

### Recent Applications in MDO and Material Identification using LS-OPT<sup>®</sup>

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#### Contents

- Overview
- MDO (Honda R&D)
- Material Identification
- Conclusions
- Preview

### **Optimization Strategies in LS-OPT**

- Surrogate-based Design Optimization
  - Strategies
    - Single Stage: Fixed computational budget
    - Sequential: Maximize Surrogate accuracy
    - Sequential with Domain Reduction: Classical SRSM algorithm
- Direct Optimization
  - Genetic Algorithm (GA)

#### Large MDO - Setup:

<u>6 Crash Modes + Body Dynamics Mode:</u> - approximately 3 million element models



<u>35 Continuous Thickness Variables:</u> 33% of BIW mass



#### Modes:

Front NCAP + Front Offset + SICE + Side Pole + Roof Crush + Rear Offset + NVH

Objective: Minimize Mass

**Constraints:** Front NCAP: **Decelerations** Intrusions Front Offset: **Intrusions** Cabin Integrity SICF: Intrusions Side Pole Intrusions Roof Crush: Force **Rear ODB** Intrusions **Fuel System Clearance** NVH: **Body Stiffness Body Frequency** 

LS-OPT SRSM Settings:

Optimization Strategy
 Sequential RSM with Domain Reduction

Termination Tolerance

0.1 for design change AND objection function

Metamodel

**Radial Basis Function Network** 

Point Selection

Adaptive Space Filling - 54 points per iteration

# Optimization Algorithm Hybrid ASA

#### Large MDO - Results:



• Optimization was aggressive with a significant initial mass reduction.

- Then optimization converges as constraints are satisfied.
- Final step shows some increase in mass as variables are switched to discrete values.

#### Large MDO - Results:

#### Side Impact B-PIr Intrusion



Sqrt PRESS 1.2%

#### Front Offset Left Toepan Intrusion



Sqrt PRESS 15.3%

Metamodel accuracy for most cases was very good.

• The metamodels for the front crash modes showed the lowest prediction accuracy, though still acceptable.

#### Large MDO - Results:

Performance Requirements Met for all Modes – Examples:

	NVH 1 <sup>st</sup> Torsion	Front Offset	Rear Offset	Side Pole	IIHS SUV
Baseline Design					
Optimum Design					

Large MDO - Results:



- Gauge changes are non-intuitive.
- Some parts have significant gauge up values.
- Rear portion of structure saw significant gauge down.

#### Switched to discrete variables in LS-OPT:

• Changed variable types to discrete and set ranges to discrete gauges which bounded continuous optimum values.

• Re-optimize the last iteration using existing metamodel via the repair task.

• Run metamodel based optimization again to create optimization history for viewer display.

• Clean start from additional iteration number to run verification runs.



60815         1.93475417         2.00           60816         0.700020898         1.00           60817         1.498846         1.40           60821         2.29999883         2.00           60828         0.70007625         0.70           60829         0.70003653         0.70           63121         0.892124782         1.40           63131         0.741664268         1.20           63216         2.13728689         2.00           63221         0.700000475         1.20           64121         1.21828247         2.00           64121         0.700000204         1.20           64211         0.700000204         1.20           64211         0.70000204         1.20           64211         0.70000204         1.20           65116         2.14313003         1.80           65118         1.41987561         1.20           65131         1.75247227         1.80           65136         0.832840044         0.75           65141         2.29998831         1.60           65142         1.2802137         1.60           65145         0.843405751         1.40	Part#	Continuous	Final
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65141         2.2999831         1.60           65142         1.2802137         1.60           65145         1.34480367         0.75           65361         0.843405751         1.40           65368         1.59697644         1.20           65611         1.18161726         1.20           65615         0.825944822         1.00           65616         0.909662213         1.00           65625         0.700001546         0.85           65711         1.67796346         2.00           65731         0.700000843         0.70           60811-0         1.43165276         1.60           60811-1         2.29999659         2.30           60812-0         1.08972173         1.20           60812-1         1.35340555         1.80	65136	0.882840044	0.75
65142         1.2802137         1.60           65145         1.34480367         0.75           65361         0.843405751         1.40           65368         1.59697644         1.20           65611         1.18161726         1.20           65615         0.825944822         1.00           65616         0.909662213         1.00           65625         0.700001546         0.85           65711         1.67796346         2.00           65731         0.700000843         0.70           65811-0         1.43165276         1.60           60811-0         1.43165276         1.60           60811-1         2.29999659         2.30           60812-0         1.08972173         1.20           60812-1         1.35340555         1.80	65141	2.29998831	1.60
65145         1.34480367         0.75           65361         0.843405751         1.40           65368         1.59697644         1.20           65561         1.18161726         1.20           655615         0.825944822         1.00           65616         0.909662213         1.00           655625         0.700001546         0.85           65711         1.67796346         2.00           65731         0.700000843         0.70           60811-0         1.43165276         1.60           60811-1         2.29999659         2.30           60812-0         1.08972173         1.20           60812-1         1.35340555         1.80	65142	1.2802137	1.60
65361         0.843405751         1.40           65368         1.59697644         1.20           655611         1.18161726         1.20           655615         0.825944822         1.00           655616         0.909662213         1.00           655625         0.700001546         0.85           65711         1.67796346         2.00           65731         0.700000843         0.70           65811-0         1.43165276         1.60           60811-0         1.43165276         1.60           60811-1         2.2999659         2.30           60812-0         1.08972173         1.20           60812-1         1.35340555         1.80	65145	1.34480367	0.75
65368         1.59697644         1.20           65511         1.18161726         1.20           65515         0.825944822         1.00           655616         0.909662213         1.00           655625         0.700001546         0.85           65711         1.67796346         2.00           65731         0.700000843         0.70           65741         0.70000098         0.70           60811-0         1.43165276         1.60           60811-1         2.2999659         2.30           60812-0         1.08972173         1.20	65361	0.843405751	1.40
65611         1.18161726         1.20           65615         0.825944822         1.00           65616         0.909662213         1.00           65625         0.70001546         0.85           65711         1.67796346         2.00           65731         0.700000843         0.70           65741         0.70000098         0.70           60811-0         1.43165276         1.60           60811-1         2.2999659         2.30           60812-0         1.08972173         1.20           60812-1         1.35340555         1.80	65368	1.59697644	1.20
65615         0.825944822         1.00           65616         0.909662213         1.00           65625         0.700001546         0.85           65711         1.67796346         2.00           65731         0.700000843         0.70           65741         0.70000098         0.70           60811-0         1.43165276         1.60           60811-1         2.2999659         2.30           60812-0         1.08972173         1.20           60812-1         1.35340555         1.80	65611	1.18161726	1.20
65516         0.909662213         1.00           65525         0.700001546         0.85           65711         1.67796346         2.00           65731         0.700000843         0.70           65741         0.70000098         0.70           60811-0         1.43165276         1.60           60811-1         2.29999659         2.30           60812-0         1.08972173         1.20           60812-1         1.35340555         1.80	65615	0.825944822	1.00
65625         0.700001546         0.85           65711         1.67796346         2.00           65731         0.700000843         0.70           65741         0.70000098         0.70           60811-0         1.43165276         1.60           60811-1         2.29999659         2.30           60812-0         1.08972173         1.20           60812-1         1.35340555         1.80	65616	0.909662213	1.00
65711         1.67796346         2.00           65731         0.700000843         0.70           65741         0.70000098         0.70           60811-0         1.43165276         1.60           60811-1         2.29999659         2.30           60812-0         1.08972173         1.20           60812-1         1.35340555         1.80	65625	0.700001546	0.85
65731         0.70000843         0.70           65741         0.70000098         0.70           60811-0         1.43165276         1.60           60811-1         2.29999659         2.30           60812-0         1.08972173         1.20           60812-1         1.35340555         1.80	65711	1.67796346	2.00
65741         0.70000098         0.70           60811-0         1.43165276         1.60           60811-1         2.29999659         2.30           60812-0         1.08972173         1.20           60812-1         1.35340555         1.80	65731	0.70000843	0.70
60811-0         1.43165276         1.60           60811-1         2.29999659         2.30           60812-0         1.08972173         1.20           60812-1         1.35340555         1.80	65741	0.70000098	0.70
60811-1         2.29999659         2.30           60812-0         1.08972173         1.20           60812-1         1.35340555         1.80	60811-0	1.43165276	1.60
60812-0         1.08972173         1.20           60812-1         1.35340555         1.80	60811-1	2.29999659	2.30
60812-1 1.35340555 1.80	60812-0	1.08972173	1.20
100	60812-1	1.35340555	1.80

#### Large MDO - Constraints:



Front modes have constraints well defined for front structure.

A good optimization algorithm will exploit all undefined constraints!

Added constraints on internal energy of some parts to control design decisions.

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12

-100

-50

Violation (%)

0

50

No Violation (%)

Iteration

1.6

0

100

Design space exploration - Iteration	n 1:	Case	Runs	CPU/Run	<b>CPU Hours</b>
	Feasible	Front Flat	53	56	15730
		Front Offset	53	56	21666
	HPC	SICE	53	56	8310
5764		Side Pole	53	56	18402
5 520-00	Job Submission	Roof Crush	53	56	14840
	of 53 Design	Rear Offset	53	56	14543
		Normal Modes	53	1	53
		Running Totals	378	18198	95310

#### **Optimization History:**





Design space exploration - Iteration	2:	Case	Runs	CPU/Run	<b>CPU Hours</b>
	Feasible	Front Flat	55	56	16027
525.00		Front Offset	55	56	22075
	HDC	SICE	55	56	8467
576-0		Side Pole	55	56	18748
S200-e	Job Submission	Roof Crush	55	56	15120
478.00	of 54 Design	Rear Offset	55	56	14818
125-0	Normal Modes	Normal Modes	55	1	54
1 1 1 1 1 1 1 1 1 1 1 1 1 1		Running Totals	756	36396	190620

#### **Optimization History:**





Design space exploration - Iteration	3:	Case	Runs	CPU/Run	<b>CPU Hours</b>
	reasible nfeasible	Front Flat	55	56	16027
		Front Offset	55	56	22075
	HDC	SICE	55	56	8467
575:09	Job	Side Pole	55	56	18748
\$ 550-0		Roof Crush	55	56	15120
17:00	of 54 Design	Rear Offset	55	56	14818
		Normal Modes	55	1	54
		Running Totals	1134	54594	285930

**Optimization History:** 







#### **Optimization History:**





Design space exploration - Iteration	า 5:	Case	Runs	CPU/Run	<b>CPU Hours</b>
	■ Feasible	Front Flat	55	56	16027
		Front Offset	55	56	22075
6.75	HDC	SICE	55	56	8467
575-08		Side Pole	55	56	18748
3.78c.00	Job Submission	Roof Crush	55	56	15120
4756-04	of 54 Design	Rear Offset	55	56	14818
42E-0		Normal Modes	55	1	54
1 15 2 15 5 15 54221		Running Totals	1890	90990	476550

#### **Optimization History:**





Design space exploration - Iteration 6:		Case	Runs	CPU/Run	<b>CPU Hours</b>
■ Fasabi ■ Maada	Γ	Front Flat	55	56	16027
		Front Offset	55	56	22075
		SICE	55	56	8467
53%.4		Side Pole	55	56	18748
Sut	Job <b>b</b> bmission	Roof Crush	55	56	15120
54	of 4 Design	Rear Offset	55	56	14818
426.0		Normal Modes	55	1	54
1 15 15 164221 65221 2 1 164221		Running Totals	2268	109188	571860

#### **Optimization History:**





Design space exploration - Iteration 7:		Case	Runs	CPU/Run	<b>CPU Hours</b>
■ Forsikh ■ bite subite	Γ	Front Flat	55	56	16027
		Front Offset	55	56	22075
		SICE	55	56	8467
5.726.05		Side Pole	55	56	18748
Joi Submit	b ission	Roof Crush	55	56	15120
435600 Of 435600 54 De	f sian	Rear Offset	55	56	14818
		Normal Modes	55	1	54
1 15 15 64221 83221 2 1 644221		Running Totals	2646	127386	667170

**Optimization History:** 





Design space exploration - Iteratio	n 8:	Case	Runs	CPU/Run	<b>CPU Hours</b>
	E Feasible Infeasible	Front Flat	55	56	16027
		Front Offset	55	56	22075
6.26.64		SICE	55	56	8467
57564		Side Pole	55	56	18748
5.551-00	Job Submission	Roof Crush	55	56	15120
4.78.0	of 54 Design	Rear Offset	55	56	14818
		Normal Modes	55	1	54
1 15 2 63221 2 1 64221		Running Totals	3024	145584	762480

#### **Optimization History:**





Design space exploration - Iteration	9:	Case	Runs	CPU/Run	CPU Hours
	Feasible Infeasible	Front Flat	55	56	16027
		Front Offset	55	56	22075
250	HPC	SICE	55	56	8467
5750		Side Pole	55	56	18748
5.55:09 90 90 90 90	Job Submission	Roof Crush	55	56	15120
4.75:46	of 54 Design	Rear Offset	55	56	14818
4.55.04		Normal Modes	55	1	54
1 15 2 15 64211 63221 2 1 64221		Running Totals	3402	163782	857790

#### **Optimization History:**





Design space exploration - Iteration 10	):	Case	Runs	CPU/Run	<b>CPU Hours</b>
■ Feada	Γ	Front Flat	55	56	16027
		Front Offset	55	56	22075
6.5K	ЦРС	SICE	55	56	8467
575c-9		Side Pole	55	56	18748
Sul	Job ubmission	Roof Crush	55	56	15120
4564	of 4 Design	Rear Offset	55	56	14818
135.9		Normal Modes	55	1	54
1 1 83211 2 1 5 8021		Running Totals	3780	181980	953100

#### **Optimization History:**





Design space exploration - Iteration 17	1:	Case	Runs	CPU/Run	<b>CPU Hours</b>
E Foodbe B Manade	Γ	Front Flat	55	56	16027
		Front Offset	55	56	22075
	HDC	SICE	55	56	8467
5.7E+6		Side Pole	55	56	18748
g szew S	Job Submission	Roof Crush	55	56	15120
475:04	of 54 Design	Rear Offset	55	56	14818
425-9	of Design	Normal Modes	55	1	54
1 13 2 15 6021 65221 2 1 6021		Running Totals	4158	200178	1048410

#### **Optimization History:**





Design space exploration - Iteration 12:	Case	Runs	CPU/Run	<b>CPU Hours</b>
E Paulé E Mésolé	Front Flat	55	56	16027
	Front Offset	55	56	22075
	SICE	55	56	8467
57569 5569	Side Pole	55	56	18748
Jo Subm	nission Roof Crush	55	56	15120
456-0 54 D	of Rear Offset	55	56	14818
436-9	Normal Modes	55	1	54
1 15 2 15 84211 53221 2 1 54221	Running Totals	4536	218376	1143720

#### **Optimization History:**





### LSOPT 4.x/VM Server

#### HPC Integrated Environment within LS-OPT:

S-DYNA OPTIONS		
LS-DYNA Version:	LS-DYNA 970 MPP SP 6763	
Input/Output Directory:	/cae/data/tmp/vs2/o14319	Browse
LS-DYNA Input File:	DynaOpt.inp	Browse
Additional Files:	Add	
Required Memory1	auto	
Required Memory2	auto	
MPP Option File (pfile):	Generic 🔄	
Generate ASCII Output:	No	
Dynamore Compression:	No	

<u>F</u> ile	Eile <u>V</u> iew <u>T</u> ask <u>H</u> elp													
Info	Strategy	Solvers [	Dist Variables	Sampling	Histories	Responses	Objective	Constraints	Algorithms	Run	Viewer	DYNA Stats		
Jo	Job ID View Log Progress													
	1	PID 18462	D 18462     Normal Termination     Case=1, Iter=1, Run=1     PBS     Number of Iterations						_					
	2	PID 18464	4 Normal 1	ermination	Case=	1, Iter=1,	Run=2	Concurren	it Jobs					
	3	PID 18466	6 Normal 1	ermination	Case=	1, Iter=1,	Run=3 <sup>=</sup>	4 Case			Baseline Run Only     Omit Last Verification Run			
	4	PID 18468	8 Normal 1	ermination	Case=	1, Iter=1,	Run=4	1		□ c	lean Sta	rt		
	5	PID 18497	7 Normal 1	ermination	Case=	=1, lter=1,	Run=5							
							•			Ru	In	Pause	Resume	Stop

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### Conclusions

- The sequential response surface method with domain reduction (SRSM) of LS-OPT has proved very effective in finding optimal solutions for single objective multi-disciplinary design optimization problems.
- By developing the LS-OPT server the application has been integrated into the HPC environment and is an effective and efficient tool for optimization.

#### Acknowledgements

- The author would like to acknowledge the work of colleagues at Honda R&D:
- Allen Sheldon<sup>1</sup>, Edward Helwig<sup>1</sup>, and Yong-Bae Cho<sup>2</sup>, "Investigation and Application of Multi-Disciplinary Design Optimization for Automotive Body Structure Development", Proceedings of the 8<sup>th</sup> LS-DYNA Users Conference, Strasbourg, 2011
- Ohio Supercomputing Center
- Trent Eggleston (LSTC)

<sup>1</sup> Honda R&D Americas, Inc. <sup>2</sup> CSM Software, Inc.

# **Parameter Identification**

- Used for calibrating material or system properties
- Technologies
  - Curve Matching
    - Ordinate-based:
    - Curve Mapping:
  - Optimization
    - Sequential with Domain Reduction
  - Approximation
    - Metamodel at each time history increment

- Use differences in the Y-coordinate
- Use the area between curves

#### **Ordinate-based**



Z

## Problems with ordinate-based curve matching

- Steep parts of the response are difficult or impossible to incorporate, e.g. linear elastic range or failure (damage models such as the GISSMO model in LS-DYNA<sup>®</sup>)
- Robustness: Ranges of the computed and test curves do not coincide in the <u>abscissa</u> at an interim stage of the optimization resulting in instability
- <u>Hysteretic</u> test curves or <u>springback</u>
   cannot be matched since the ordinate values are non-unique



Witowski K, Feucht M & Stander N, An Effective Curve Matching Metric for Parameter Identification using Partial Mapping. *Proceedings of the* 8<sup>th</sup> European LS-DYNA Users Conference, Strasbourg, 2011

## **Partial Curve Mapping**



## LS-OPT 4.2 Interface for Curve Mapping



## Example 4: Bauschinger effect (Material 125)

- Automotive sheet steel, particularly advanced high strength steels, display the Bauschinger effect and require special material models
- LS-DYNA Material 125 (Yoshida model with recent improvements by Shi, Zhu, Xia & Stoughton)
- Model identification requires a tension and compression test

## Example 4: Bauschinger effect (Material 125)



Number of Iterations

### Conclusions

- LS-OPT has been shown to run successfully on industrial design optimization and material identification problems
- The design problem was solved entirely on site by the customer with support of the LS-OPT team.
- The bulk of the effort was to refine the job scheduling capabilities
- As a result, and with the correct support, a similar setup could recently be achieved very quickly at another major automotive customer
- Material calibration: The Partial Curve Mapping algorithm is able to easily identify complex materials with hysteretic behavior

# **Preview: Version 5**

#### Process modeling Merging and branching



#### LS-OPT Goals – Version 5

- Process Simulation & Optimization
  - Process flow with merging and branching
  - File handling: Copy, move, link, delete
  - Load balancing of the process jobs
- Preserve simplicity: launch/monitor single Dyna job
- Step-wise analysis
- Display run status
  - Unfinished stages, error terminations

## Process Modeling (Version 5)



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### **Outlook: Multiple surrogates**

- Improved accuracy: Use multiple surrogate types as basis models for generating a surface potentially more accurate than any single surrogate
- Automates the model choice: Eliminates user choice
- Basis models: polynomials, RBF, neural nets, Kriging, <u>Support Vector Regression</u>



### Other topics/recent implementations

- Upgrade of Mode Tracking for MPP implicit version of LS-DYNA (v4.2) - complete
- Standalone history
   filter (v4.2) complete
- Improved convergence for Multi-objective optimization (v5.0).

