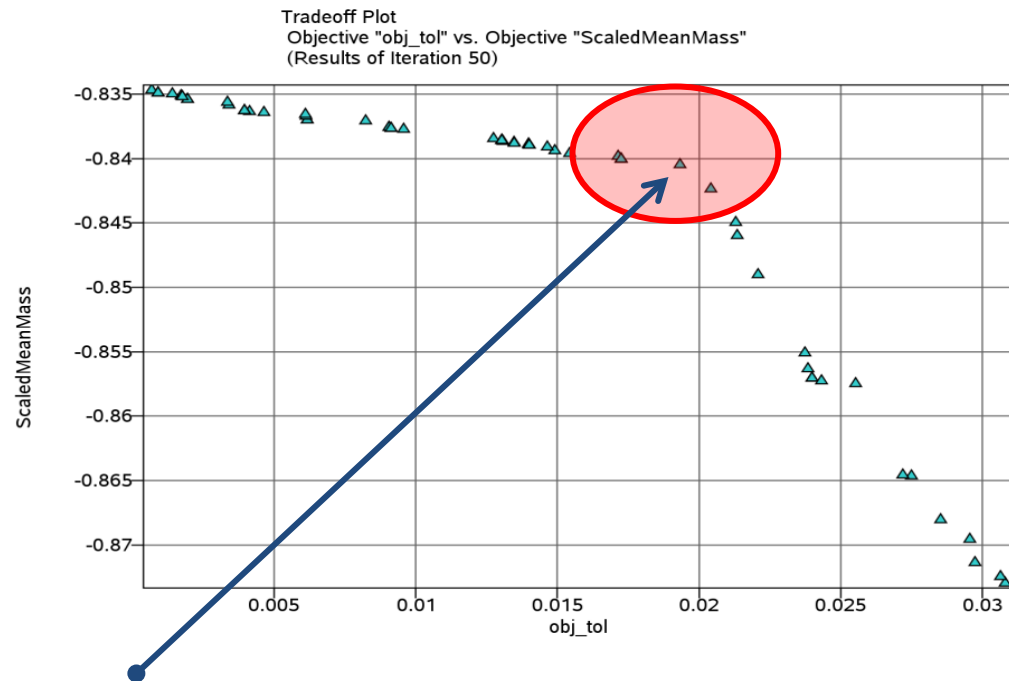
7 variables:
6 thickness design parameters
1 relative tolerance (%) parameter

2 objectives:
Minimize nominal mass
Maximize tolerance

Total vehicle mass: 1800 kg
Mass of optimized parts: 138.14 kg

Maximum Mass Reduction: 22.8 kg

Maximum Tolerance: 0.031 or 3.1%
with 17.54 kg mass reduction

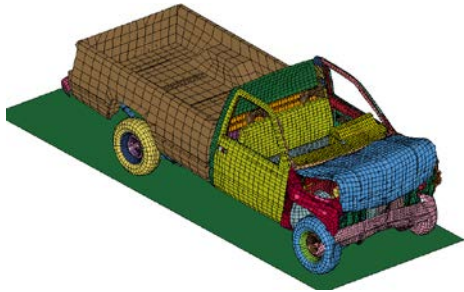


2% tolerance with 22 kg mass reduction

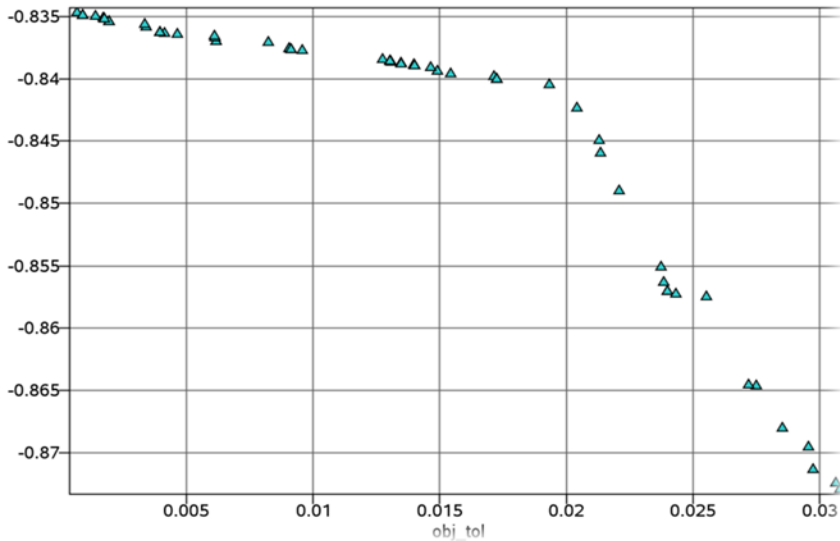
Accuracy check

7 variables:
6 thickness design parameters
1 relative tolerance (%) parameter

2 objectives:
Minimize nominal mass
Maximize tolerance

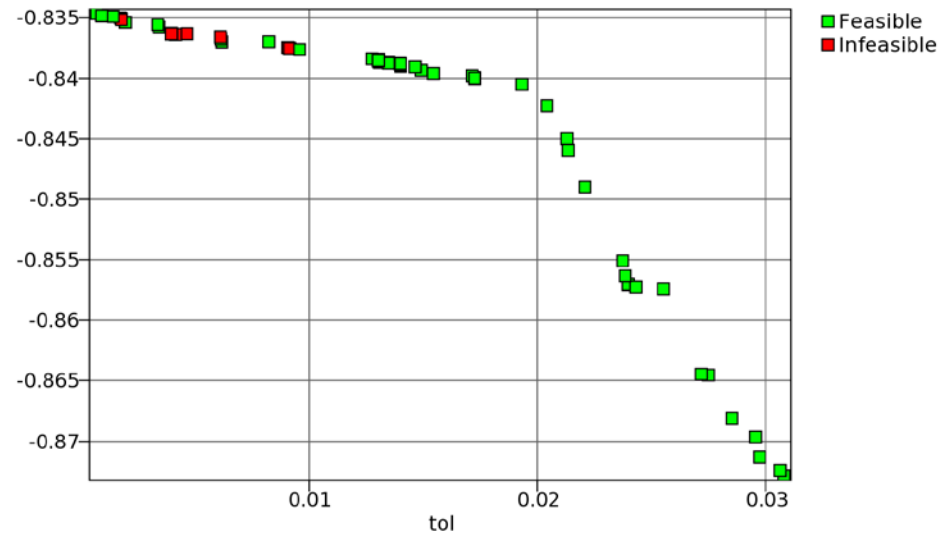


Tradeoff Plot
Objective "obj_tol" vs. Objective "ScaledMeanMass"
(Results of Iteration 50)



Metamodel

Scatter Plot
Variable "tol" vs. Composite "Scaled_Mass1"
(Results of Iteration 1)



LS-DYNA

Summary

- Tolerance optimization using LS-OPT
- Multi-level optimization, multi-objective setup
- Facilitates the search for a robust optimum
- Two different distinct categories of Pareto Optimal designs obtained for Chevrolet truck
- Future work entails simplification of the interface, allowing a single level setup that handles the multi-level nature of the problem internally