Car style optimization by CFD and modeFRONTIER

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Contents

1. Introduction
2. Optimization by RSM
3. Technical Approach
4. Conclusive & Future Remarks

Introduction

Background & motivation

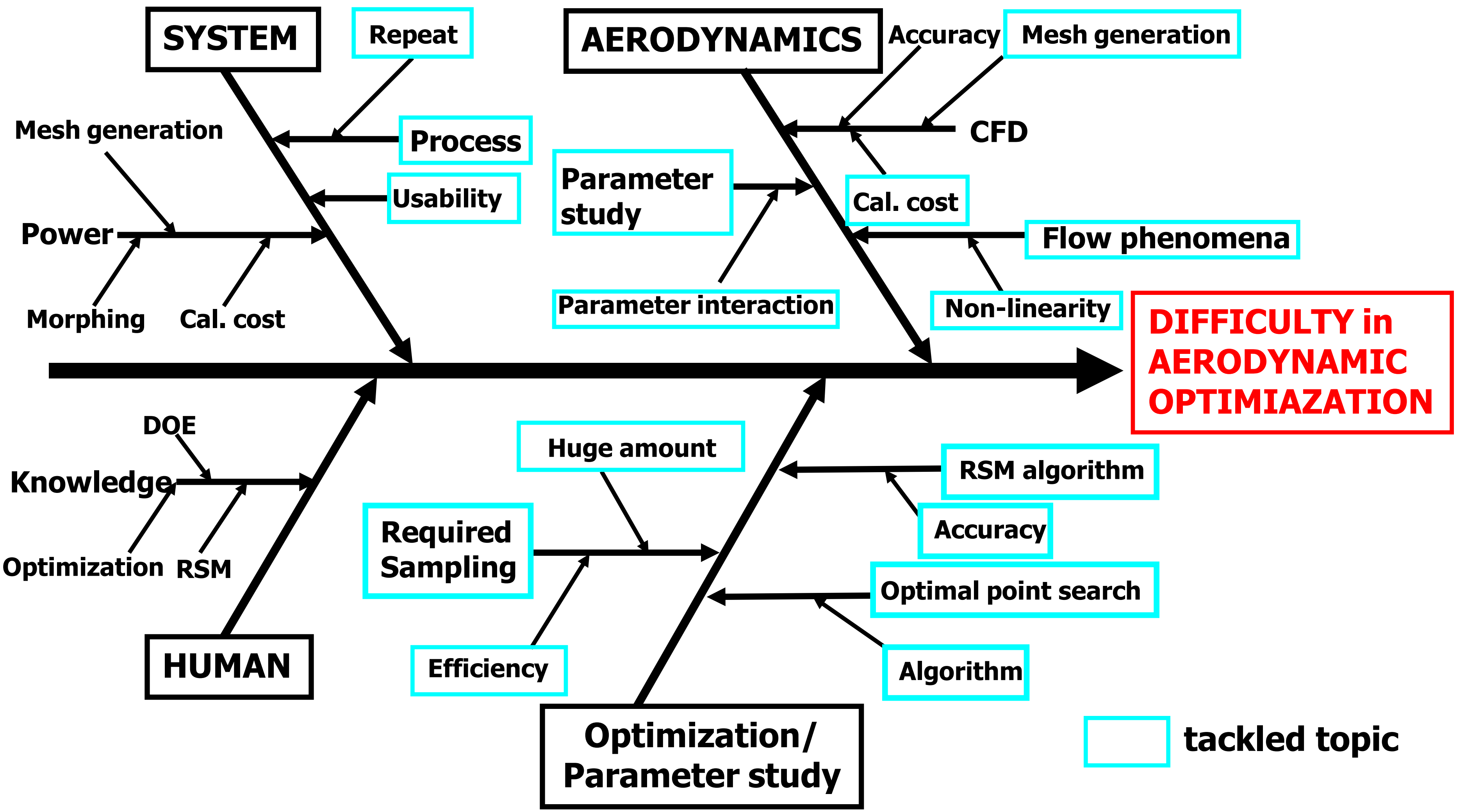
Requirements

1. Performance
   - high fuel efficiency (Low C_D)
   - dynamic stability
   - high balance between styling & aero-performance
2. Development
   - aerodynamic design at early development stage
   - tool with usability for practical development

Introduction

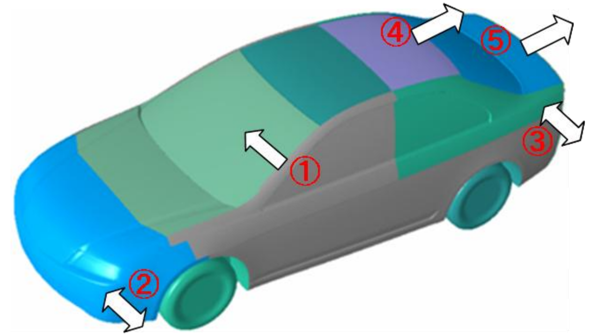
Background & motivation

Why optimization has not been widely adopted for aerodynamic development



Introduction

Optimization by conventional parameter study



Main Drawbacks

1. **Huge amount of CFD calculation**
2. **Small amount of obtained information**
3. **High dependence of CFD sampling on obtained C_D**

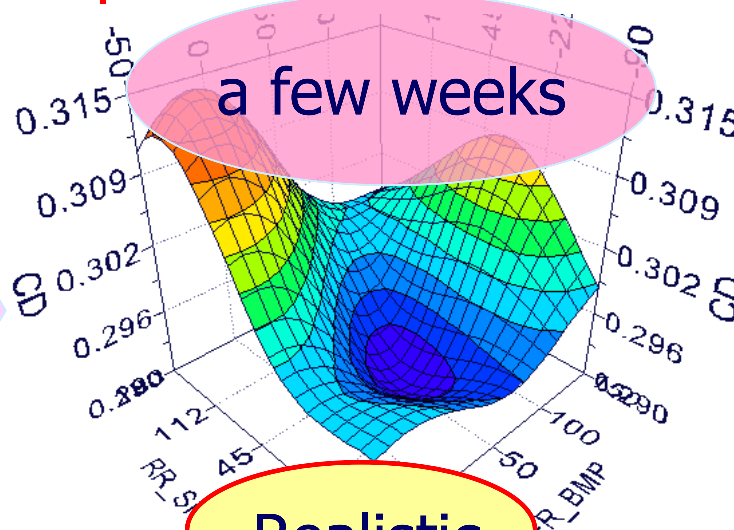
Full Factorial Sampling

ID	A	B	C	D	E	CD
1	5	4	2	10	-2	0.293
2	10	[illegible]	[illegible]	20	[illegible]	0.295
3	[illegible]	[illegible]	[illegible]	30	[illegible]	0.289
4	20	[illegible]	[illegible]	40	[illegible]	0.287
…	…	…			…	…
3125						

5-level 5-parameter
= 3125 CFD calculations
A few months

Unrealistic

Response Surface Modeling



a few weeks

Realistic

1. Introduction

2. **Optimization by RSM**

3. Technical Approach

4. Conclusive & Future Remarks

Optimization by RSM (Response Surface Modeling)

Conventional Optimization by RSM

DOE (Design of Experiments)

デザインテーブル

ID	RID	M	CATEGORY	Cowltop	Cpillar	Diffuzer	Froverhang	Frwin	Hood	Roof	Rrbumper1	Rrwin_angle	Sidebody	Tru
0		☐		3.900E2	6.000E2	-4.000E1	-4.400E2	-9.600E2	-1.300E2	7.600E2	5.600E2	4.900E2	6.000E2	3.9
1		☐		2.300E2	-3.600E2	-3.200E2	1.000E2	-3.800E2	-9.000E1	7.600E2	3.900E2	8.500E2	-7.000E2	4.4
2		☐		2.800E2	4.200E2	2.800E2	-3.800E2	5.700E2	1.200E2	8.900E2	-4.000E2	6.600E2	4.000E2	2.7
3		☐		3.900E2	-4.200E2	-8.000E1	-1.400E2	-2.600E2	-2.800E2	6.500E2	-4.600E2	3.800E2	-6.000E2	5.9
4		☐		2.000E2	-2.400E2	2.800E2	-2.000E2	9.200E2	-3.700E2	5.700E2	-1.400E2	7.500E2	-1.000E2	4.9
5		☐		3.900E2	4.800E2	-3.600E2	2.800E2	2.500E2	-3.200E2	-3.300E2	3.400E2	3.900E2	1.000E3	2.6
6		☐		2.300E2	4.200E2	-8.000E1	-5.000E2	3.700E2	-2.900E2	-3.100E2	-4.200E2	7.300E2	9.000E2	5.0
7		☐		3.700E2	-4.200E2	2.400E2	-7.400E2	-5.000E2	-3.000E1	-6.000E1	1.500E2	8.200E2	1.000E3	5.8
8		☐		3.100E2	1.800E2	4.000E1	-3.200E2	4.500E2	4.000E1	1.900E2	1.800E2	5.600E2	-8.000E2	4.2
9		☐		3.700E2	6.000E1	-8.000E1	-8.000E2	-5.700E2	-1.600E2	1.000E1	3.600E2	2.300E2	-6.000E2	2.6
10		☐		2.300E2	-4.800E2	3.200E2	-8.000E2	1.800E2	-3.000E1	-3.000E2	3.900E2	3.100E2	-1.000E2	2.2
11		☐		3.500E2	-1.200E2	3.200E2	2.200E2	-6.100E2	6.000E1	3.000E1	-3.100E2	3.600E2	6.000E2	4.8
12		☐		3.400E2	-3.000E2	3.600E2	-6.200E2	-1.000E2	-2.900E2	6.800E2	1.400E2	6.100E2	8.000E2	2.5
13		☐		4.000E2	4.800E2	2.000E2	-8.000E1	-4.400E2	-1.100E2	-1.500E2	-1.000E2	4.300E2	2.000E2	3.0
14		☐		2.500E2	-3.000E2	4.000E2	2.200E2	-8.200E2	-3.000E2	5.500E2	3.300E2	6.600E2	-8.000E2	2.2
15		☐		2.500E2	1.800E2	-4.000E2	-8.000E1	-7.900E2	-1.500E2	-2.200E2	8.000E1	6.500E2	9.000E2	4.3
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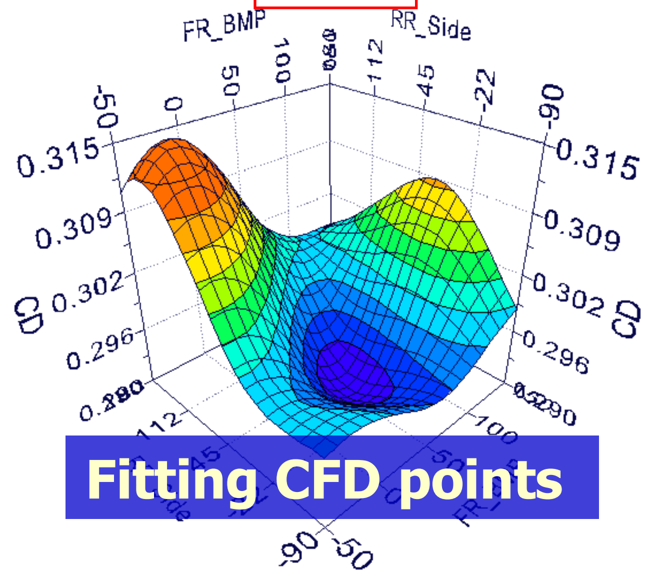
17		☐		3.300E2	1.200E2	2.000E2	-5.000E2	7.200E2	-3.300E2	7.900E2	-1.000E1	8.700E2	3.000E2	6.0
18		☐		3.200E2	3.600E2	1.600E2	-7.400E2	-5.400E2	-3.300E2	0.000E0	6.000E1	4.700E2	2.000E2	5.1
19		☐		2.200E2	-1.200E2	0.000E0	-2.000E1	2.400E2	-3.600E2	2.000E1	-1.500E2	9.200E2	-7.000E2	3.1
20		☐		2.800E2	4.200E2	1.600E2	2.800E2	8.700E2	-3.000E2	-1.600E2	4.700E2	8.300E2	7.000E2	5.2
21		☐		3.600E2	-6.000E1	2.000E2	-2.000E2	4.000E2	-1.000E1	9.700E2	-6.000E1	4.400E2	-1.000E3	5.2
22		☐		2.100E2	0.000E0	-1.200E2	-6.200E2	3.100E2	-4.000E1	7.100E2	-3.000E2	4.000E2	-1.000E2	4.9
23		☐		2.200E2	5.400E2	2.400E2	-2.600E2	7.000E1	1.600E2	-2.500E2	2.500E2	5.900E2	-9.000E2	5.3
24		☐		2.500E2	2.400E2	4.000E1	-1.400E2	-3.000E2	-4.000E2	5.900E2	-5.300E2	5.200E2	0.000E0	3.6
25		☐		3.500E2	1.200E2	4.000E2	4.000E1	9.000E2	-9.000E1	8.000E2	4.000E1	5.300E2	-5.000E2	4.8
26		☐		3.300E2	1.200E2	-8.000E1	-2.000E1	-8.500E2	9.000E1	1.500E2	-3.600E2	7.600E2	2.000E2	4.6
27		☐		4.000E2	4.200E2	[illegible]	1.000E2	[illegible]	[illegible]	9.900E2	[illegible]	7.000E2	-8.000E2	2.8
28		☐		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.000E2	6.0
29		☐		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.000E2	3.1
30		☐		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-9.000E2	2.4
31		☐		3.400E2	[illegible]	4.000E1	[illegible]	5.400E2	-3.100E2	[illegible]	4.300E2	5.800E2	-4.000E2	2.9
32		☐		2.500E2	-5.400E2	1.600E2	2.800E2	-1.700E2	-3.500E2	-9.000E1	-5.100E2	7.900E2	4.000E2	4.1
33		☐		2.400E2	5.400E2	4.000E1	-6.800E2	9.500E2	7.000E1	2.500E2	4.000E1	9.600E2	8.000E2	4.4

Sampling CFD points

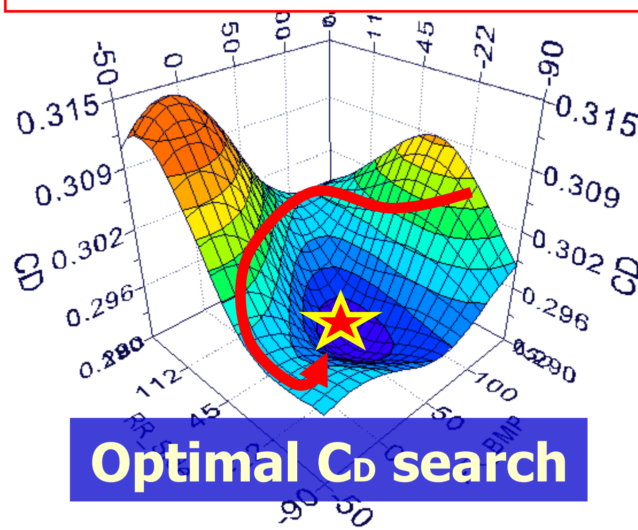
Process

RSM



Fitting CFD points

Optimization Algorithm



Optimal C_D search

Optimization by RSM

Merits & Demerits of conventional RSM optimization

Merits

1. Reasonable CFD cost
2. Valuable information (contribution, interaction)
3. C_D values for any parameter values (C_D=f(a, b, c…))

Demerits

1. Difficulty in creating an accurate surface
2. Obscure relationship between CFD sampling and parameter numbers

Resolve the demerits by employing modeFRONTIER

modeFRONTIER
multi-objective optimization and design environment

NEW

Adaptive Multi-Stage Response Surface Modeling (AMS-RSM)

Optimization System & Methodology applicable to Aerodynamic Design Development

1. Introduction
2. Optimization by RSM
3. **Technical Approach**
4. Conclusive & Future Remarks

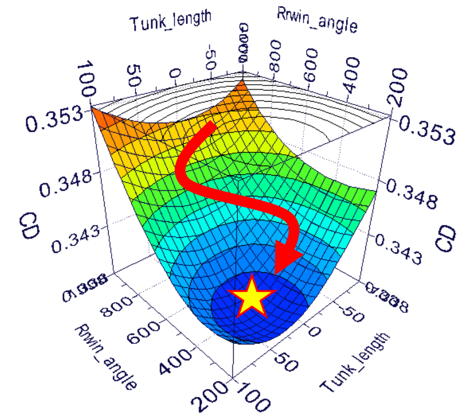
Optimization System & Process

System Concept

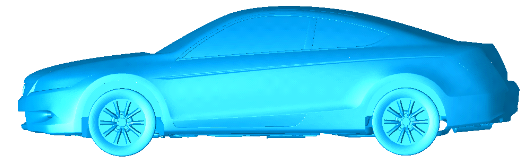
System requirements

- automatic
- reasonable time cost
- reasonable accuracy
- valuable outputs
- usability

Search optimal point



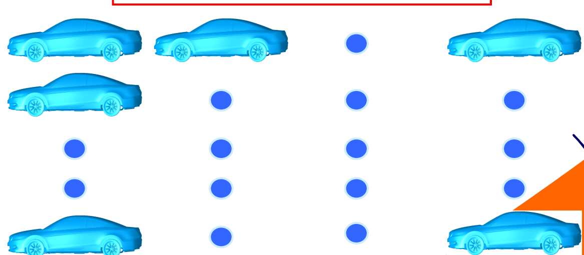
Optimized shape



modeFRONTIER
multi-objective optimization and design environment

SCULPTOR
OPTIMAL SOLUTIONS

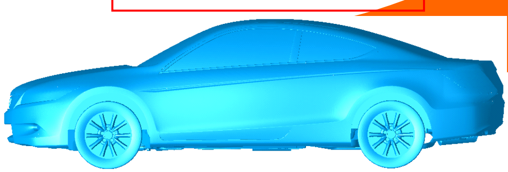
Create models



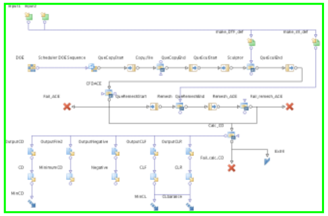
Build & improve RS

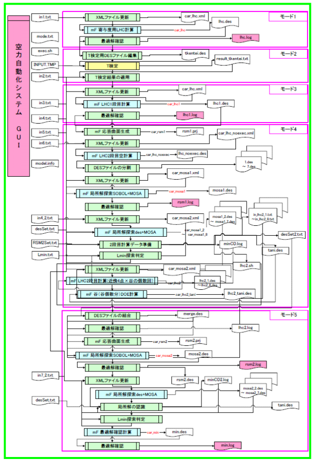
modify

Base model



CFD-ACE+
CFD-ViSCART

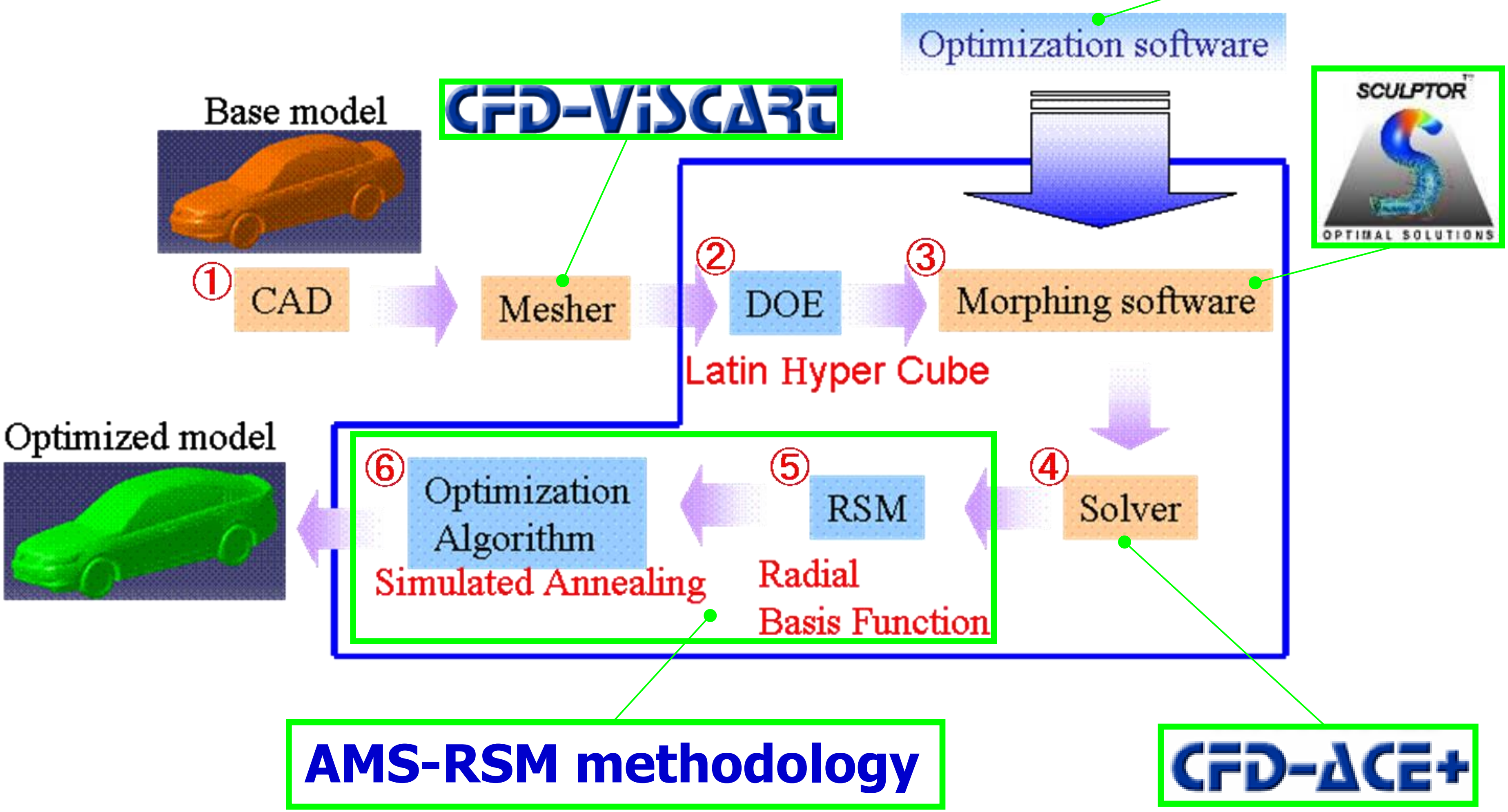




Optimization System & Process

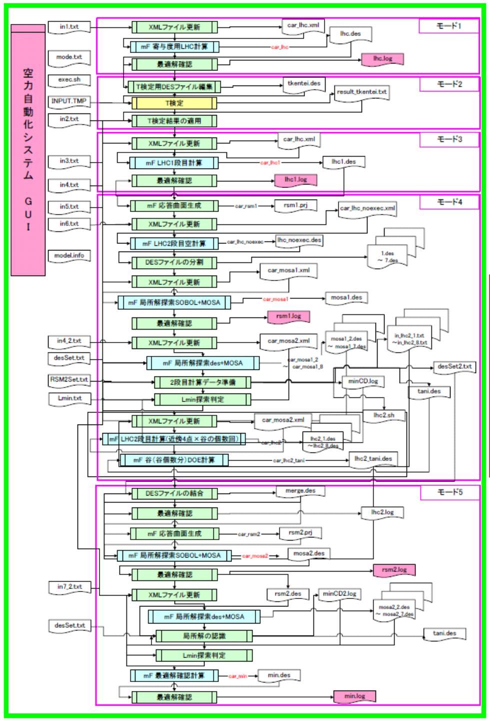
<u>Optimization system</u>

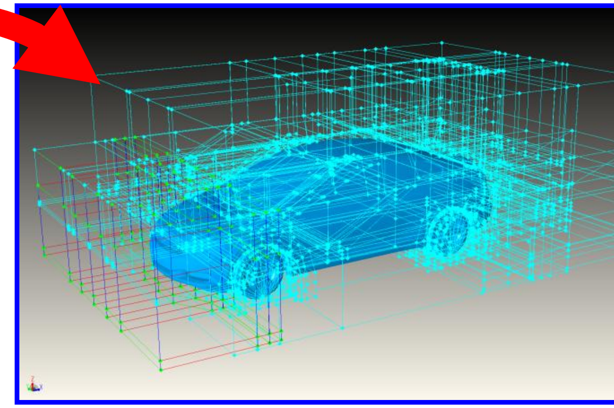
modeFRONTIER controls the process



Parameter Setting

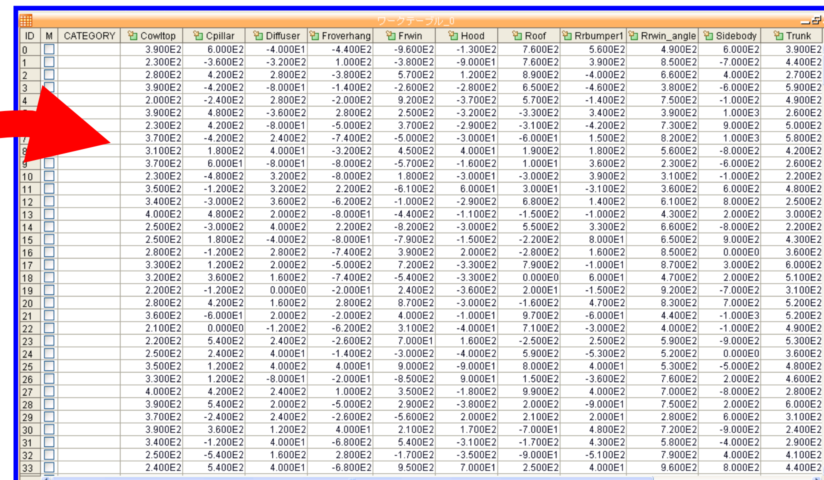
Graphical User Interface for Morphing Definition





Morphing Boxes

No	変数名称	変数タイプ			最大値	刻み	従属変数元
1	Sidebody	固定		-1000	1000	100	
2	Cowltop	従属変数		200	400	30	Sidebody
3	Cpillar	変数		-600	600	60	
4	Diffuzer	変数	0	-400	400	40	
5	Froverhang	変数	-400	-800	400	60	
6	Frwin	変数	0	-1000	1000	10	
7	Hood	変数	-200	-400	200	10	
8	Roof	変数	250	-500	1000	10	
9	Rrbumper1	変数	0	-600	600	10	
10	Rrwin_angle	変数	600	200	1000	10	

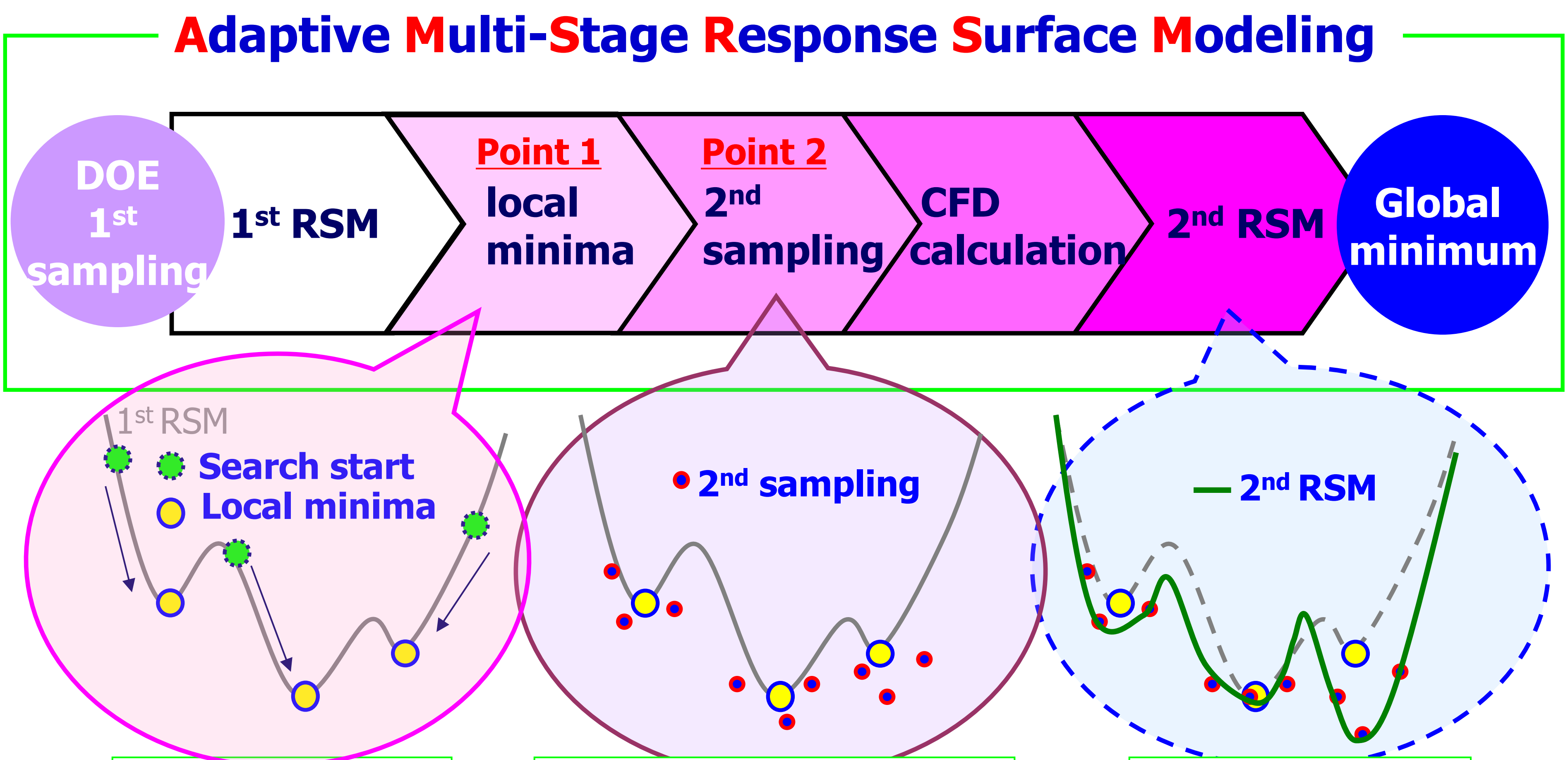


ID	M	CATEGORY	Cowltop	Cpillar	Diffuser	Froverhang	Frwin	Hood	Roof	Rrbumper1	Rrwin_angle	Sidebody	Trunk
0			3.900E2	6.000E2	-4.000E1	-4.400E2	-9.600E2	-1.300E2	7.600E2	5.600E2	4.900E2	6.000E2	3.900E2
1			2.300E2	-3.600E2	-3.200E2	1.000E2	-3.800E2	-9.000E1	7.600E2	3.900E2	8.500E2	-7.000E2	4.400E2
2			2.800E2	4.200E2	2.800E2	-3.800E2	5.700E2	1.200E2	8.900E2	-4.000E2	6.600E2	4.000E2	2.700E2
3			3.900E2	-4.200E2	-8.000E1	-1.400E2	-2.600E2	-2.800E2	6.500E2	-4.600E2	3.800E2	-6.000E2	5.900E2
4			2.000E2	-2.400E2	2.800E2	-2.000E2	9.200E2	-3.700E2	5.700E2	-1.400E2	7.500E2	-1.000E2	4.900E2
			3.900E2	4.800E2	-3.600E2	2.800E2	2.500E2	-3.200E2	-3.300E2	3.400E2	3.900E2	1.000E3	2.600E2
			2.300E2	4.200E2	-8.000E1	-5.000E2	3.700E2	-2.900E2	-3.100E2	-4.200E2	7.300E2	9.000E2	5.000E2
7			3.700E2	-4.200E2	2.400E2	-7.400E2	-5.000E2	-3.000E1	-6.000E1	1.500E2	8.200E2	1.000E3	5.800E2
8			3.100E2	1.800E2	4.000E1	-3.200E2	4.500E2	4.000E1	1.900E2	1.800E2	5.600E2	-8.000E2	4.200E2
9			3.700E2	6.000E1	-8.000E1	-8.000E2	-5.700E2	-1.600E2	1.000E1	3.600E2	2.300E2	-6.000E2	2.600E2
10			2.300E2	-4.800E2	3.200E2	-8.000E2	1.800E2	-3.000E1	-3.000E2	3.900E2	3.100E2	-1.000E2	2.200E2
11			3.500E2	-1.200E2	3.200E2	2.200E2	-6.100E2	6.000E1	3.000E1	-3.100E2	3.600E2	6.000E2	4.800E2
12			3.400E2	-3.000E2	3.600E2	-6.200E2	-1.000E2	-2.900E2	6.800E2	1.400E2	6.100E2	8.000E2	2.500E2
13			4.000E2	4.800E2	2.000E2	-8.000E1	-4.400E2	-1.100E2	-1.500E2	-1.000E2	4.300E2	2.000E2	3.000E2
14			2.500E2	-3.000E2	4.000E2	2.200E2	-8.200E2	-3.000E2	5.500E2	3.300E2	6.600E2	-8.000E2	2.200E2
15			2.500E2	1.800E2	-4.000E2	-8.000E1	-7.900E2	-1.500E2	-2.200E2	8.000E1	6.500E2	9.000E2	4.300E2
16			2.800E2	-1.200E2	2.800E2	-7.400E2	3.900E2	2.000E2	-2.800E2	1.600E2	8.500E2	0.000E0	3.600E2
17			3.300E2	1.200E2	2.000E2	-5.000E2	7.200E2	-3.300E2	7.900E2	-1.000E1	8.700E2	3.000E2	6.000E2
18			3.200E2	3.600E2	1.600E2	-7.400E2	-5.400E2	-3.300E2	0.000E0	6.000E1	4.700E2	2.000E2	5.100E2
19			2.200E2	-1.200E2	0.000E0	-2.000E1	2.400E2	-3.600E2	2.000E1	-1.500E2	9.200E2	-7.000E2	3.100E2
20			2.800E2	4.200E2	1.600E2	2.800E2	8.700E2	-3.000E2	-1.600E2	4.700E2	8.300E2	7.000E2	5.200E2
21			3.600E2	-6.000E1	2.000E2	-2.000E2	4.000E2	-1.000E1	9.700E2	-6.000E1	4.400E2	-1.000E3	5.200E2
22			2.100E2	0.000E0	-1.200E2	-6.200E2	3.100E2	-4.000E1	7.100E2	-3.000E2	4.000E2	-1.000E2	4.900E2
23			2.200E2	5.400E2	2.400E2	-2.600E2	7.000E1	1.600E2	-2.500E2	2.500E2	5.900E2	-9.000E2	5.300E2
24			2.500E2	2.400E2	4.000E1	-1.400E2	-3.000E2	-4.000E2	5.900E2	-5.300E2	5.200E2	0.000E0	3.600E2
25			3.500E2	1.200E2	4.000E2	4.000E1	9.000E2	-9.000E1	8.000E2	4.000E1	5.300E2	-5.000E2	4.800E2
26			3.300E2	1.200E2	-8.000E1	-2.000E1	-8.500E2	9.000E1	1.500E2	-3.600E2	7.600E2	2.000E2	4.600E2
27			4.000E2	4.200E2	2.400E2	1.000E2	3.500E2	-1.800E2	9.900E2	4.000E2	7.000E2	-8.000E2	2.800E2
28			3.900E2	5.400E2	2.000E2	-5.000E2	2.900E2	-3.800E2	2.000E2	-9.000E1	7.500E2	2.000E2	6.000E2
29			3.700E2	-2.400E2	2.400E2	-2.600E2	-5.600E2	2.000E2	2.100E2	2.000E1	2.800E2	6.000E2	3.100E2
30			3.900E2	3.600E2	1.200E2	4.000E1	2.100E2	1.700E2	-7.000E1	4.800E2	7.200E2	-9.000E2	2.400E2
31			3.400E2	-1.200E2	4.000E1	-6.800E2	5.400E2	-3.100E2	-1.700E2	4.300E2	5.800E2	-4.000E2	2.900E2
32			2.500E2	-5.400E2	1.600E2	2.800E2	-1.700E2	-3.500E2	-9.000E1	-5.100E2	7.900E2	4.000E2	4.100E2
33			2.400E2	5.400E2	4.000E1	-6.800E2	9.500E2	7.000E1	2.500E2	4.000E1	9.600E2	8.000E2	4.400E2

CFD calculation sampling

AMS-RSM -Flow-

AMS-RSM Flow



Find local minima

The 2nd sampling around the local minima

Build the 2nd RSM

AMS-RSM -Flow-

Local & Global minimum search

Different parameter setting allows two types of search.

⊟ MOSA

Algorithm based on a single and Multi Objective Simulated Annealing (MOSA).

Main features:

1) Obeys boundary constraints on continuous variables.
2) Allows user defined discretization (base).
3) Enforces user defined constraints by objective function penalization.
4) Allows concurrent evaluation of the n independent points.
5) After a 'hot phase' (T>0) a 'cold phase' (T=0) follows.
6) The evolution is governed by the Temperature Scheduler and by the Spatial Perturbation Length Scheduler.

The entries in the DOE ta

Parameter setting

⊟ Parameters

Number of Iterations	[1,5000]	100
Initial Temperature	[0.0,1.0]	0.1
Fraction of 'Hot' Iterations	[0.0,1.0]	0.5

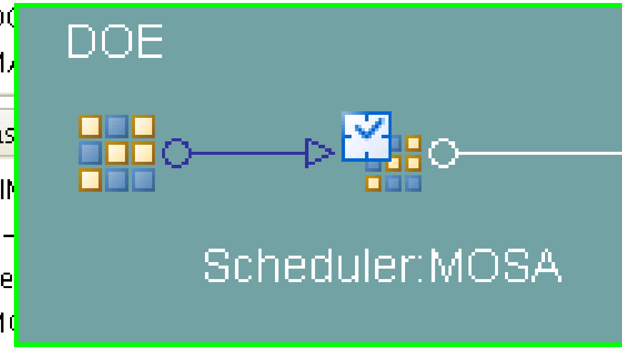
⊟ Advanced Parameters

Minimum Perturbation Length (fra...	[1.0E-6,1.0]	0.05
Feasibility of Points		No Unfeasible Points
Random Generator Seed	[0,999]	1

Optimization Wizard

Schedulers
- DO
- MA

Bas
- SIM
- B-
- Le
- MO
- ARMOGA



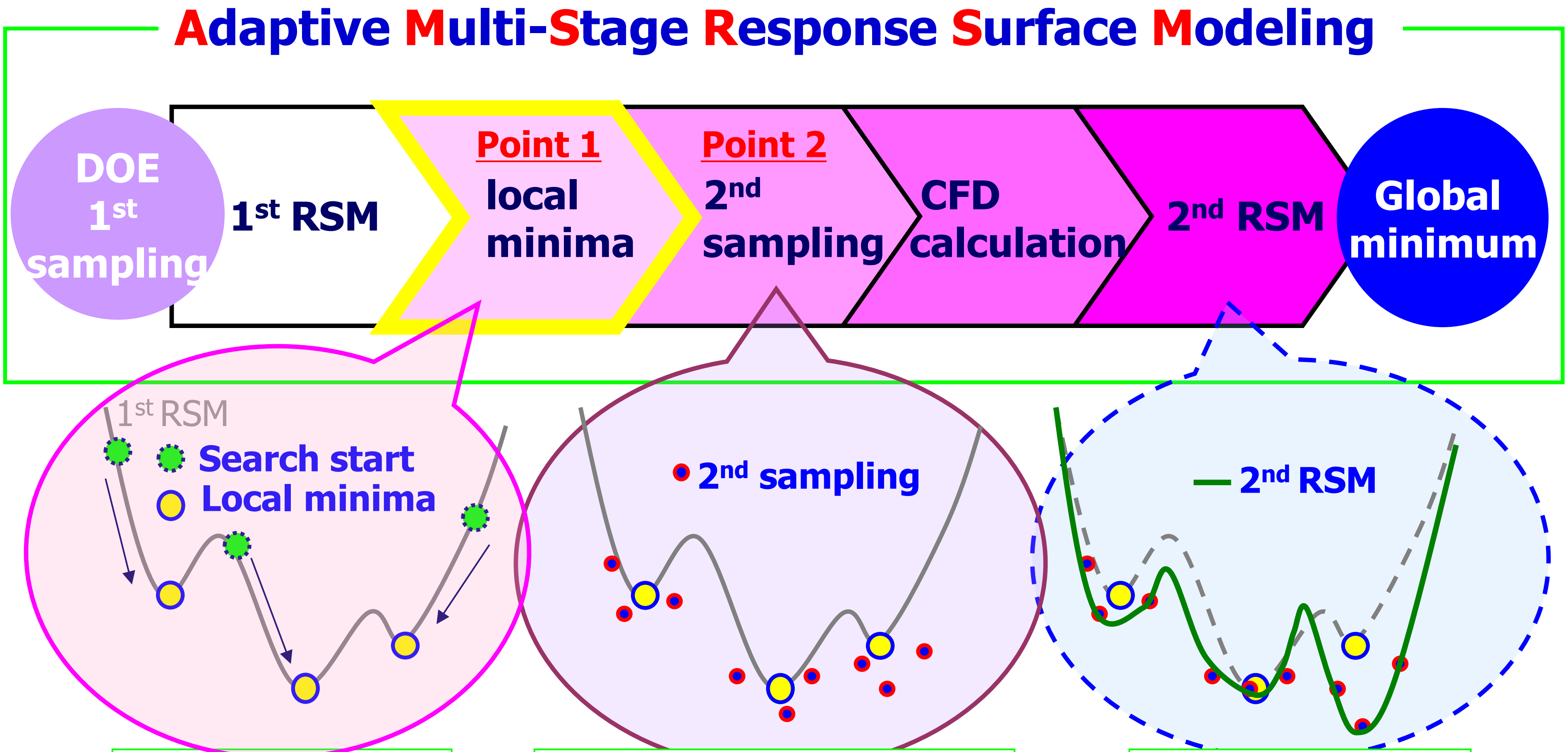
Advanced Optimizers
- MOSA
- NSGA-II
- MOGT
- MOPSO
- FMOGA-II
- FSIMPLEX

Evolution Strategies
- 1P1-ES
- DES
- MMES

Sequential Quadratic Programming
- NLPQLP
- NBI-NLPQLP

AMS-RSM -Flow-

AMS-RSM Flow



Find local minima

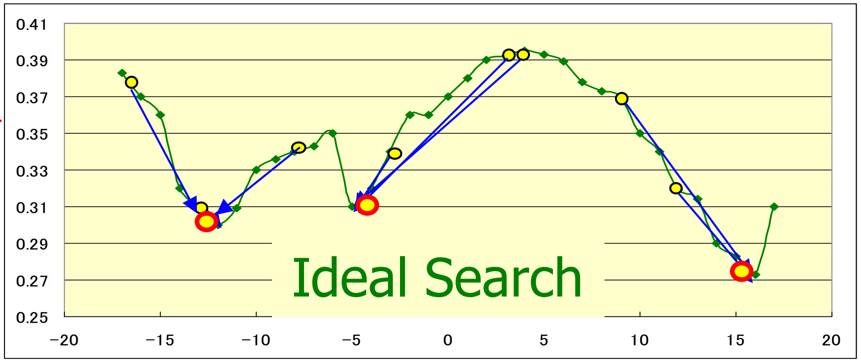
The 2nd sampling around the local minima

Build the 2nd RSM

AMS-RSM -Search of local minima-

Point 1 : Search of local minima by Simulated Annealing (SA)

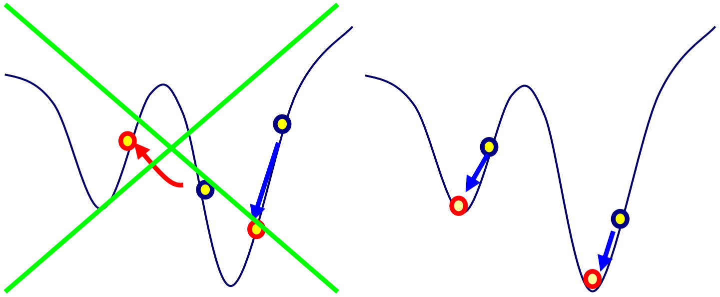
all searches reach the nearest local minima



Two algorithm setting

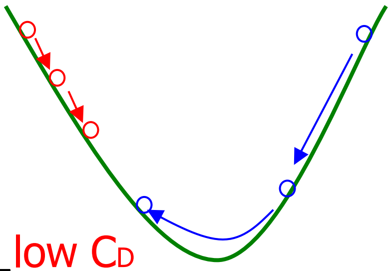
1. Fraction of random search

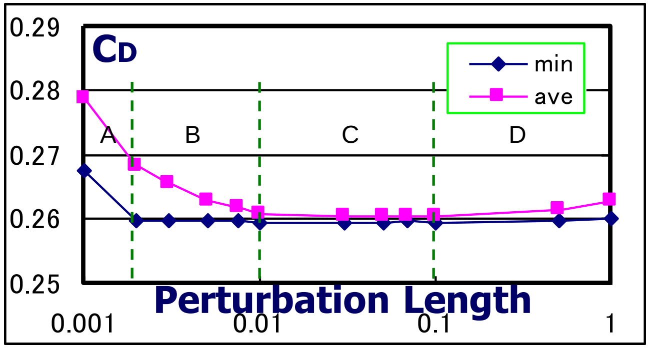
Control escape from local minima

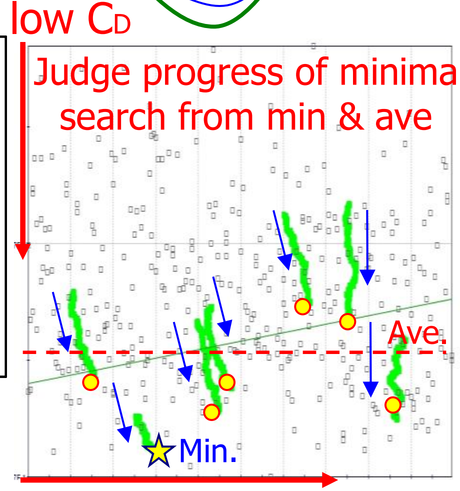


2. Perturbation length setting

- small length → incomplete search
- large length → jump over local minima



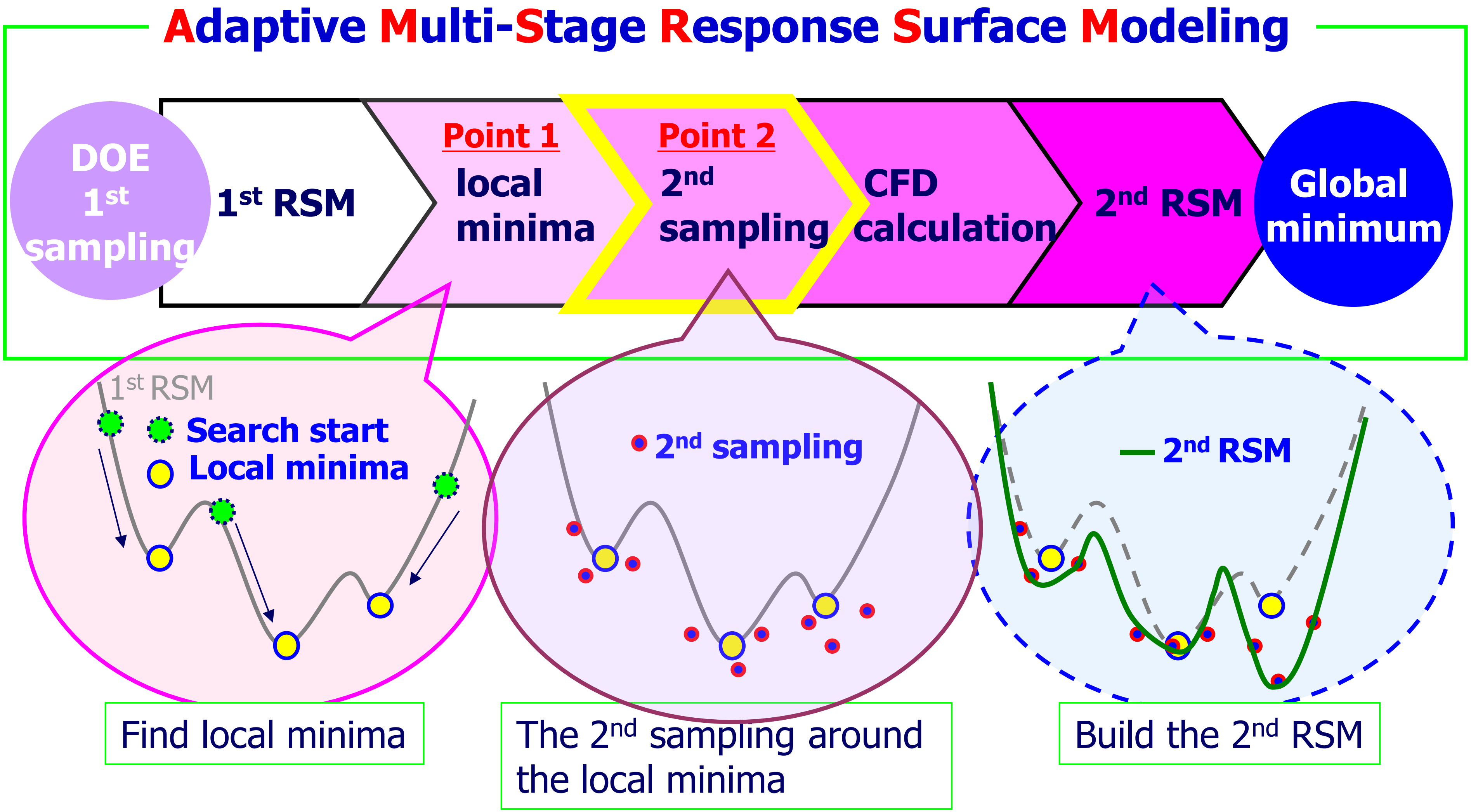




Appropriate Perturbation Length

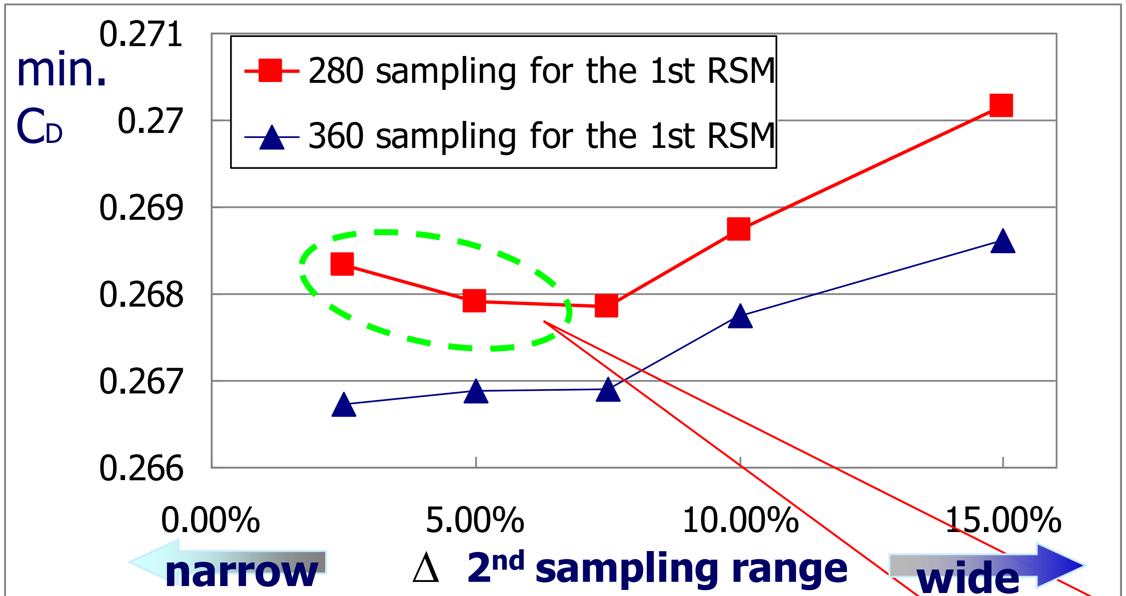
AMS-RSM -Flow-

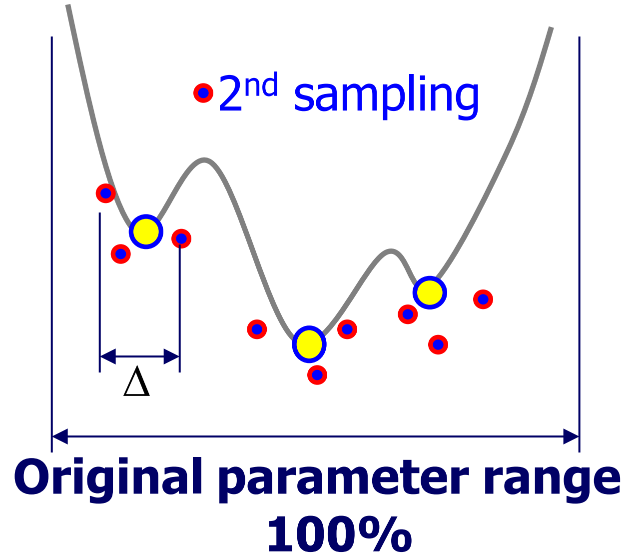
AMS-RSM Flow



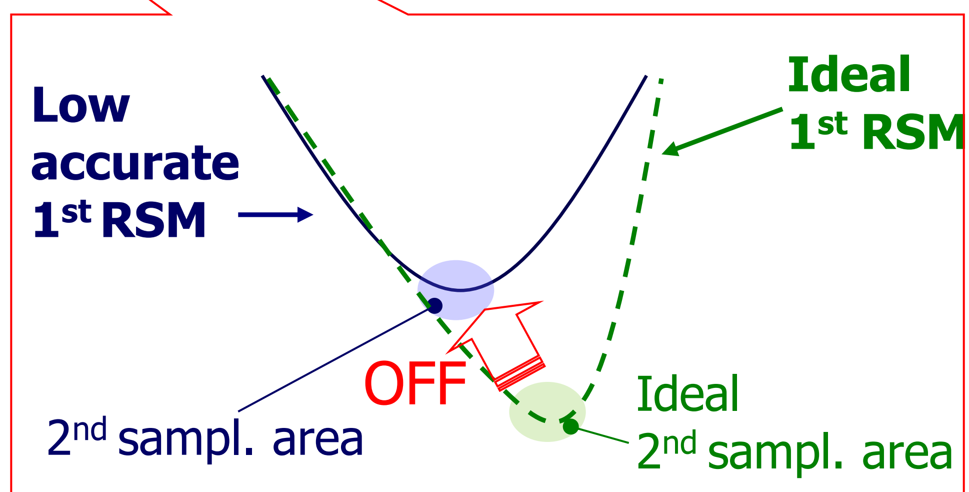
AMS-RSM -The 2nd sampling-

Point 2 : 2nd sampling range





Approx. 7% is appropriate
(7% in our system)



AMS-RSM -Robustness-

Robustness test for sampling pattern

LHC is a quasi-random sampling which may result in different RS.

How to make sampling-B

Original Sampling

ID	A	B	C	......	C_D
1	-89	4	6	......	0.299
2	-78	5	12	......	0.310
.	.	.	.		.
116	-90	6.	7	......	0.289
.	.	.			.
240	-39	8	44	......	0.306

Sampling points with lower 3% C_D

Replace

Sampling points with ordinary C_D

241	-58	2	3	......	0.304

Create response surface by the same algorithm

Search an optimal point by the same optimization algorithm

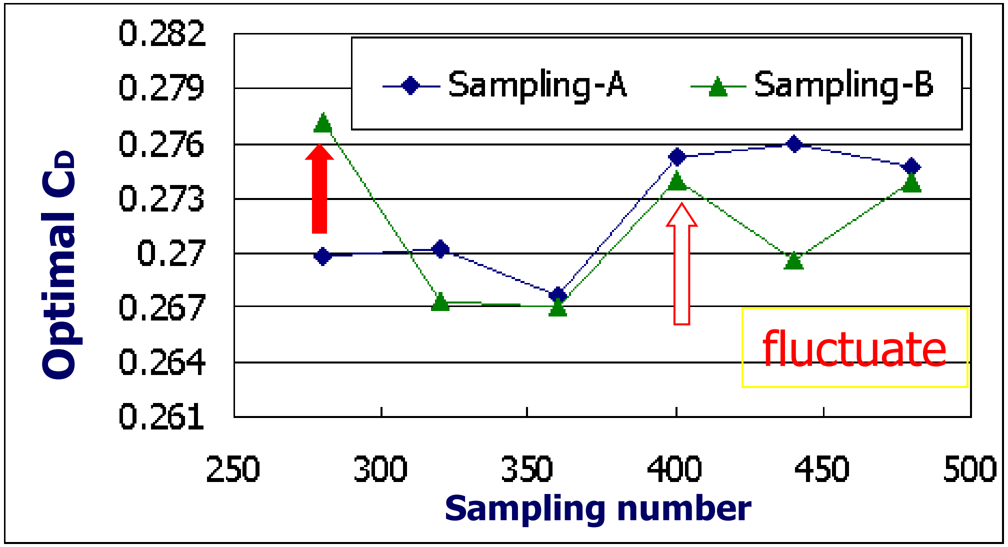
AMS-RSM -Robustness-

Robustness Test Result

Dependence of sampling numbers & patterns on optimal C_D

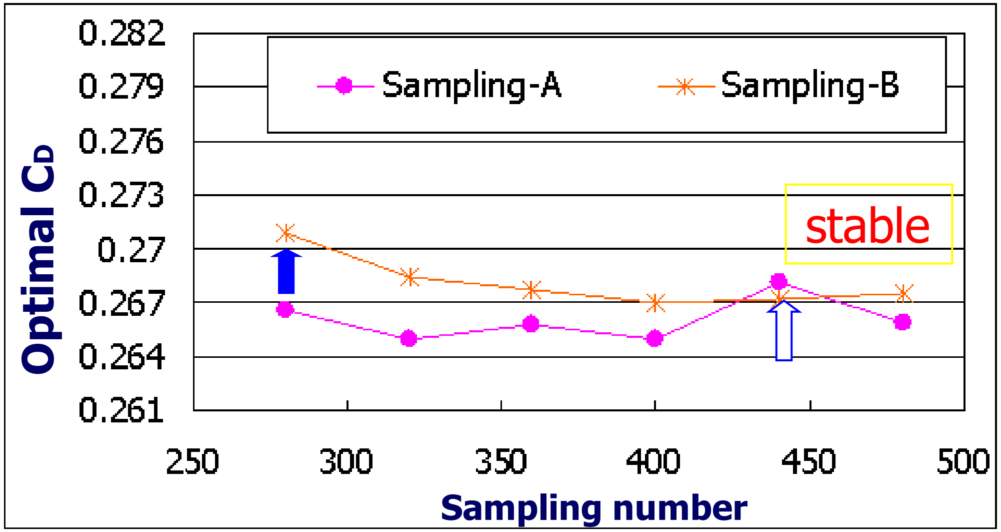
Conventional RSM

- large variation by sampling pattern change
- large variation by sampling number change



AMS-RSM

- small variation by sampling pattern change
- small variation by sampling number change

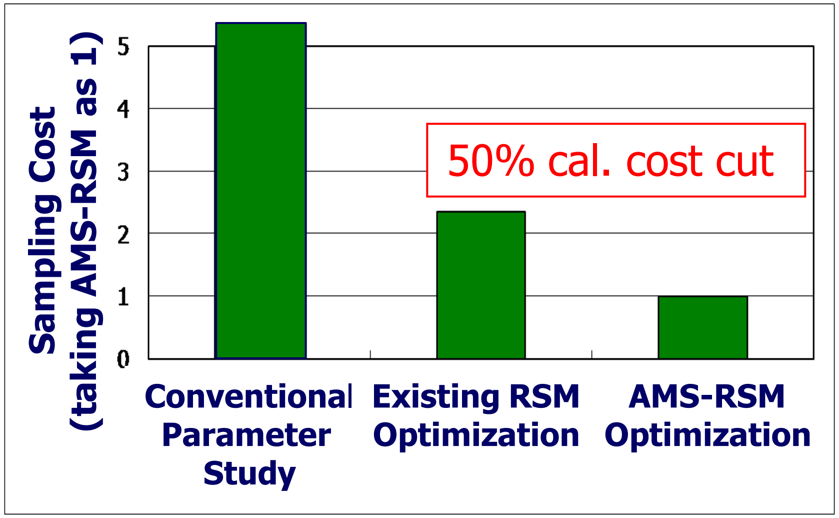


AMS-RSM -Performance-

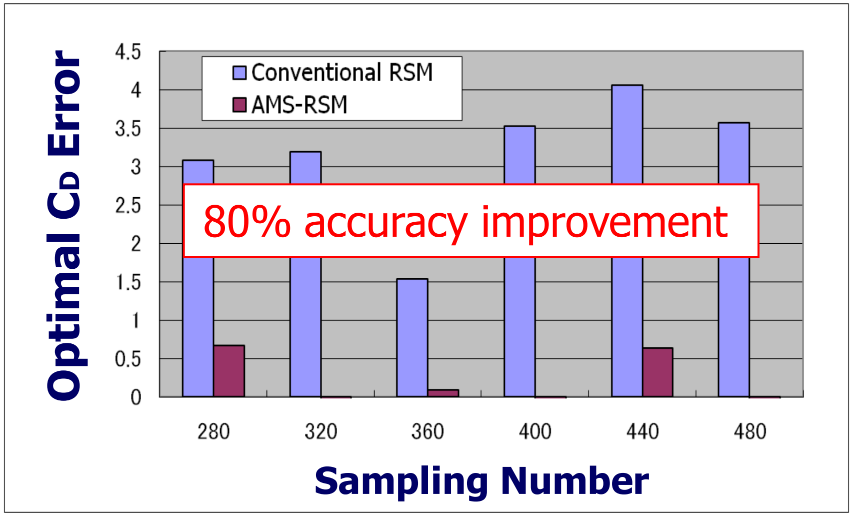
Performance & Accuracy

Relative to conventional method, …

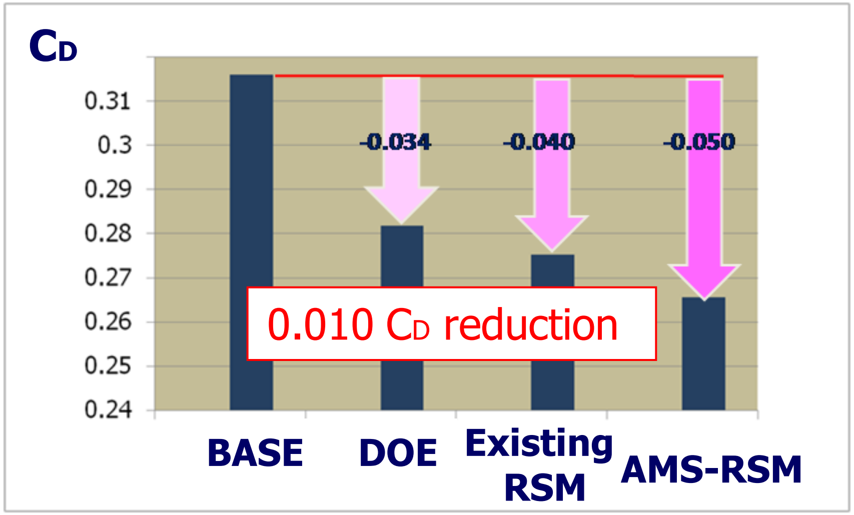
- Calculation cost cut
- Optimization performance improvement
- Accuracy improvement



Sampling cost (normalized by AMS-RSM)



Accuracy of conventional RSM and AMS-RSM



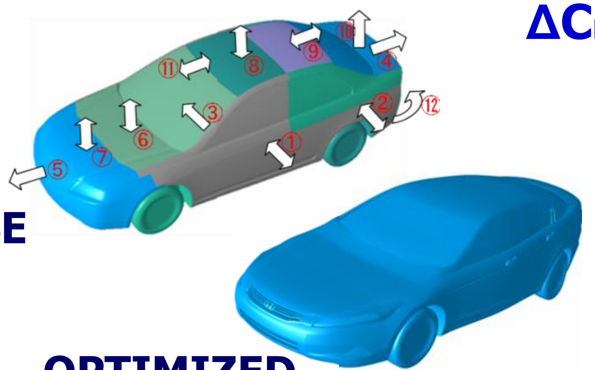
Optimum C_D (the same sampling number)

System Application & Outputs

12-parameter study

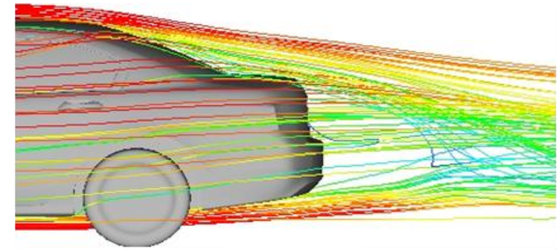
ΔC

ΔC_D**=-0.051**

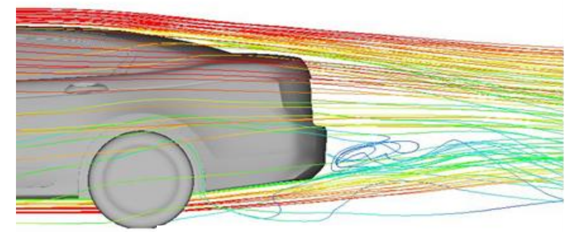


BASE

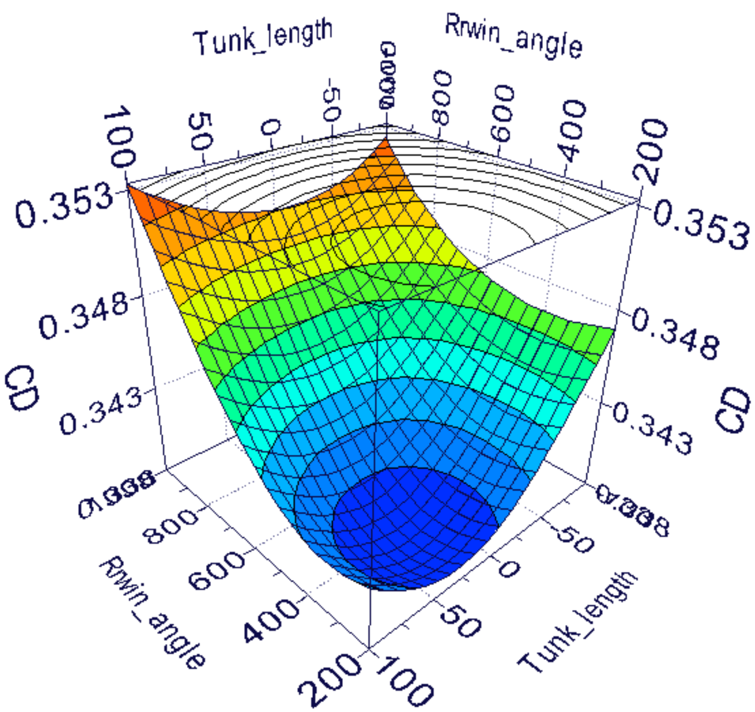
OPTIMIZED

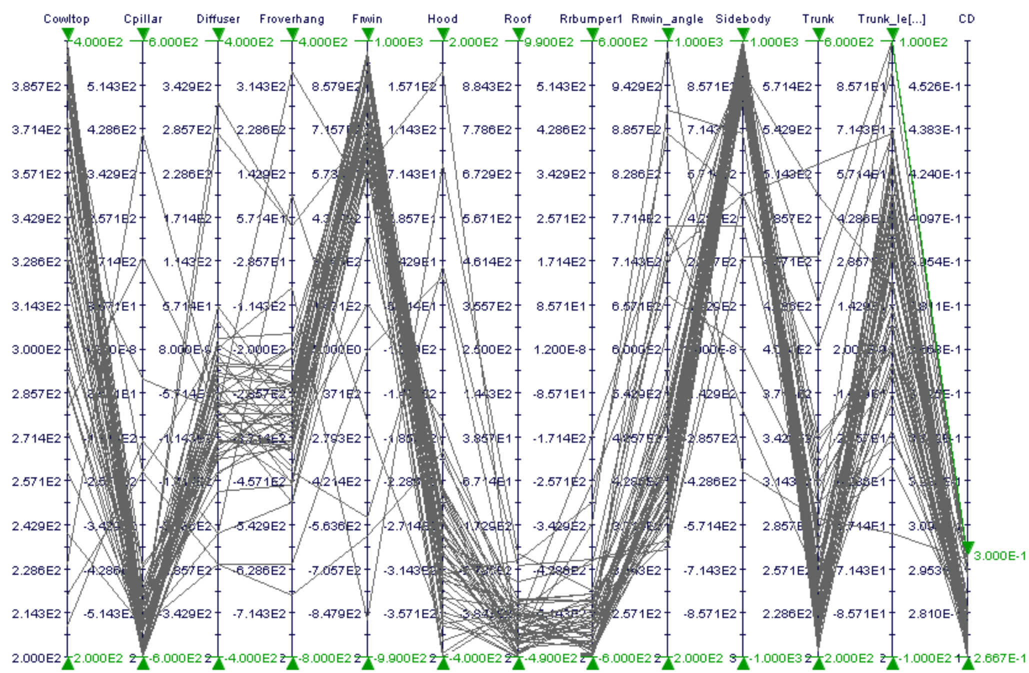


BASE



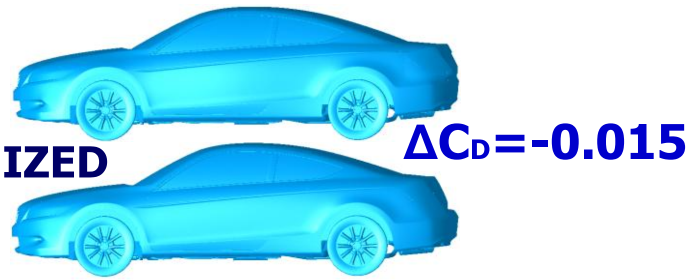
OPTIMIZED

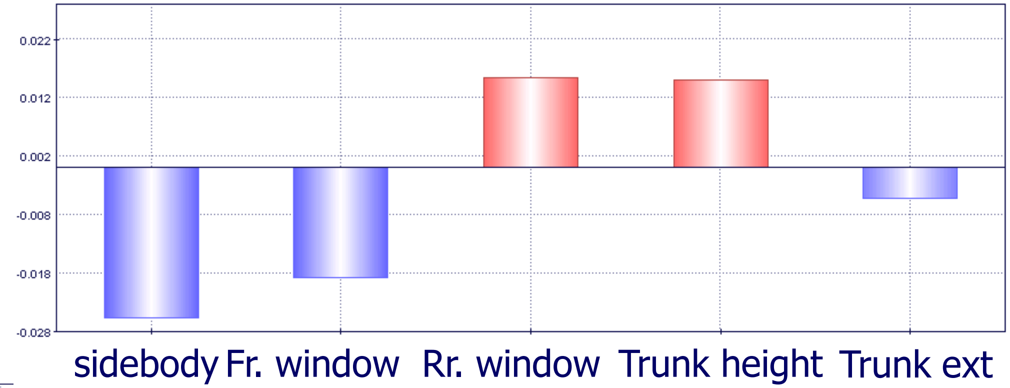


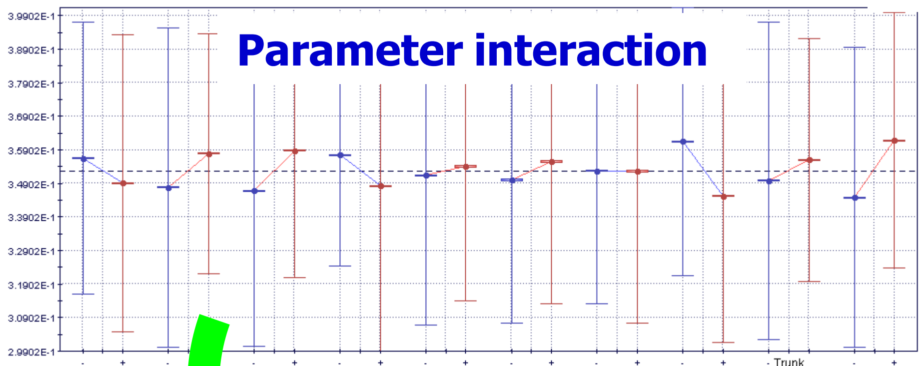


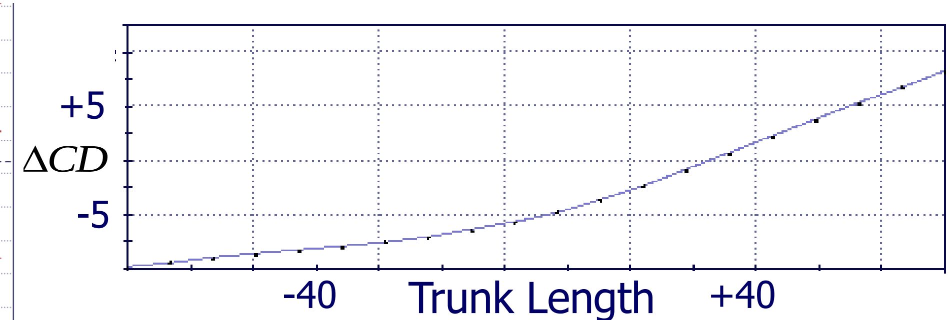
System Application & Outputs

5-parameter study









	Fr Window	Rr Window	Trunk Ext.	Trunk Height	Side body
Fr Window		●	●	●	●
Rr Window			●	●	●
Trunk Ext.	-	-		●	●
Trunk Height	-	-	-		●
Sidebody	-	-	-		

Various outputs give design guideline.

1. Introduction

2. Optimization by RSM

3. Technical Approach

4. **Conclusive & Future Remarks**

Conclusive & Future Remarks

Conclusion

1. Aerodynamic optimization system has been developed

2. The system can supply…

- better aerodynamic designs automatically
- design guidelines (not only the optimized shape) within 1.5-2 weeks
- usability for practical aerodynamic design development

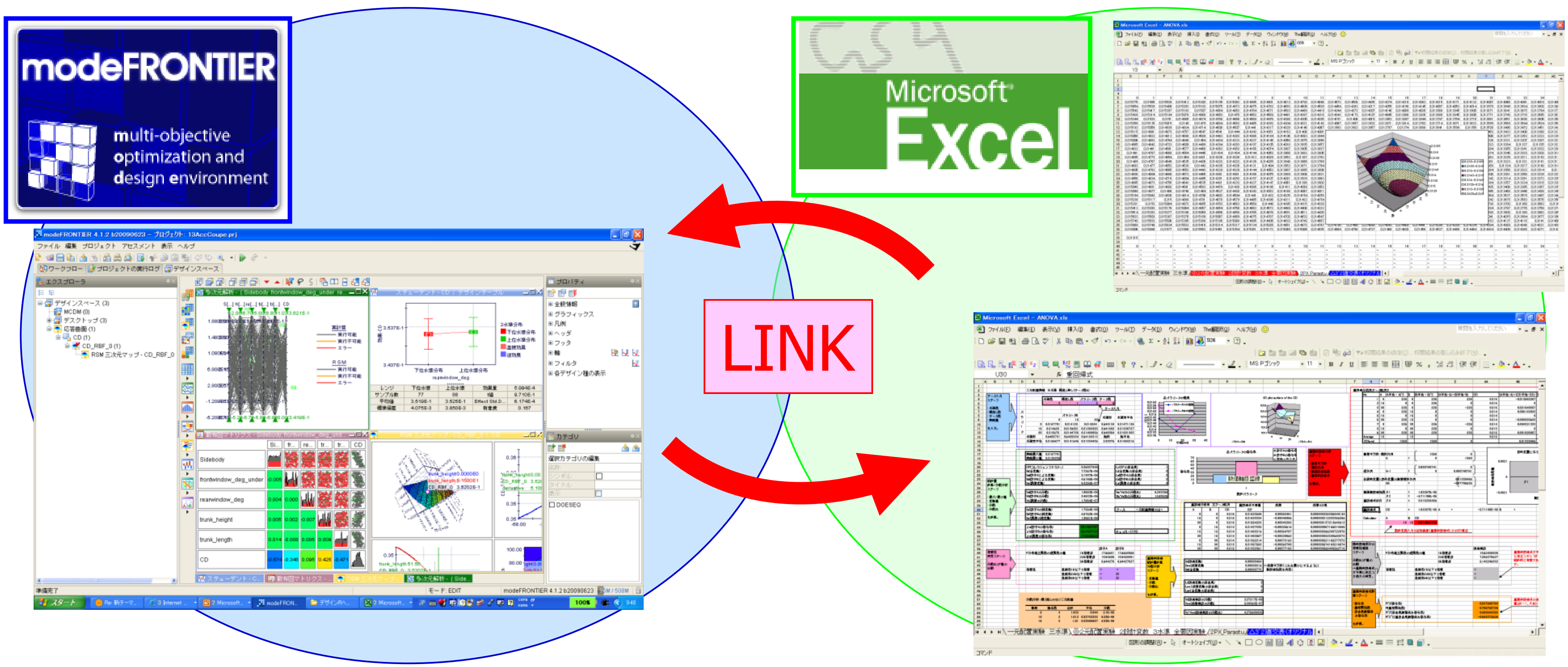
3. AMS-RSM can achieve…

- lower CD
- accurate response surface
- low CFD calculation cost
- robustness for sampling numbers & patterns

Conclusive & Future Remarks

Future

1. **Realization of 1-week optimization**
2. **Improvement in system toughness**
3. **Supply of more various output (link to Microsoft Excel e.t.c.)**



Thank you

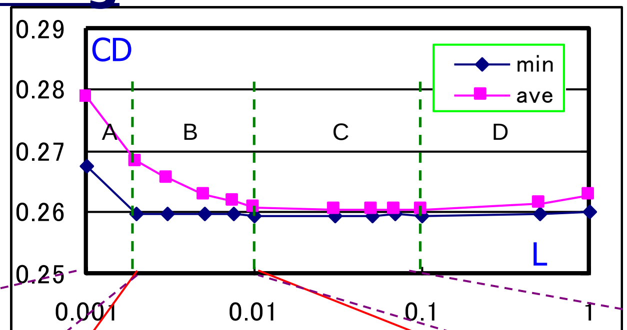
Thank you for your kind attention !

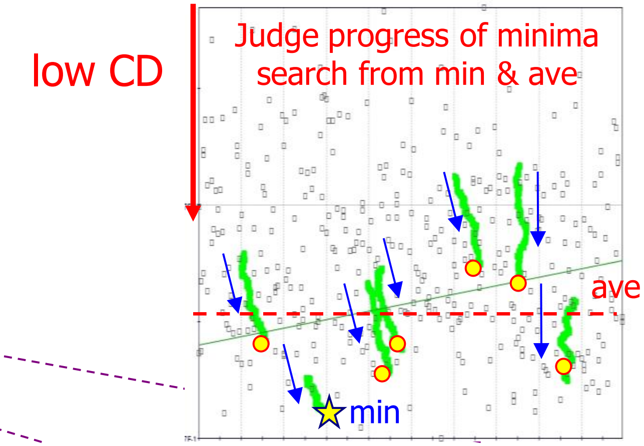
APPENDIX A

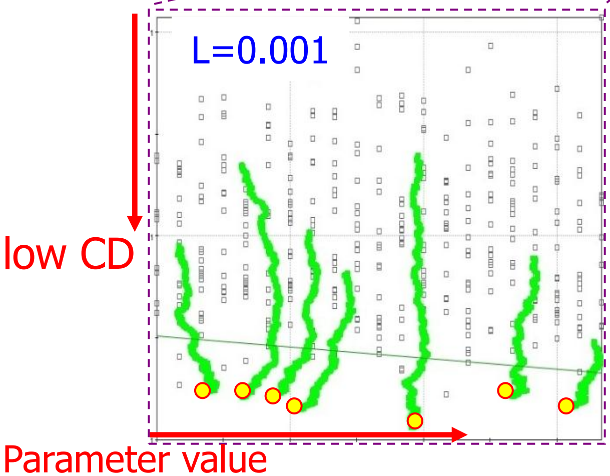
Perturbation Length setting

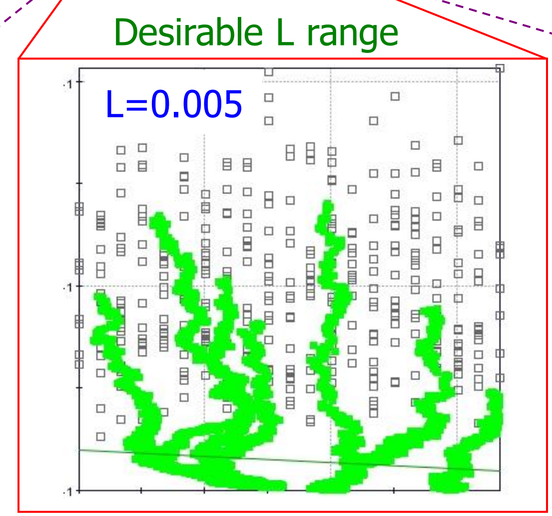
For each Perturbation Length

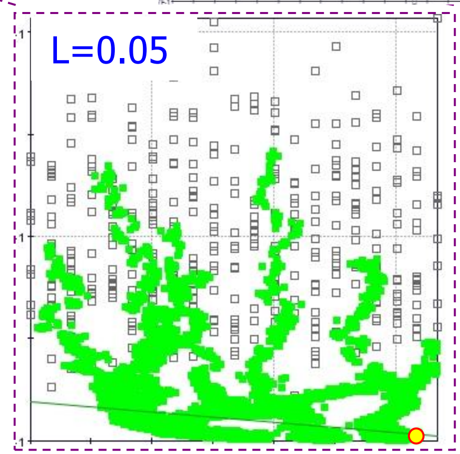
Take average & minimum CD
at the end of minima searches











$$\frac{d(\min CD)}{dL} < 0$$

$$\frac{d(\min CD)}{dL} = 0$$

$$\min(CD) \neq ave(CD)$$

$$\min(CD) \approx ave(CD)$$

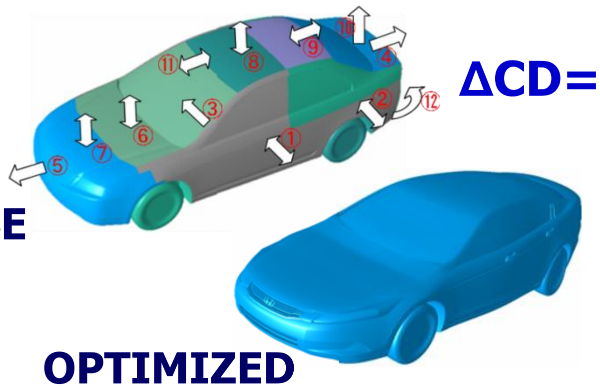
No search reaches
a global minimum

At least one search reaches
a global minimum.
Others reach local minima.

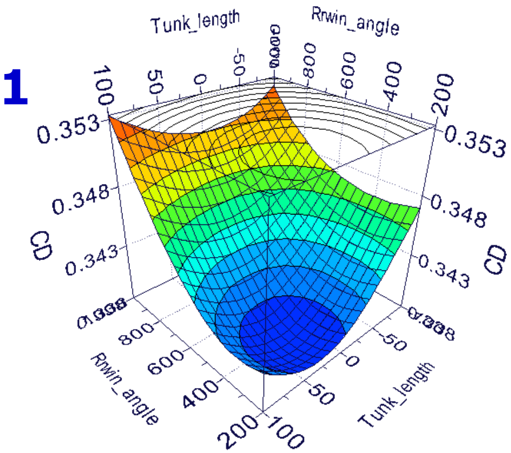
All searches jump over local
minima and fall into a global
minimum.

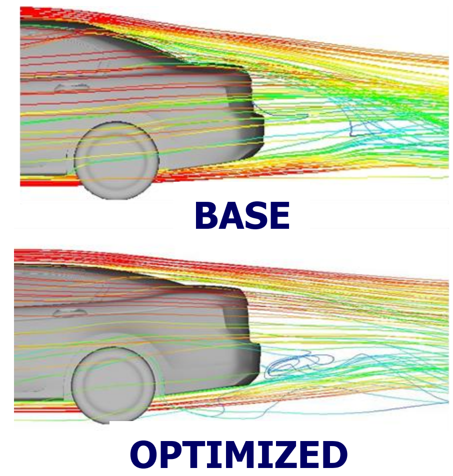
APPENDIX B

12-parameter study

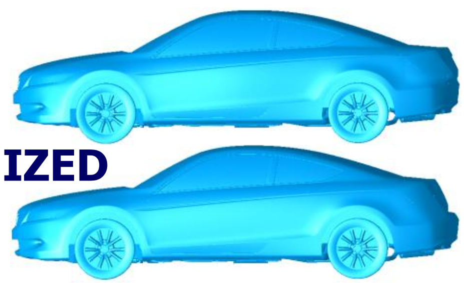


ΔCD=-0.051

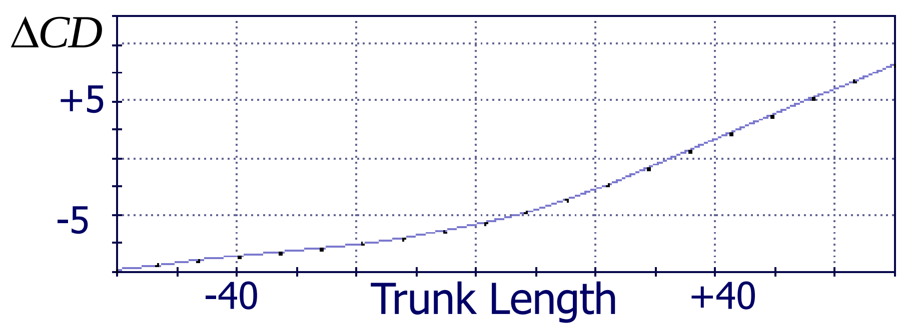


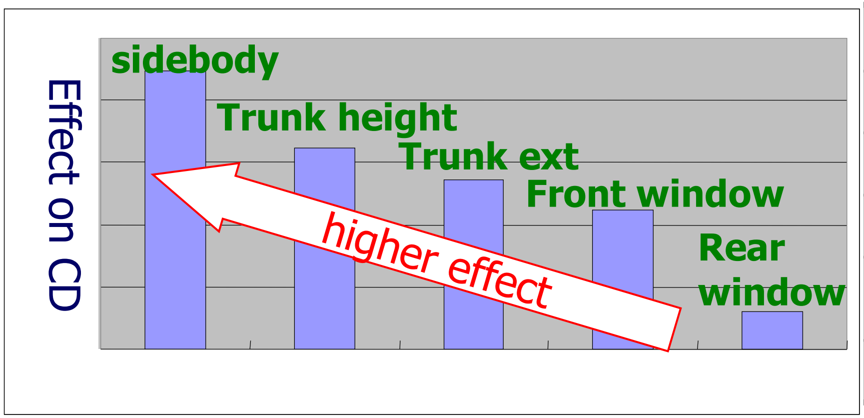


5-parameter study



ΔCD=-0.015





	Fr Window	Rr Window	Trunk Ext.	Trunk Height	Sidebody
Fr Window		●	●	●	●
Rr Window	-		●	●	●
Trunk Ext.	-	-		●	●
Trunk Height			-		●
Sidebody	-	-	-	-	

Parameter interaction