

Robustness Analysis with LS-OPT[®]







Bamberg, 12.10.2016



Outline

- About LS-OPT
- Motivation
- Robustness Analysis
 - Direct and metamodel-based Monte Carlo Analysis
- Example Robustness Analysis
 - Live demonstration
- Optimization
 - RBDO/RDO
 - Tolerance Optimization
- Summary
- Outlook



About LS-OPT

- LS-OPT is a standalone optimization software
 - \rightarrow can be linked to any simulation code
 - Interface to LS-DYNA, MSC-Nastran, Excel, Matlab
 - User-defined interface
 - Interfaces to preprocessors, e.g. for shape optimization
 - Interface to LS-PrePost, ANSA, Hypermorph, ...
 - User-defined interface to any preprocessor
 - Result extraction
 - Interface to META Post
 - User-defined interface





About LS-OPT

- LS-DYNA Integration
 - Checking of LS-DYNA keyword files (*DATABASE_)
 - Importation of design parameters from LS-DYNA keyword files (*PARAMETER)
 - Support of include files (*INCLUDE)
 - Monitoring of LS-DYNA progress
 - Result extraction of most LS-DYNA response types
 - D3plot compression (node and part selection)

	Stage Case1							
	Setup Parameters Histories Responses	File Operations						
	Response definitions							
	New response	X	BNDOUT D3PLOT					
Name	Subcase	Multipiler Offset	DBBEMAC					
Displ			DBFSI					
		Not metamodel-linked	DEFORC ELOUT					
			<u>FLD</u>					
	rection		FREQUENCY					
	X Component Y Component		GCEOUT					
	Z Component		GLSTAT					
	Resultant		INTFORC					
O Rotational Displacement	Resultant		MASS					
Rotational Velocity		MATSUM						
Rotational Acceleration								
Deformation			NODOUT					
O Distance			NODFOR					
			PSTRESS					
IdentifierType ID			RBDOUT					
ID \$ 42000128			RCFORC					
Select Fr	om time To time		RWFORC					
Maximum Value			<u>SBTOUT</u>					
			SECFORC					
Filtering		SPCFORC						
SAE Filter 🗘		SPHOUT						
Frequency Time unit			SWFORC					
			THICK					
60 Seconds	•							
		<u>C</u> ancel <u>O</u> K	<u>O</u> K					



About LS-OPT

- Current production version is LS-OPT 5.2
- LS-OPT Support web page
 - → <u>www.lsoptsupport.com</u>
 - Download of Executables
 - Tutorials

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- HowTos / FAQs
- Documents

Welcome to LS-OPT S	LS-OPT Suppo	Search Site	
		HOME EXAMPLES DOWNLOADS DOCUMENTS HOWTOS	
	Navigation	Welcome to LS-OPT Support Site	
	Getting Started Documents	LS-OPT, the graphical optimization tool that interfaces perfectly with LS-DYNA,	
	Examples HowTos Glossary Downloads	allows the user to structure the design process, explore the <u>design space</u> and compute optimal designs according to specified constraints and objectives. The program is also highly suited to the solution of <u>system identification</u> problems and <u>stochastic</u> analysis.	
	FAQs News About us	The graphical tool LS-OPTui interfaces with LS-DYNA and provides an environment to specify optimization input, monitor and control parallel simulations and post-process optimization data, as well as viewing multiple designs using LS-PREPOST.	
	News New Curve Matching Metric	Applications: Design Optimization, Design of Experiments (Sensitivity Analysis), System Identification, Reliability Studies	
	in LS-OPT 4.2 Aug 18, 2011 Full Vehicle MDO -	Optimization	
	Example Jun 03, 2011	Size-/Shape optimization Constraints, mixed continuous/discrete variables, multiple load cases, etc.	
	Release of LS-OPT®	Multi-Objective optimization (Pareto Frontier) Reliability based design optimization	
	Version 4.2 May 13, 2011 Official Release of	Kenaoliny based design opumization more	
	LS-TaSC (Topology and Shape Computation)	System./Parameter Identification	
	available Apr 19, 2011	Material parameter evaluation	
	Beta Release of LS-TaSC (Topology and Shape	Calibration of test results more	
	Computation) available Feb 02, 2011	Design Exploration	
	more	Meta Models: Interrelation design variables vs. system responses Study of design changes more	



Robustness Analysis with LS-OPT



Motivation

- Simulation
 - Design parameters (sheet thicknesses, material properties, ...) fully controllable
- Reality
 - Design parameters are associated with uncertainties
- Sources of uncertainties
 - Manufacturing imperfections
 - Load variations
 - Environment variations

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Variation of design parameters (uncertainties) should be considered in design process simulation



Estimation of probability quantities of variables and responses

t1

t2 t3 t4 t5

t6 t10 t64

t73

-1

-0.75

-0.5

-0.25

Coefficient of Correlation

- mean
- standard deviation
- distribution function
- Analysis of relationship (sensitivities)
 variables ← → responses
 - correlation analysis
 - stochastic contributions
- Reliability of a system
 - evaluation of probability of failure







0.75

0.5

0.25

- Uncertainties of variables (sheet thicknesses, material properties, ...)
 - Probability density function
 - Uniform distribution
 - Normal distribution
 - ...
 - *PERTURBATION (LS-DYNA keyword)
 - Geometric imperfections
 - Material imperfections
 - → Buckling analysis





sheet thickness variation by a harmonic random field, amplitude: m=0,s=0.005mm in both directions



LS-DYNA Keyword *PERTURBATION

- Scatter of parameters constituted by means of probability distributions
- Approximation of probability distributions using appropriate samples = experiments
- Investigation of the FEA-model = system using experiments
- Distribution of the system responses
 → Approximation to exact distribution
- Permitted area





- Monte Carlo Analysis using direct simulations
 - Random process
 - Large number of simulation runs (100+)
- Monte Carlo Analysis using metamodels
 - Construction of a metamodel (Polynomials, Radial Basis Functions, Feedforward Neural Networks, ...)
 - Number of simulations depends on number of variables
 - Reliability, Robustness Analysis through functional evaluation of sampling points (10⁶) on the metamodel







Example

- Tube impact
- Variables (Noise variables)
 - Thickness
 - Scale factor of stress-strain curve
- Response
 - Intrusion

Distribution Name t	
📴 Problem global setup	
	Normal 🗘
Parameter Setup Stage Matrix Sampling Matrix Resources Features	
Mean 1	
Show advanced options Standard Dev	OF
Noise Variable Subregion Size (in Standard Deviations) 2.0 (default)	0.05
	1. Chil D
Enforce Variable Bounds Preview Mean	n = 1; Std Dev = 0.05
Type Name Starting Minimum Maximum Distribution D	
Noise v T1 t v f 6	
Noise V SIGY SIGY	
Add	
	1
	-
	ancel <u>O</u> K



Live demonstration



Optimization considering uncertainties



Optimization

- Deterministic optimization
 - Minimize Objective Function subject to Constraints
 - Optimum very often lies on the constraint boundary



RBDO/Robust Parameter Design

- Includes uncertainty of variables and responses into optimization
- Requires statistical distribution of variables
- Control Variables (Design Parameters)
 - Nominal value controlled by designer
 - Gauge
 - Shape

Noise Variables (Environment)

- Values not controlled by designer but can vary
 - Load
 - Yield stress
 - Friction

I .		Problem global setup							
Parameter Setup	Sta	age Matrix	Sampling Matrix	Resources	Featur	es			
Show advance	d op	tions		- 					
🗌 Enforce Variab	le Bo	ounds							
Туре		Name		Starting	Mi	nimum	Maximum	Distributior	Delete
Noise	~	Area						area	✓ ▲ ×
Continuous	~	Base			0.8	0.1	1.6	(none)	✓ ▲ ×
	~	Base			0.8	0.1	1.6	(none)	✓ ▲ ×
Add									



16

RBDO/Robust Parameter Design

- Robust Parameter Design (RDO)
 - Improve/Maximize the robustness of the optimum
- Reliability Based Design Optimization (RBDO)
 - Improve failure probability of optimum









Tolerance Optimization

- RBDO/RDO
 - Variables associated with distribution
 - Mean variable values (distribution means) are optimized
- Tolerance Optimization
 - Variables associated with tolerance values
 - → Optimize nominal design variables and tolerances
 - Maximize tolerance
 - No failure within tolerance
 - → incorporate uncertainties into optimization if variable distributions are not available





Summary

- Monte Carlo Analysis (Robustness Analysis)
 - Direct or metamodel based
 - Estimation of PDF, mean, standard deviation, ... of responses
 - Significance of parameters
 - Correlation coefficients
 - Stochastic contribution (only metamodel based MC Analysis)
 - Reliability of system
 - Confidence intervals
 - Buckling Analysis
 - DYNAStats: fringe of statistics on the FE model



Summary

- Reliability Based Design Optimization (RBDO)
 - Probabilistic bounds on constraints
- Robust Parameter Design
 - Minimize Standard Deviation of response
- Tolerance Optimization
 - Incorporate uncertainties into optimization if no distribution information of the variables is available
 - Maximize tolerance
 - no failure within tolerance



Thank you!

