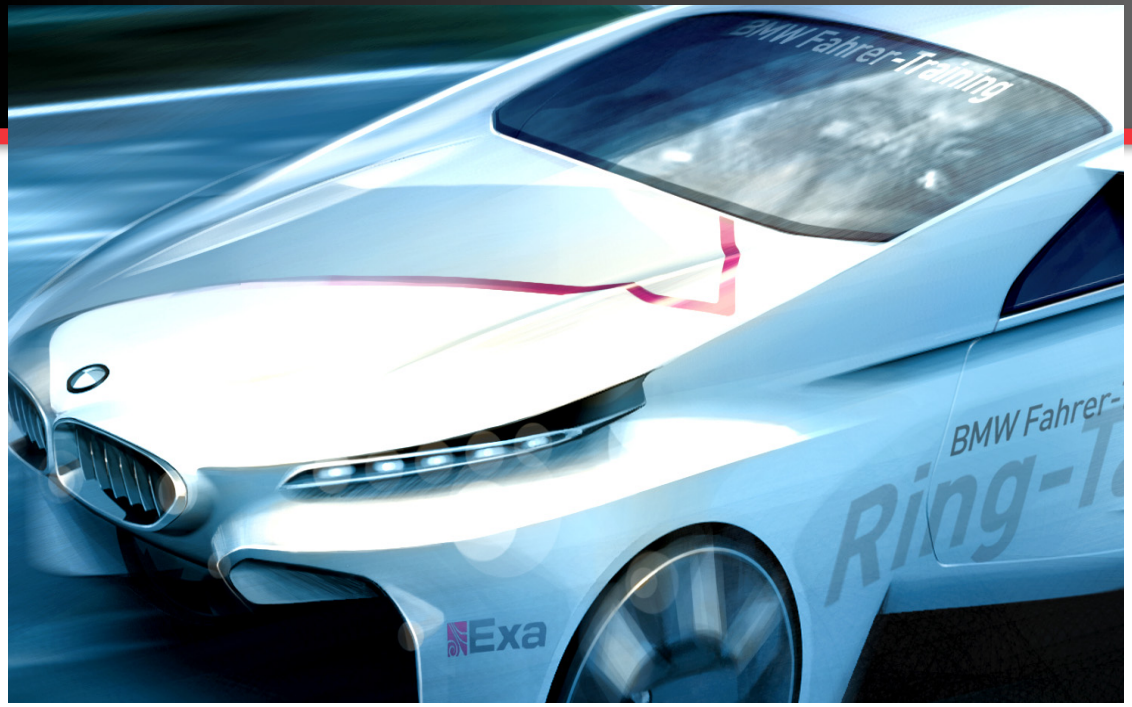


Automotive Design Space Exploration and Optimization

Dr. Andrea Shestopalov

Exa Corporation

Applied Modeling & Simulation (AMS) Seminar Series
NASA Ames Research Center, October 16, 2014

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Objectives

- Share some of our studio experience
  - *Explain the Designers point of view*
- Describe our freeform methods
  - *Think beyond analysis – consider how to design*
- Connect Design to Simulation Accuracy
  - *Theoretical skills are still needed*
- Speculate on what comes next

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Objectives

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  - *Theoretical skills are still needed*
- Speculate on what comes next

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Challenges
Design Standards are Increasing

- Regulatory Pressure (CO2, NOX, …)
  - *US greenhouse gas and emissions / CAFE standards*
    - Passenger Cars – 5% annual increase through 2025
    - Light Truck – 3.5% annual increase through 2025
    - Heavy Truck - 23% increase from 2014 to 2018
- Design Pressure
  - *Aggressive goals require multiple design parameters*
  - *Optimum solutions lead to conflicts between multiple objectives*
  - *It is harder to find gains each year as designs improve*
- Competitive Pressure
  - *Competitive OEM's are meeting these challenges*
    - Either with process change or additional resources

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Aerodynamic Potential



Toyota Prius

Cd = 0.26



Mercedes Bionic

Cd = 0.19



Audi A2

Cd = 0.25

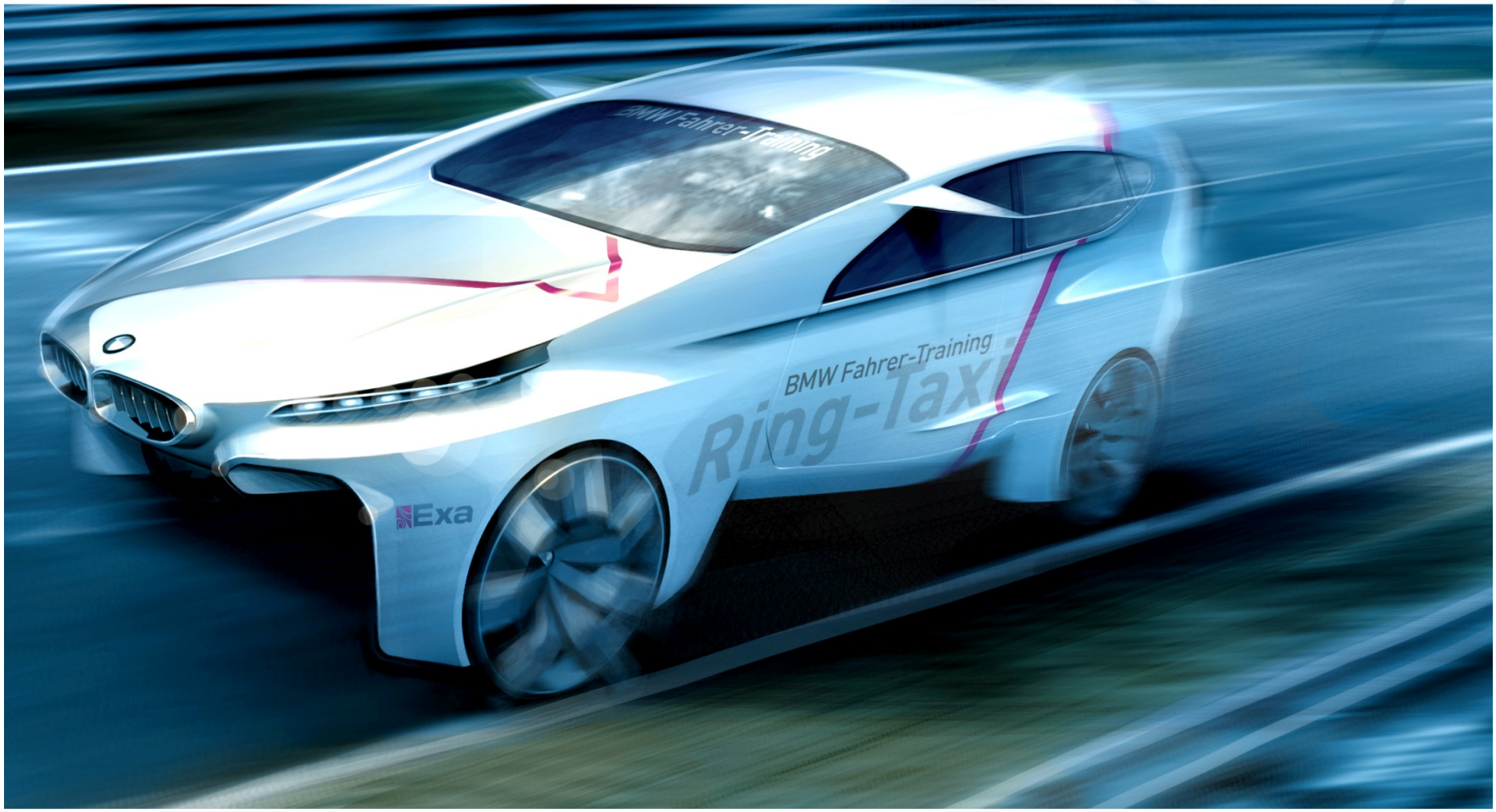


Aptera

Cd = 0.11

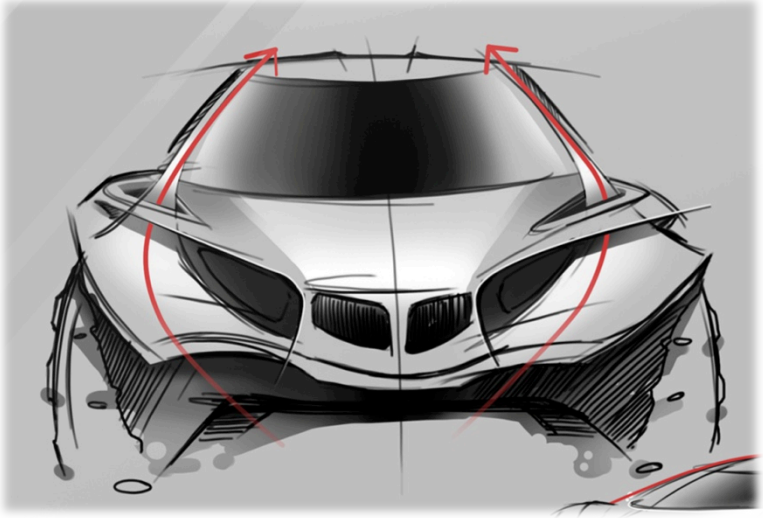
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Styling Potential



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Goals
Is Aero corrective or can it reshape the design language?



First – Respect the Character Lines





Second –

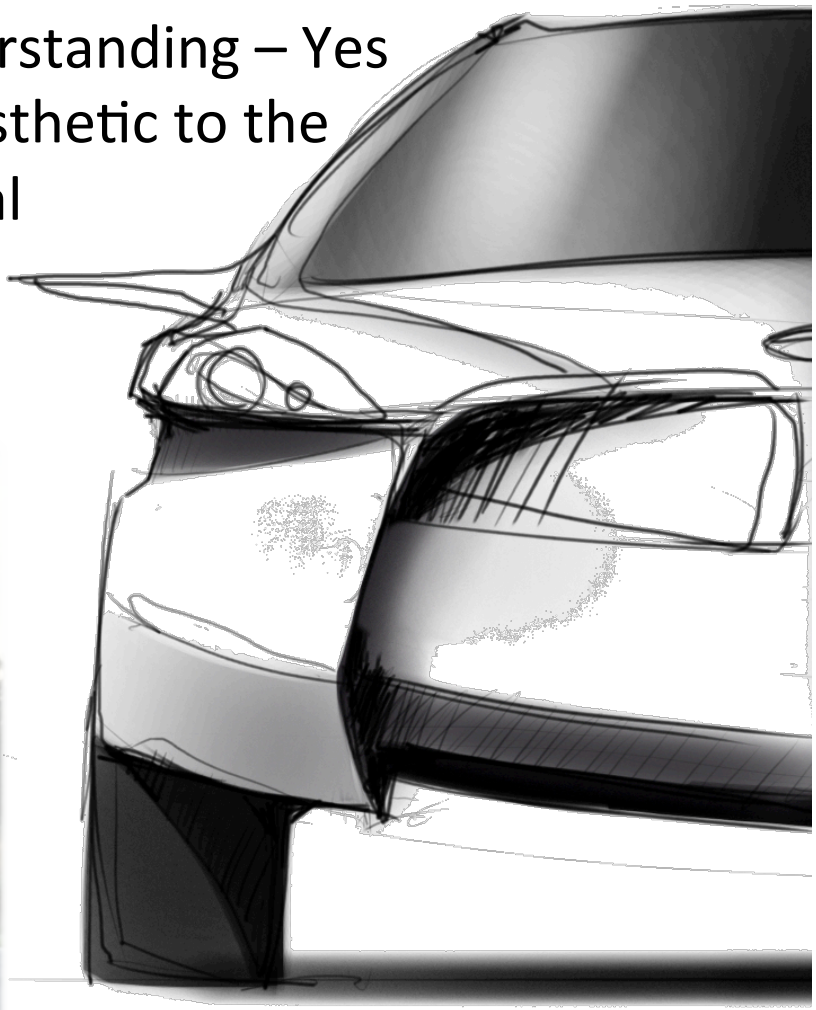
Teach and Let the Designer lead

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Goals
Can the Design Studio be a Partner in Innovation?



With a Common Understanding – Yes
Translating the aesthetic to the practical

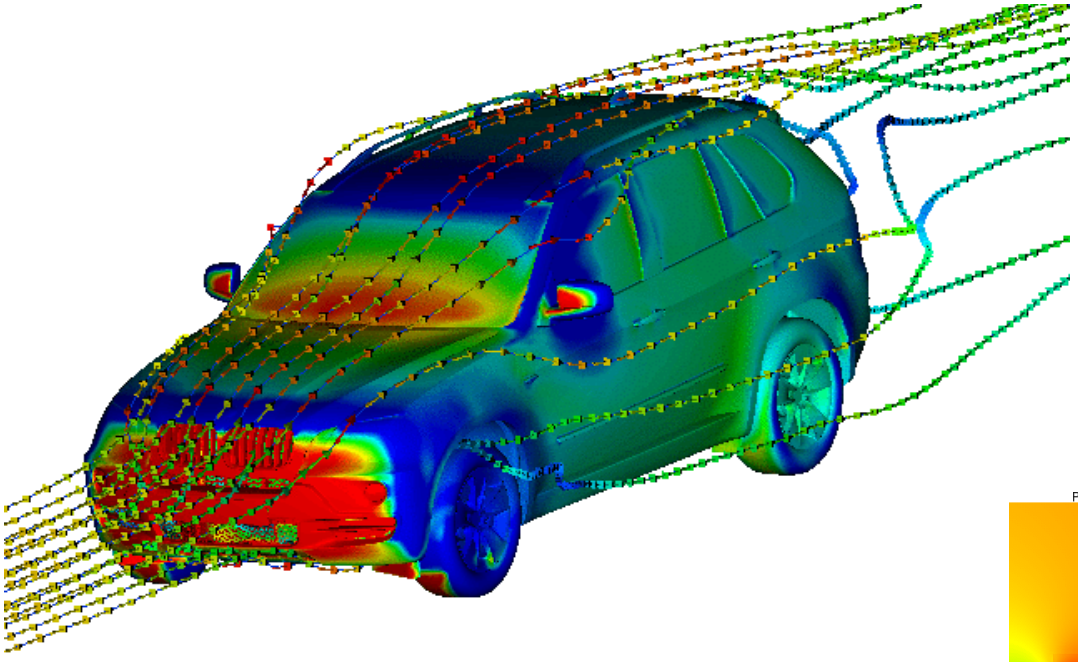




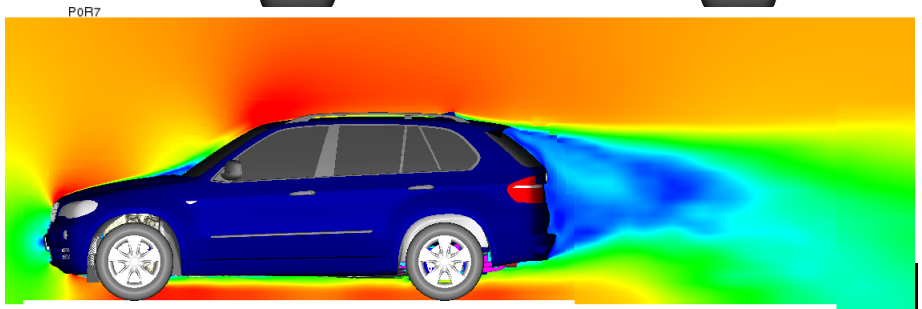
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X5 +20 Project
BMW and Art Center in Pasadena

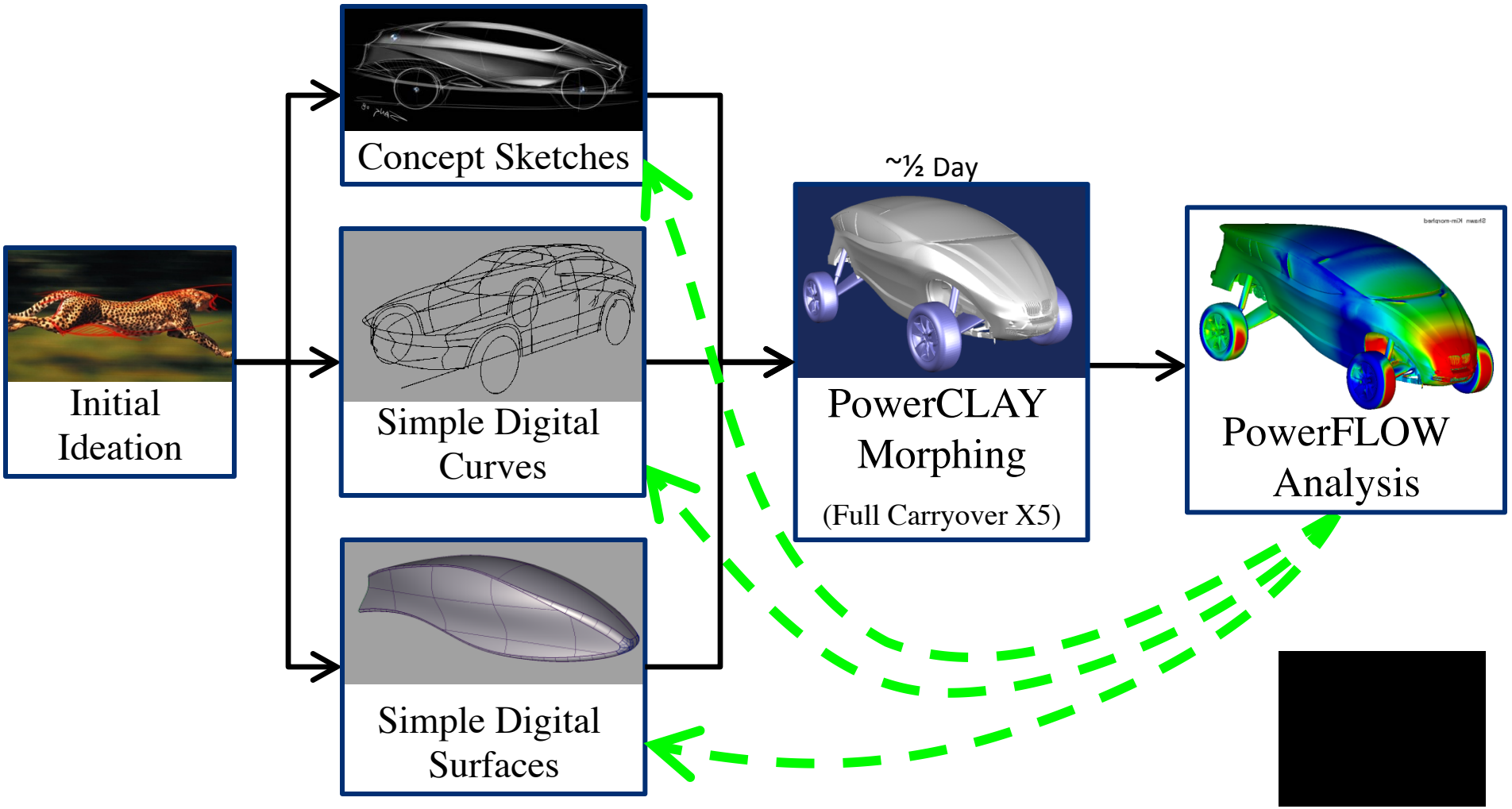
- Dynamic Design
  - *Define the BMW look in 2+ Generations*
  - *Achieve a 30%+ Reduction in Drag*
    - Respect Current Package / Cooling Constraints





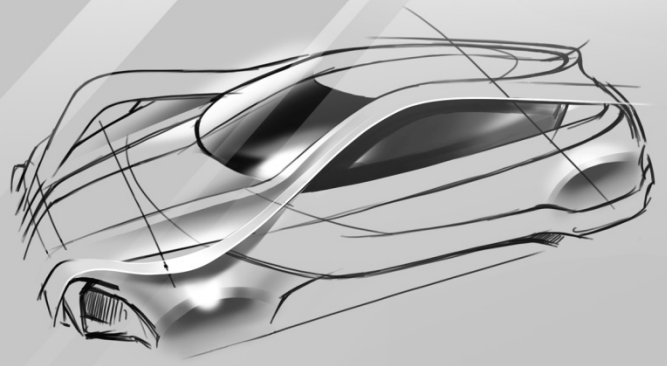


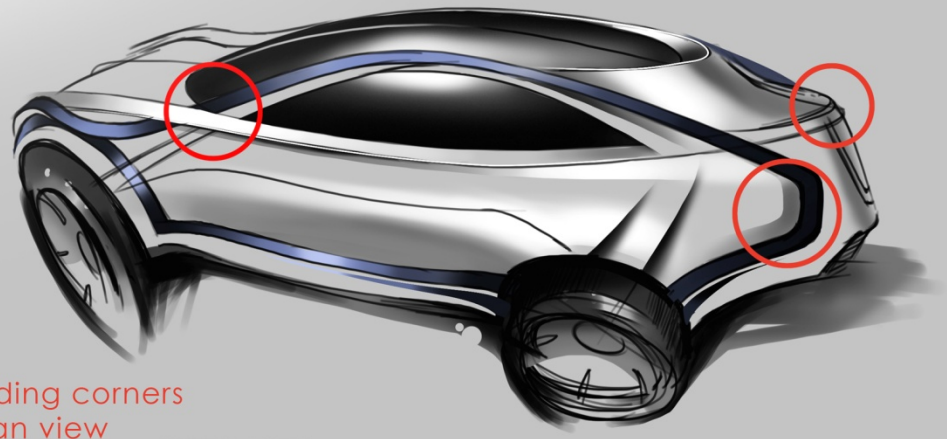
Rapid Design Process



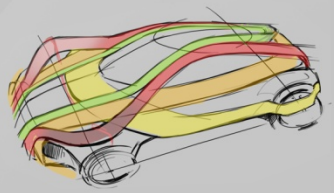
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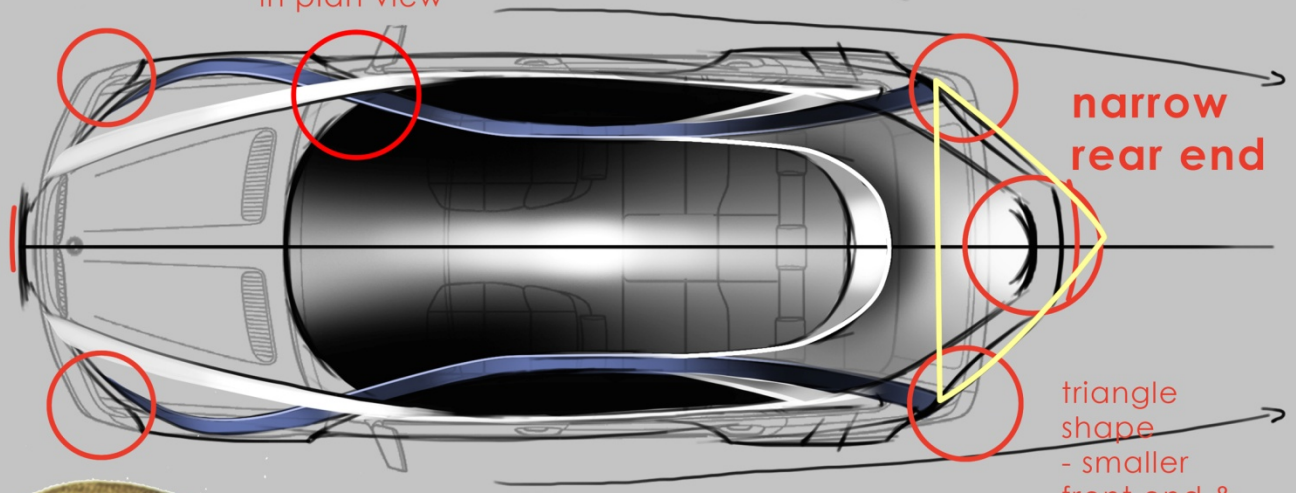
Direction 1





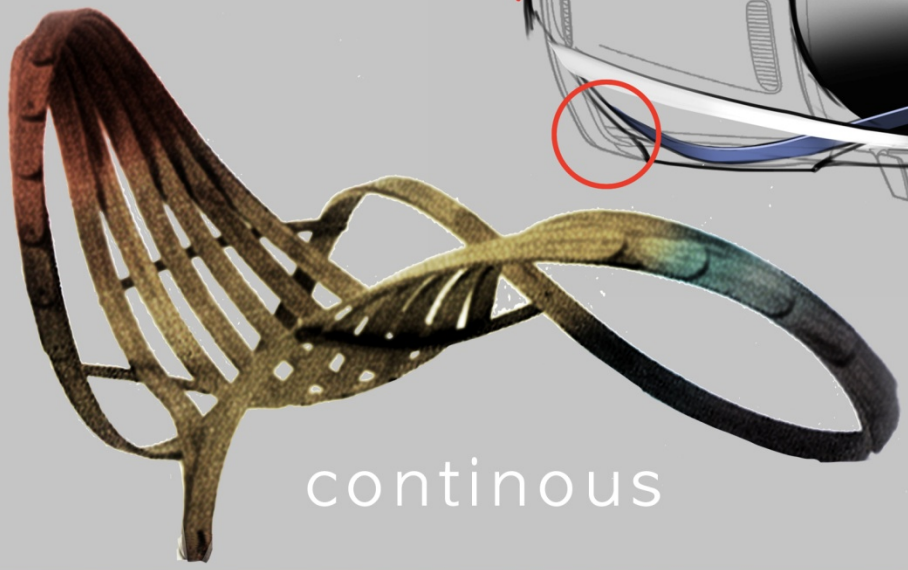
rounding corners
in plan view





narrow
rear end

triangle
shape
- smaller
front end &
rear end



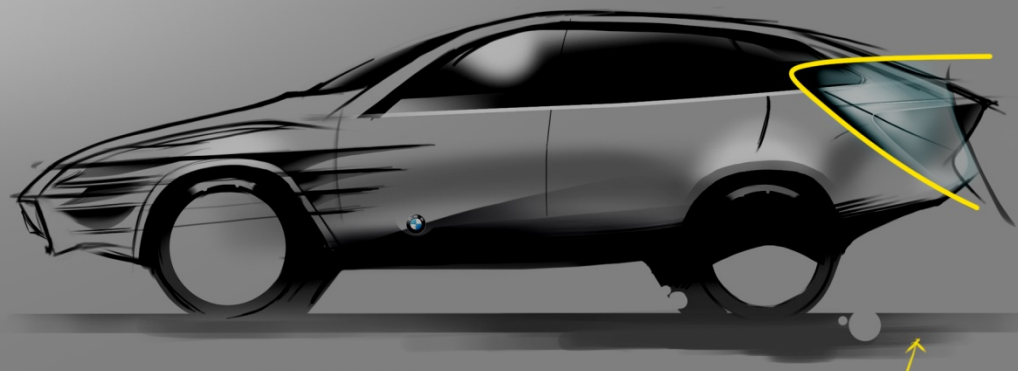
continous

A styling / aero DNA that can evolve later

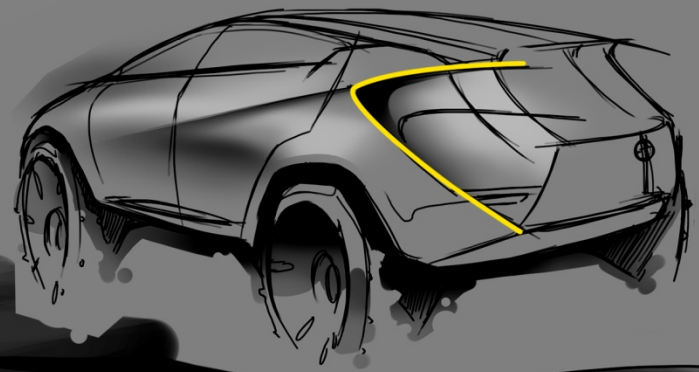
Exa
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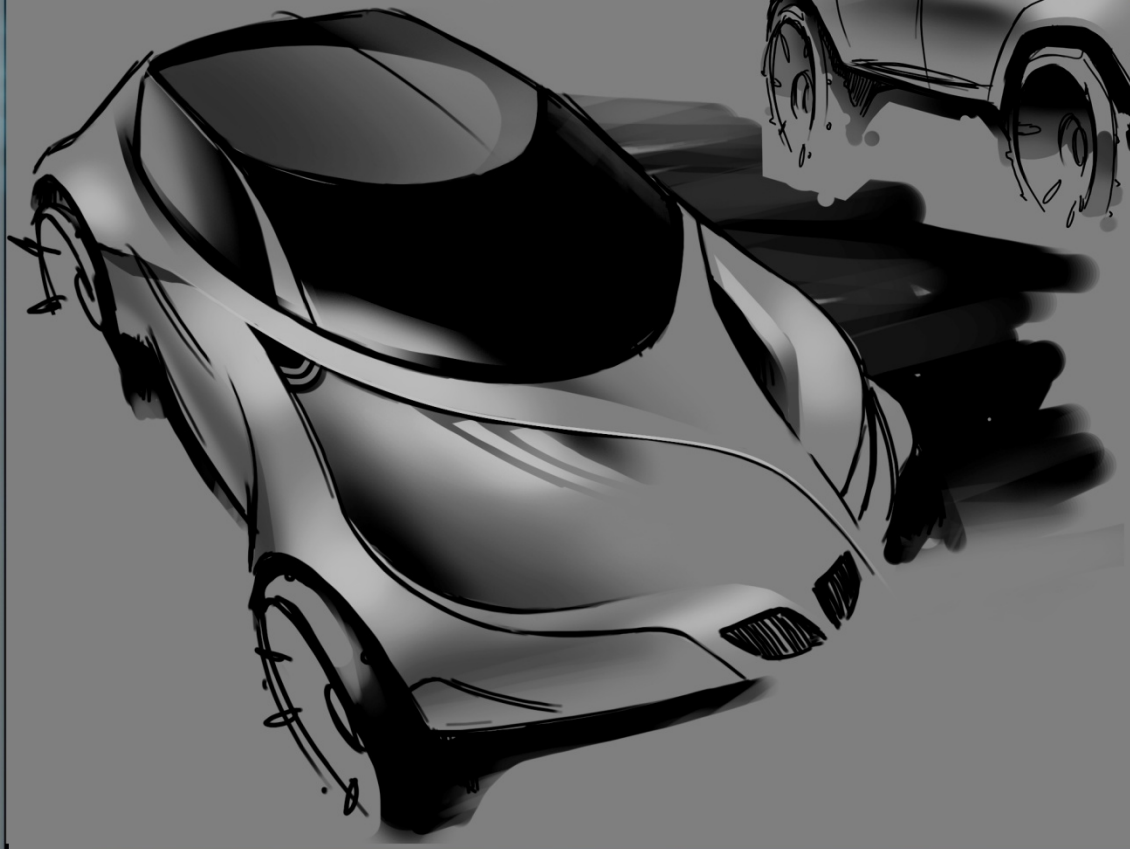
Direction 2

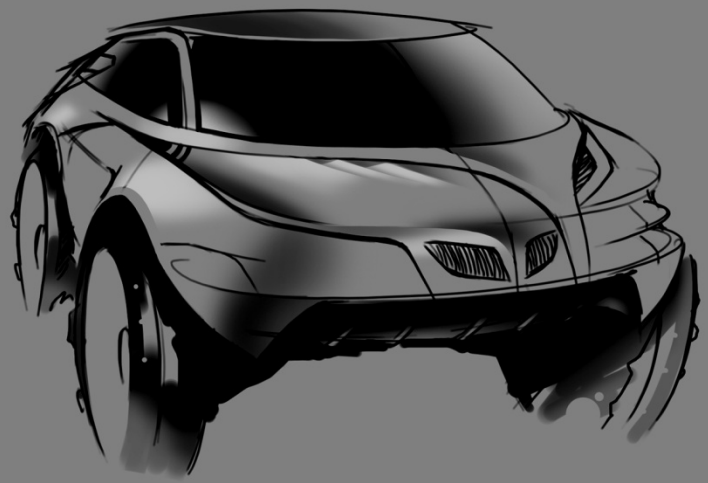




working?

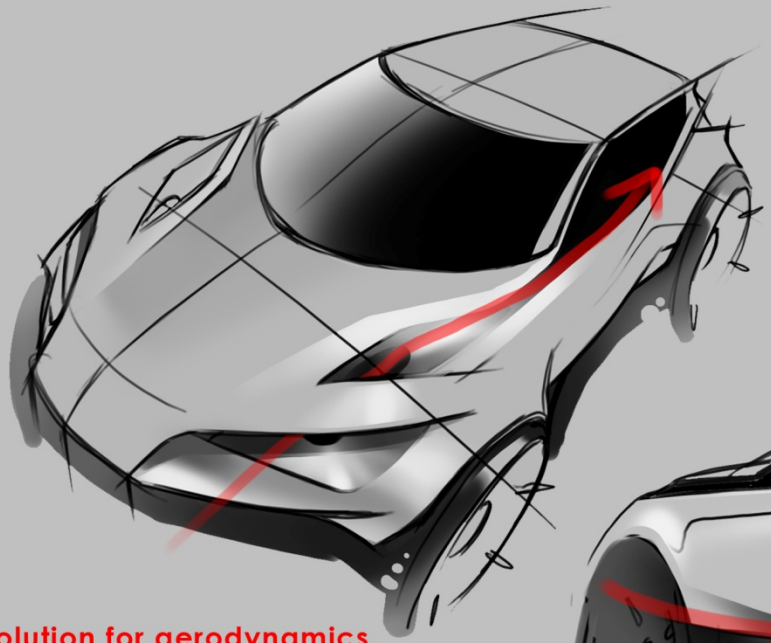


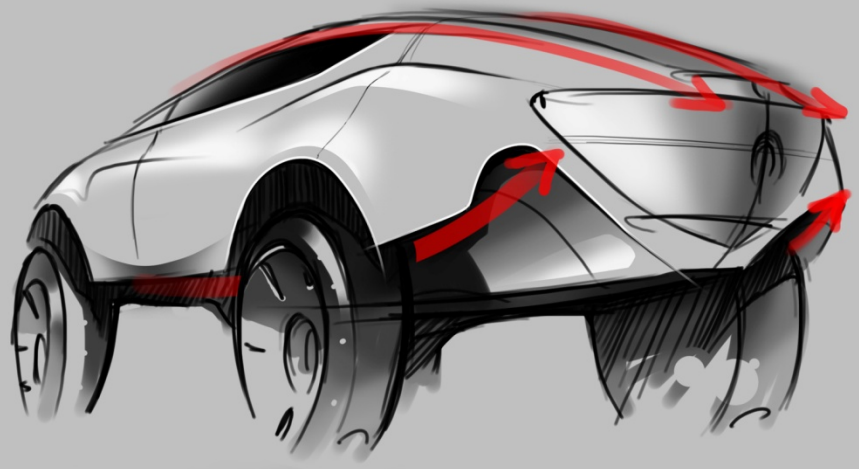


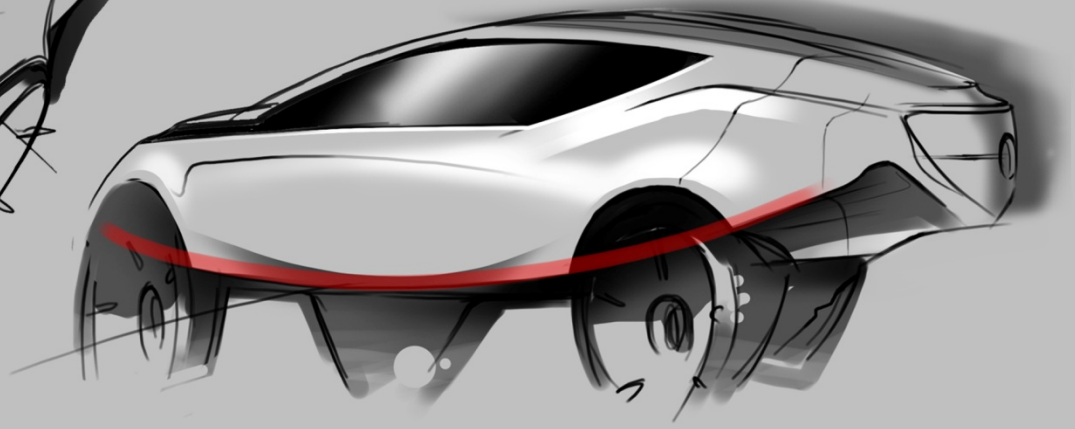


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Direction 3





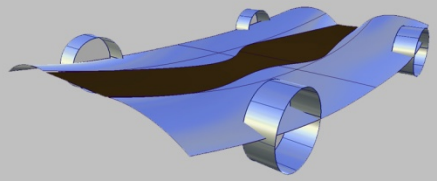


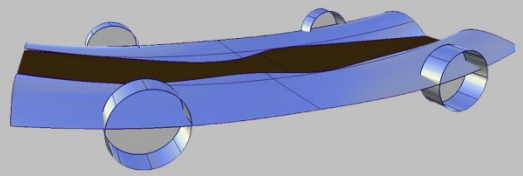
solution for aerodynamics

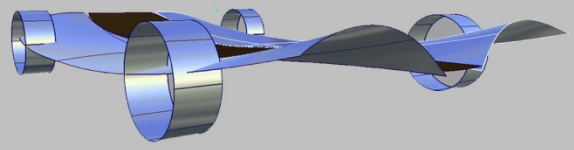


design theme
(carved stone by wind)



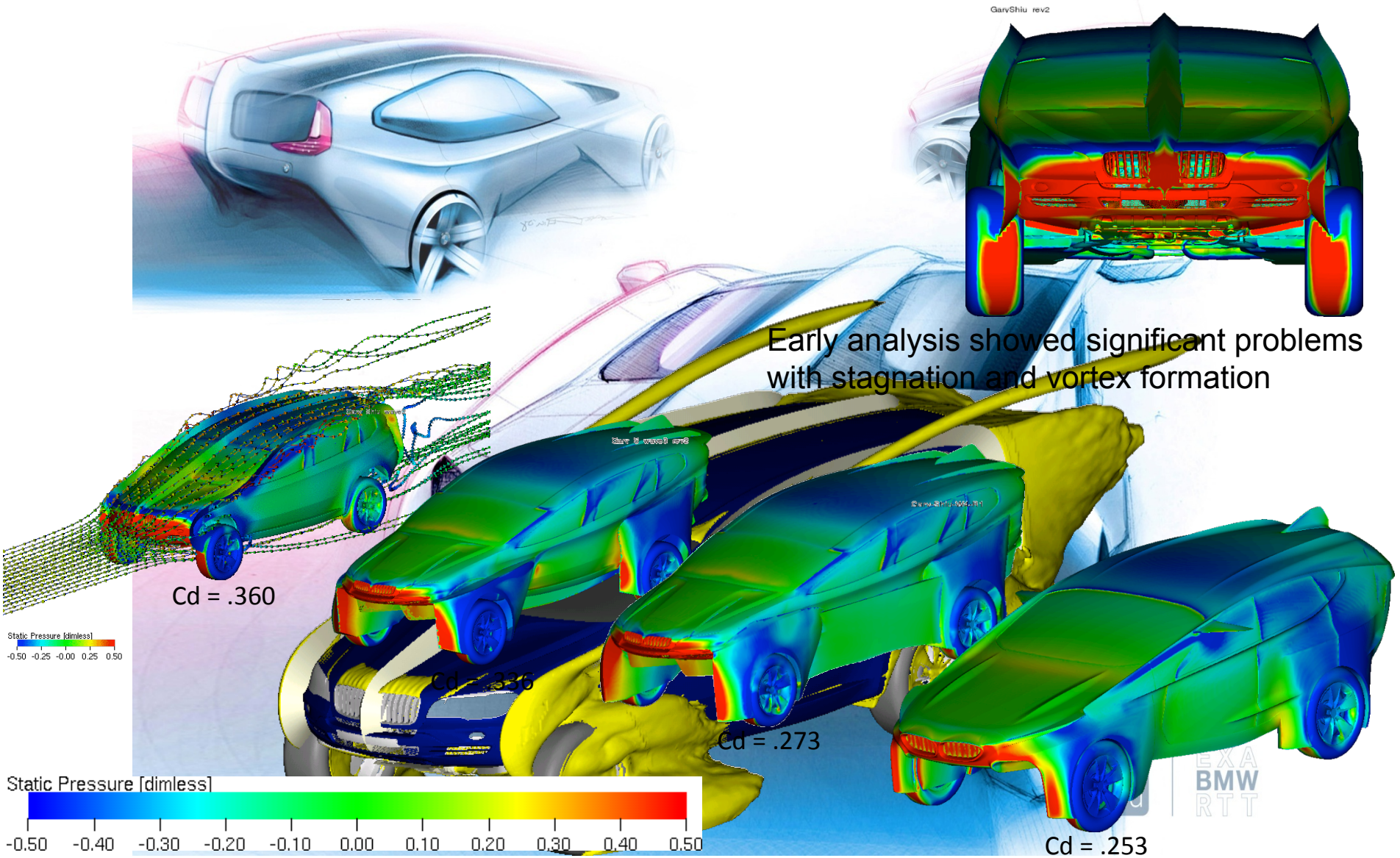






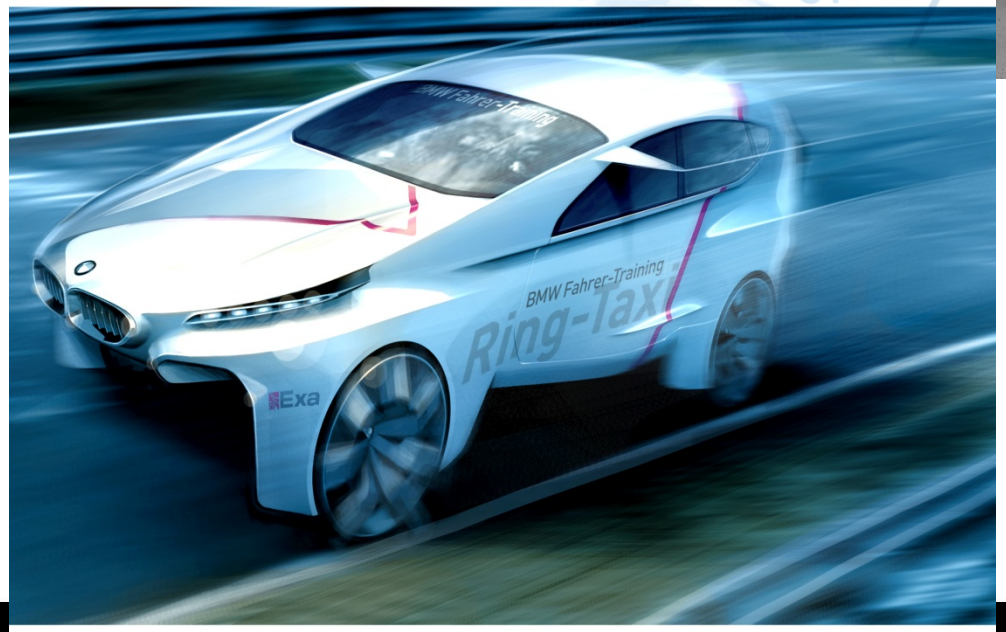
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Case Study
Gary Shiu



Fluid Pressure
Gary Shiu





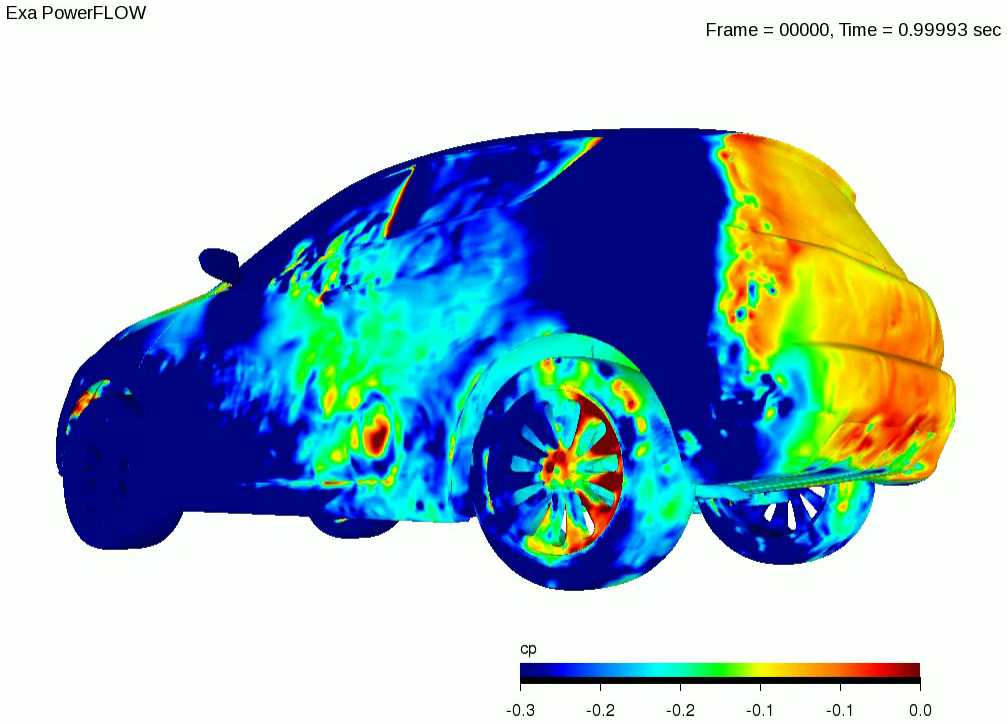
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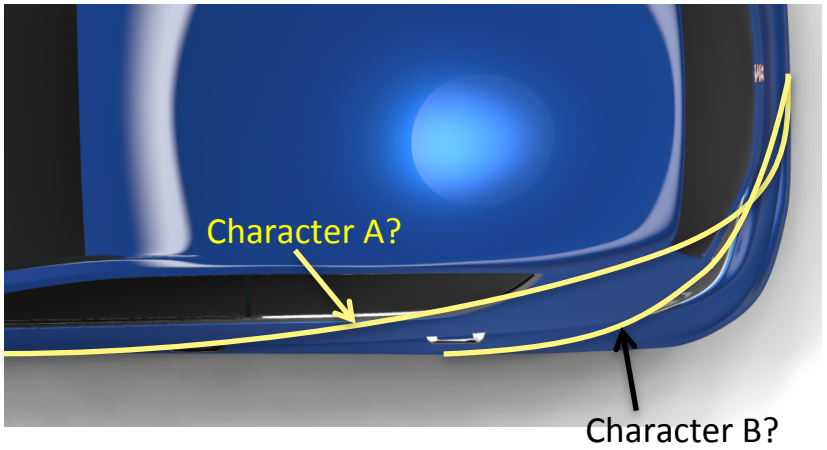
Key Roles for Aerodynamicist

- Exa's DSE process uses
  - *Unsteady flow accuracy*
  - *Design quality morphing*



Unsteady surface pressure

- Let's User Focus on Design Space
  - *User role*
    - Parameters that influence flow
  - *System role*
    - Quantify effective parameters
    - Find best combinations



Boat-tail parameter

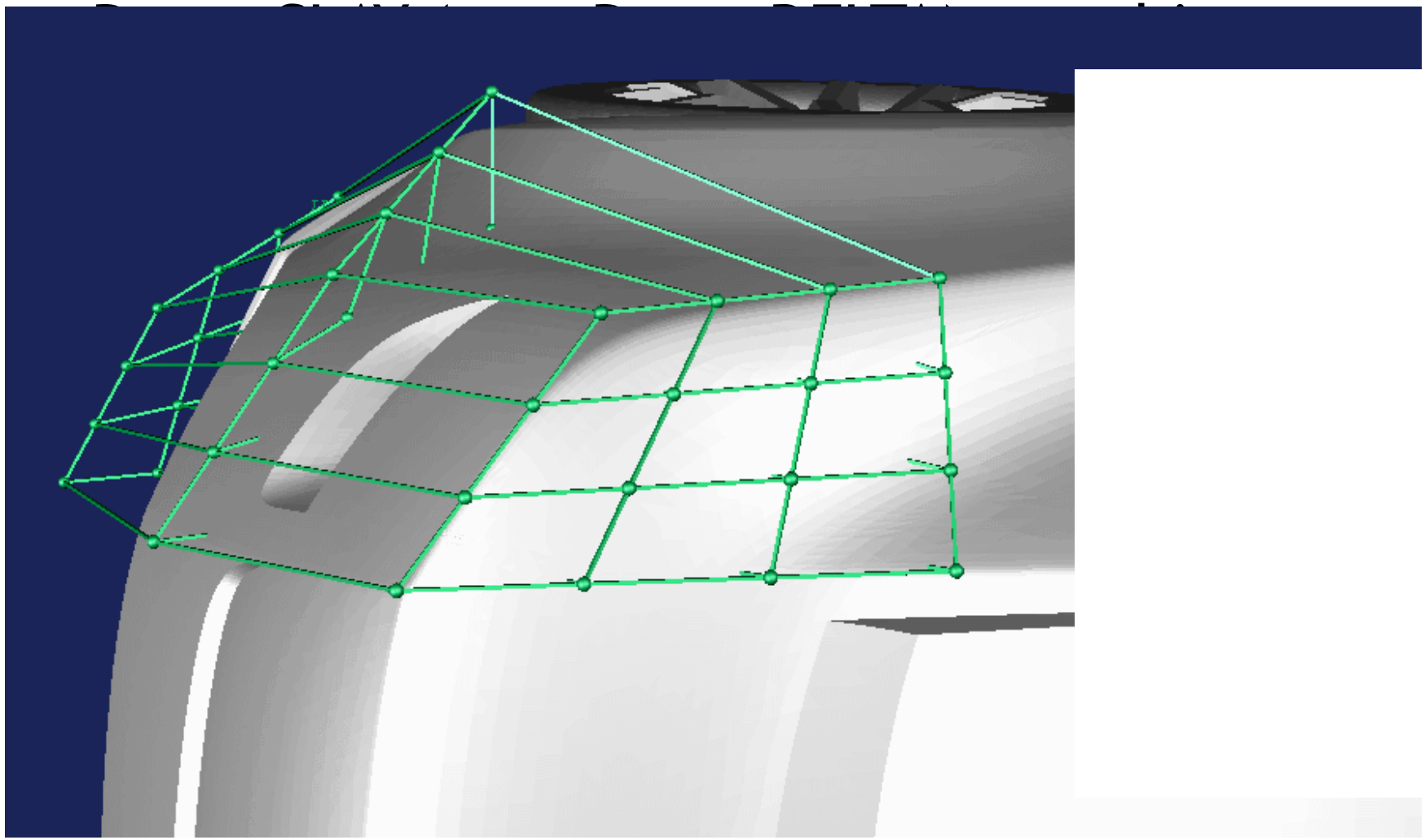
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Introduction
Just 5 Parameters → Unlimited Variations



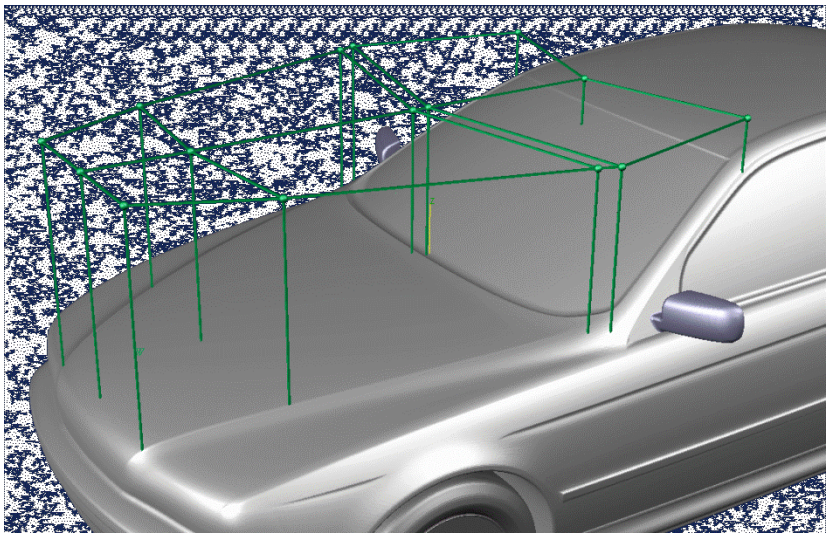
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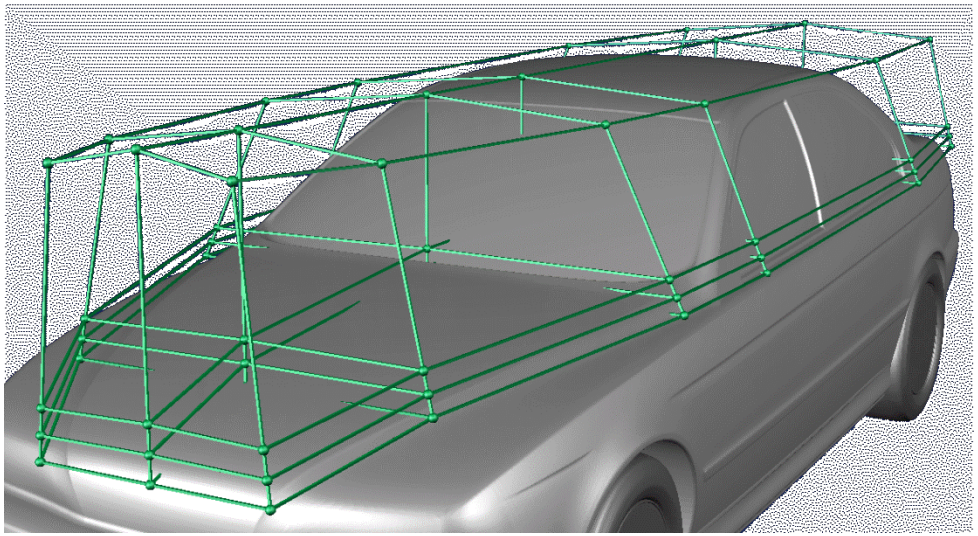
Parametric Features



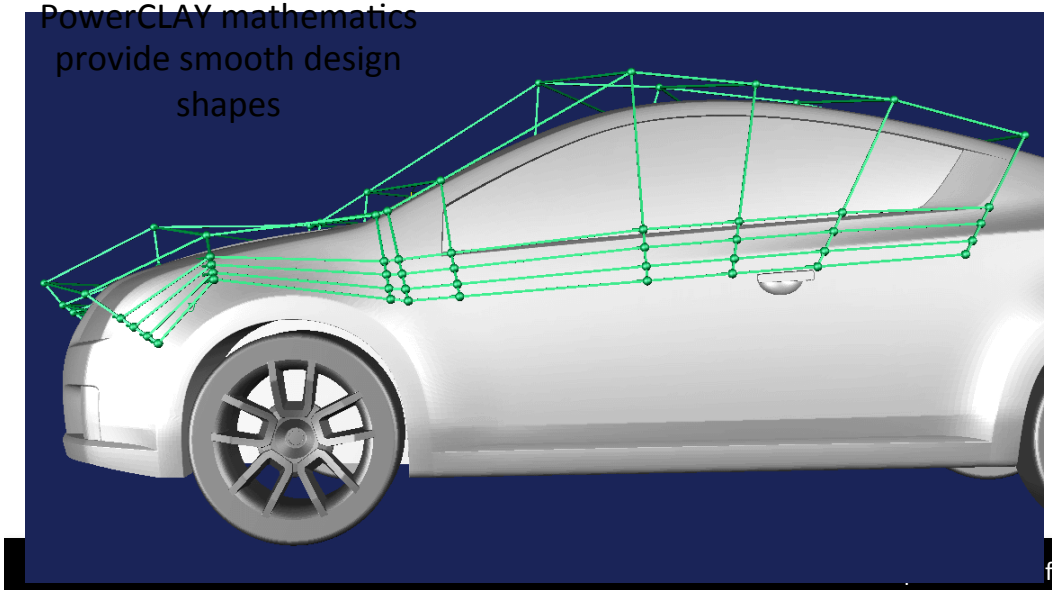
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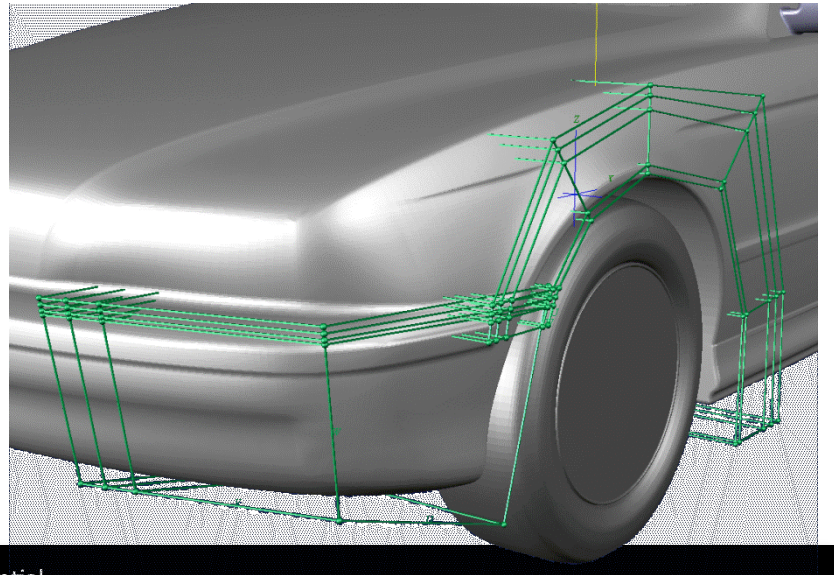
Parametric Features





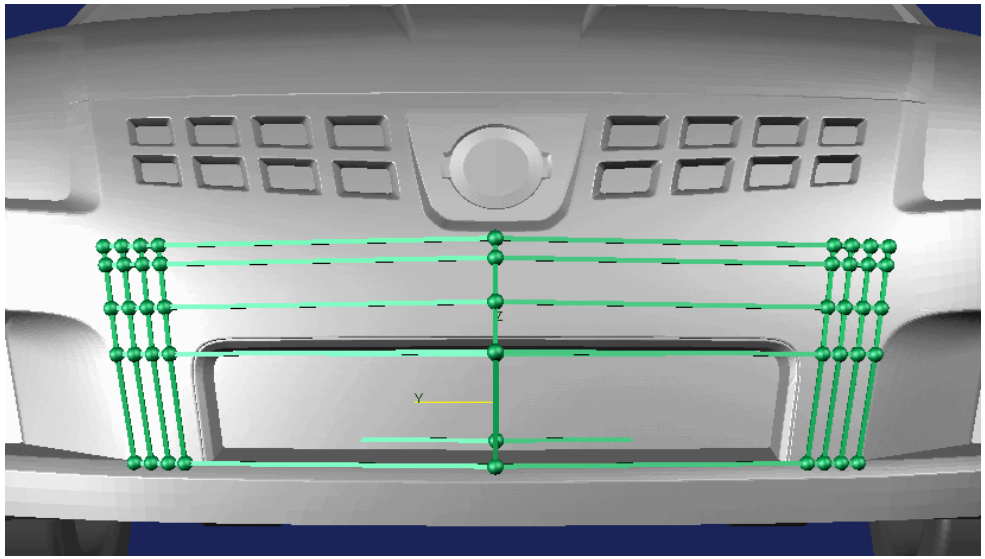
PowerCLAY mathematics provide smooth design shapes

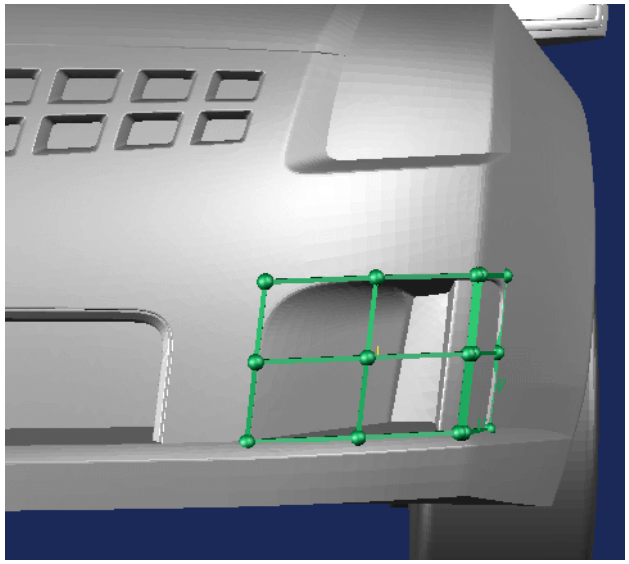


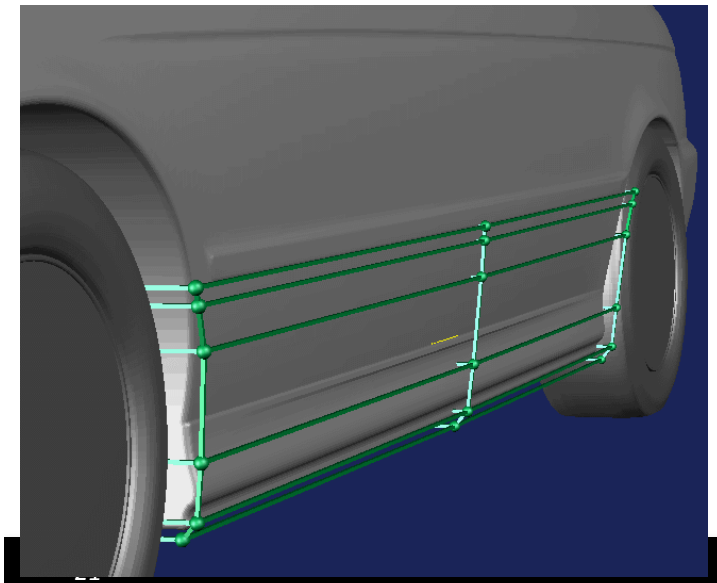


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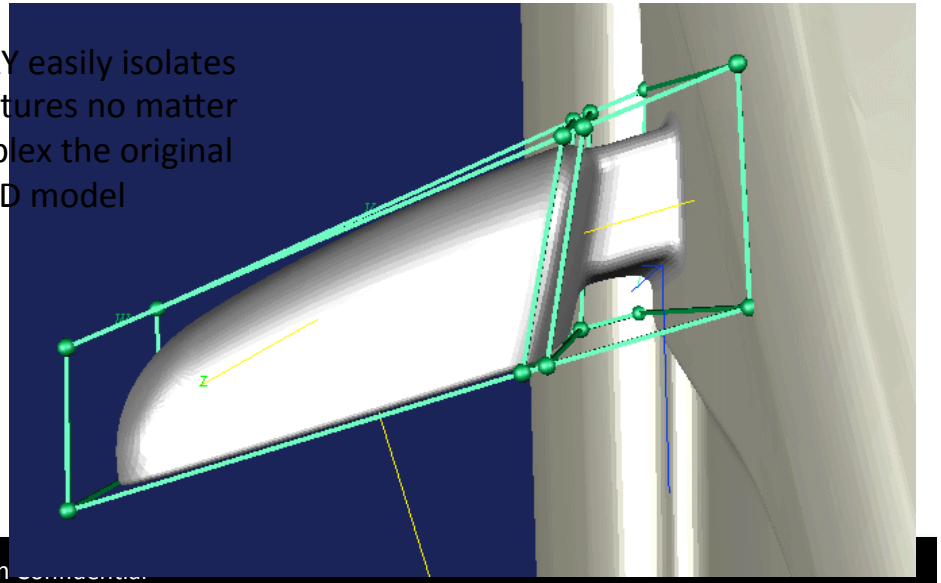
Parametric Features







PowerCLAY easily isolates design features no matter how complex the original CAD model



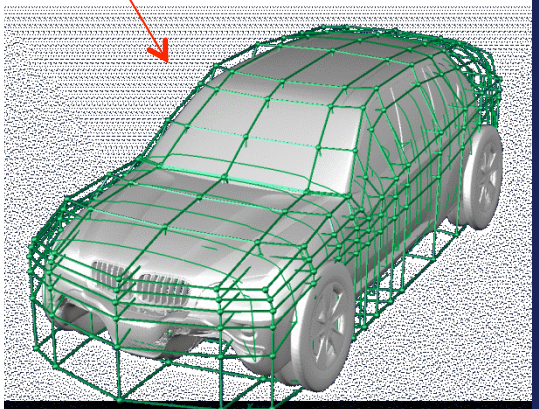
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Rapid Design Process
Full Body Morphing

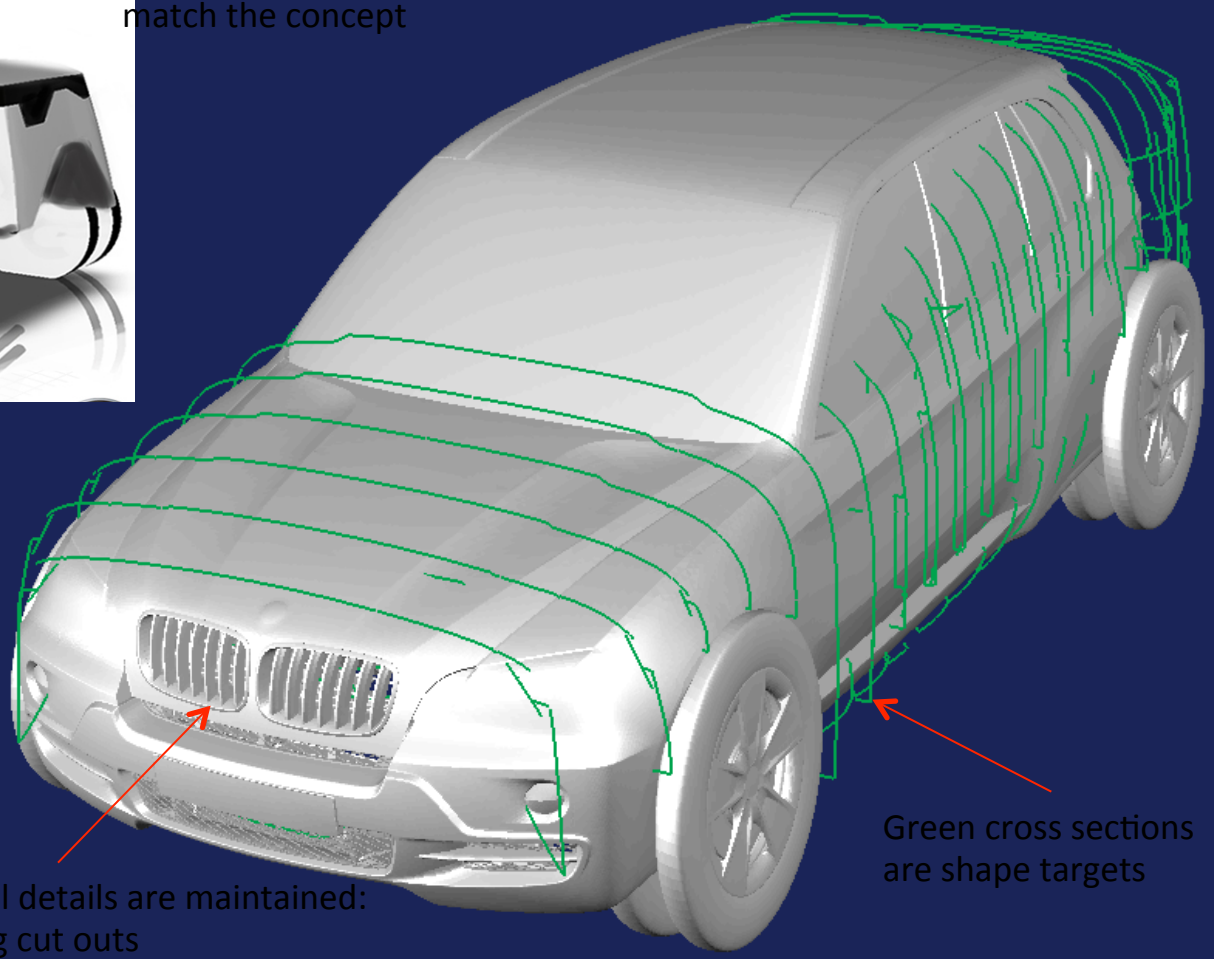


Input for this example is a basic surface model

Lattice features achieve smooth shapes



The entire X5 mesh model is morphed to match the concept



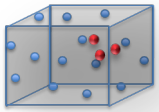
All model details are maintained:
- Cooling cut outs
- Engine detail
- Fillets and radii

Green cross sections are shape targets

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Methodology Overview
DSE with Response Surface Models



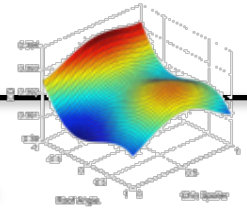


(Add Samples)

Improve Response Model

Baseline geometry

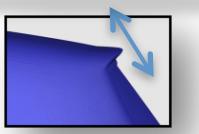
Simulate Design Variations



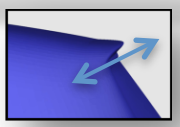
Analyze Response Model

Answer Design Questions

Original Design Space



Improve Design Space



(Add Features)

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Methodology Overview
One Step DoE



Run List	Design Parameters				
#	A	B	C	D	Output
1	0.47	0.65	0.43	-0.19	3.52
2	0.69	0.27	-0.12	0.51	3.48
3	0.03	0.17	0.82	0.20	2.11
4	0.63	0.76	0.51	0.11	10.15
5	0.10	0.11	0.95	-0.17	-19.07
6	0.16	0.61	0.91	-0.21	-4.31
7	0.46	0.95	-0.78	0.35	-6.67
8	0.26	0.95	-0.88	0.63	-0.46
9	0.72	0.69	0.43	0.17	10.04
10	0.92	0.01	0.30	-0.10	1.25
11	0.86	0.83	0.72	-0.14	12.71
12	0.41	0.13	0.72	0.09	3.57
13	0.69	0.05	0.76	0.33	8.35
14	0.63	0.57	0.70	0.27	11.65
15	0.12	0.78	-0.57	-0.21	-8.78

Run list from DoE

Execution in parallel

- Studio characterization
  - *Same features on every model*
  - *Submit on Friday – review on Monday*
  - *Incorporate aero into the DNA*
  - *Have every model meet drag targets*

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Methodology Overview
Adaptive Sampling



Run List	Design Parameters				
#	A	B	C	D	Output
1	0.47	0.65	0.43	-0.19	3.52
2	0.69	0.27	-0.12	0.51	3.48
3	0.03	0.17	0.82	0.20	2.11
4	0.63	0.76	0.51	0.11	10.15
5	0.10	0.11	0.98	-0.17	-19.07
6	0.16	0.22	0.77	-0.21	-4.31
7	0.47	0.65	0.43	0.35	-6.67
8	0.26	0.95	-0.88	0.63	-0.46
9	0.72	0.69	0.43	0.17	10.04
10	0.92	0.01	0.30	-0.10	1.25
11	0.86	0.83	0.72	-0.14	12.71
12	0.41	0.13	0.72	0.09	3.57
13	0.69	0.05	0.76	0.33	8.35
14	0.63	0.57	0.70	0.27	11.65
15	0.12	0.78	-0.57	-0.21	-8.78
16	0.08	0.08	-0.21	0.28	-7.68
17	0.47	0.65	0.43	-0.19	-7.40
18	0.69	0.27	-0.12	0.51	2.49
19	0.03	0.17	0.82	0.20	-14.43
20	0.47	0.22	-0.74	-0.40	-14.49
21	0.08	0.97	-0.33	0.52	2.42
22	0.89	0.98	-0.75	0.38	4.96
23	0.63	0.67	0.43	0.90	16.33

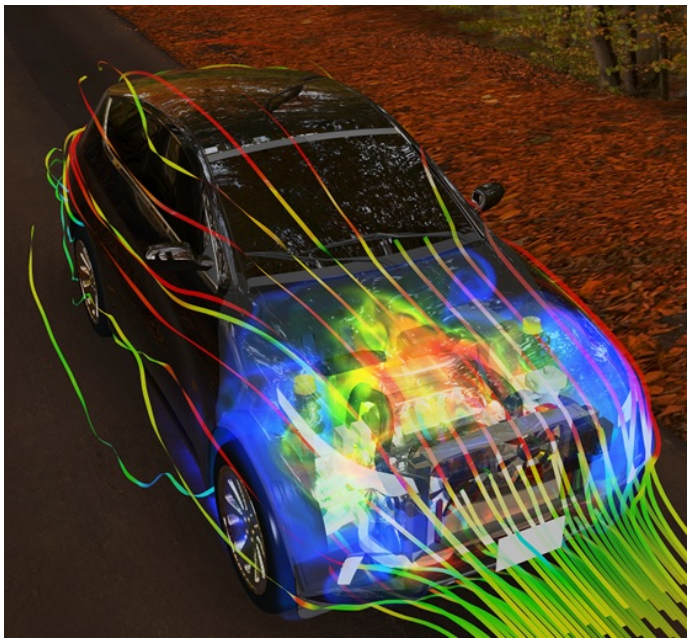
Run list from DoE

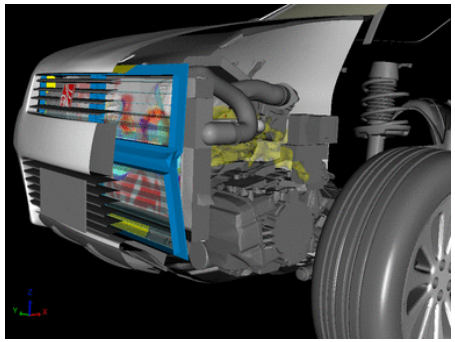
Iterative Adaptive Refinement

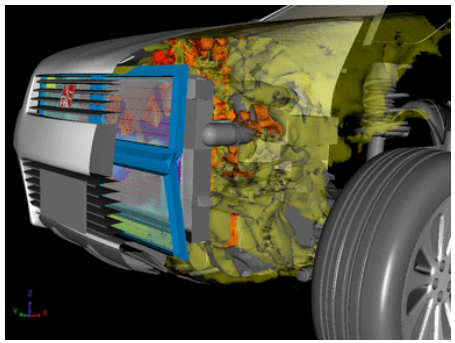
- Engineering Design
  - *Several week time frame*
  - *Adjust parameter ranges if required*
  - *Stop early if design space potential is low*

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Methodology Overview
Evolving Design Space (with Adaptive Sampling)







Run List	Design Parameters				
#	A	B			Output
1	0.47	0.65			-4.20
2	0.69	0.27			-13.50
3	0.03	0.17			2.11
4	0.63	0.13			-9.10
5	0.10	0.00			-19.07
6	0.16	0.51			2.30
	Design Parameters				
	A	B	C		Output
7	0.69	0	0.76		8.35
8	0.12	0	-0.57		4.90
9	0.26	0	-0.88		-2.30
10	0.00	0	0.00		6.00
11	0.94	0	0.74		8.10
12	0.34	0	-0.22		-4.50
	Design Parameters				
	A	B	C	D	Output
13	0.47	0	-0.74	-0.40	15.80
14	0.22	0	-0.53	0.91	1.79
15	0.20	0	0.27	-0.70	-2.60
16	0.47	0	0.64	-0.78	5.89
17	0.26	0	-0.88	0.63	17.17
18	0.14	0	0.31	0.99	-6.39
19	0.57	0	0.57	0.57	13.80
20	0.34	0	0.52	0.52	2.39
21	0.66	0	-0.33	0.33	-2.47
22	0.46	0	0.58	-0.19	1.48
23	0.22	0	-0.67	-0.12	5.72
24	0.95	0	0.91	-0.51	12.90
25	0.25	0	-0.19	-0.34	7.53
26	0.73	0	0.85	-0.04	5.92
27	0.47	0	-0.74	-0.40	18.90

Run list from DoE

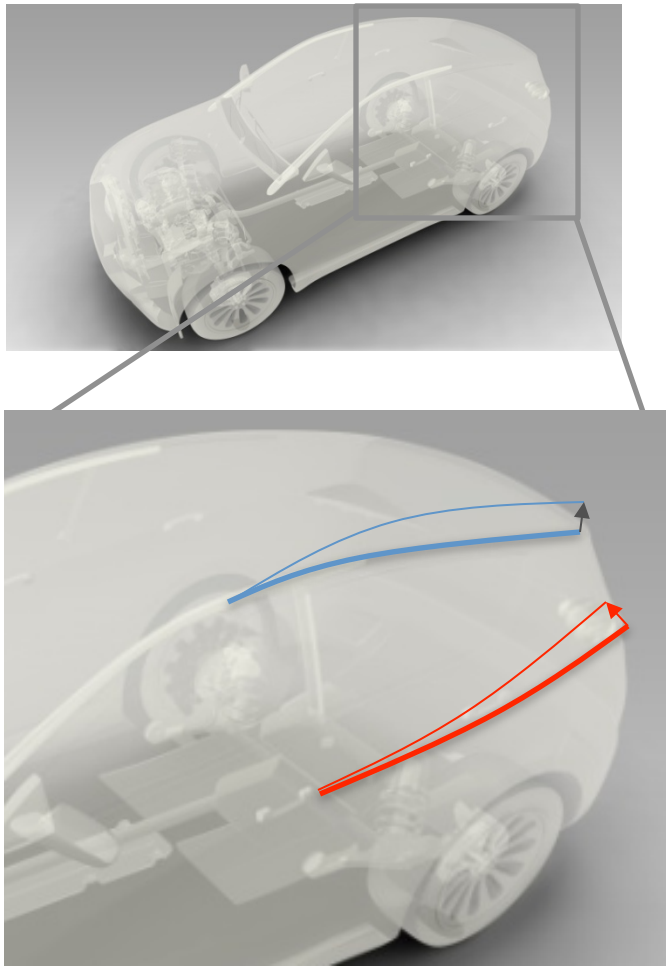
Design Space changes

Iterative Adaptive Refinement

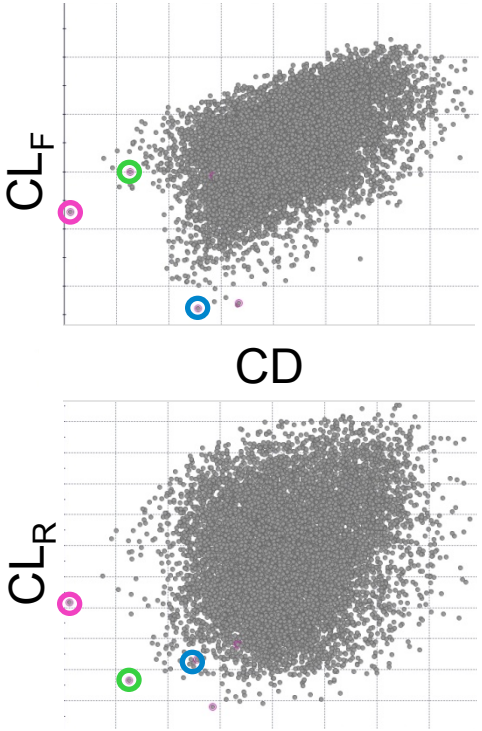
- New concept exploration
  - *When it's not clear what to change*
  - *Add / change parameters*
  - *Evolve until targets are met*

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Main Applications
Aerodynamics



Design Quality Morphing

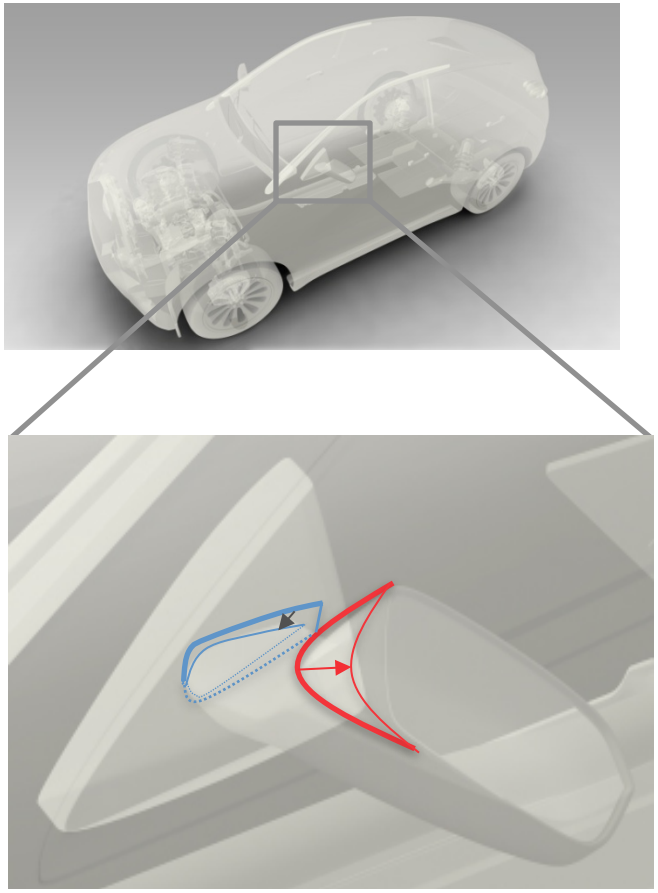


- Virtual performance trade-offs
- Complex interactions
- Part cost benefits

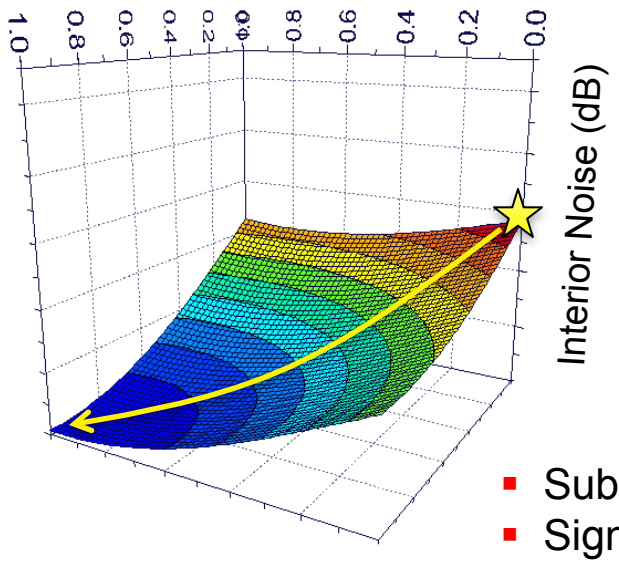
- Project Success
  - *~ 60 production projects*
  - *~ 30-75 runs for 6-15 parameters*
  - ***~ 2 - 8% performance increase***

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Main Applications
Acoustics



Design Quality Morphing

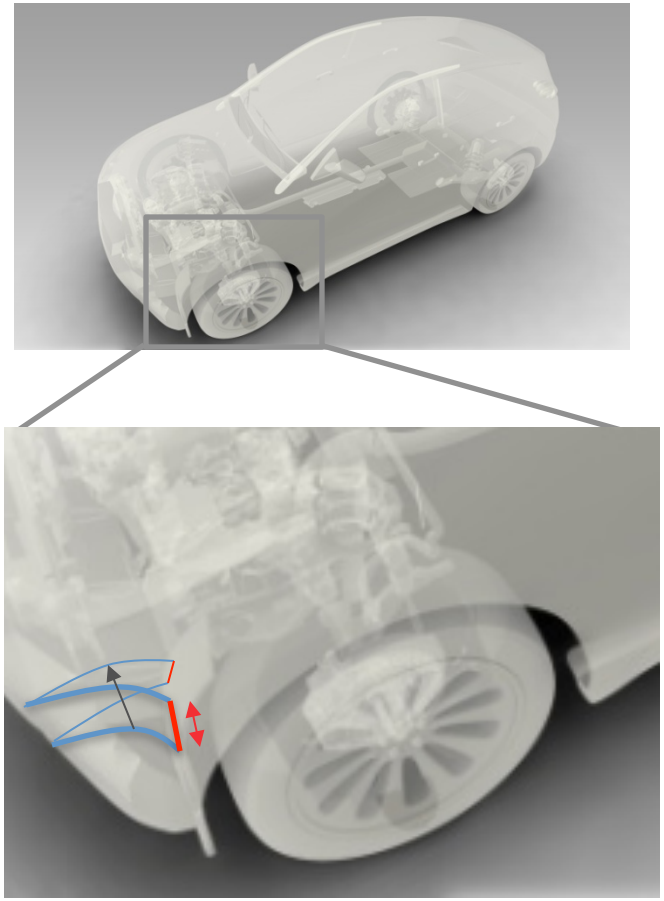


- Subtle design changes
- Significant performance impacts

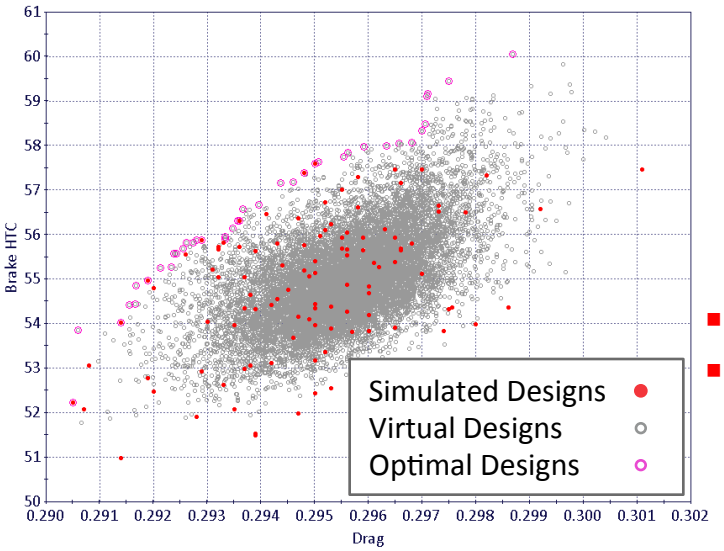
- Project Success
  - *~ 10 production projects*
  - *~ 20-40 runs for 4-7 parameters*
  - ***~ 5 - 7% performance increase***

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Main Applications
Brake Cooling / Component Optimization



Design Quality Morphing

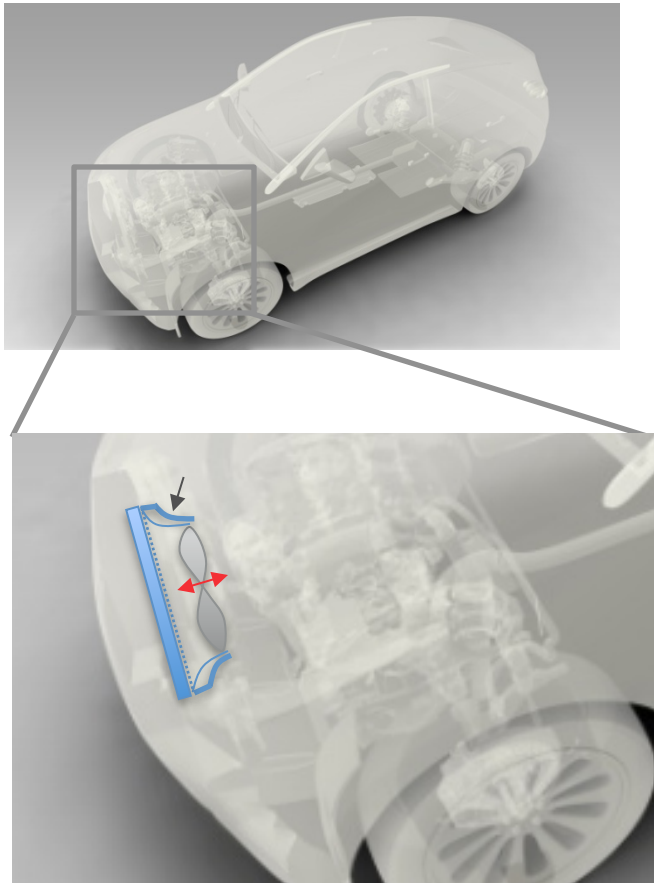


- Concept investigations
- Virtual trade-offs

- Project Success
  - *~ 10 production projects*
  - *~ 20-50 runs for 5-10 parameters*
  - ***~ 5 - 10% performance increase***

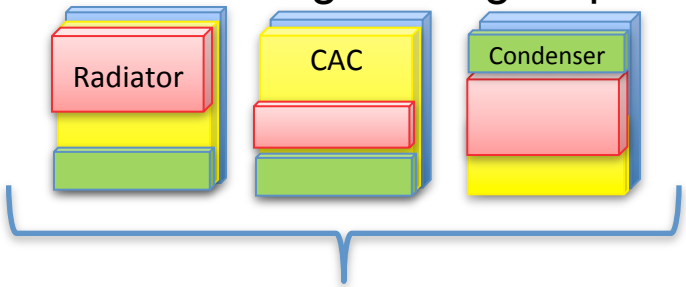
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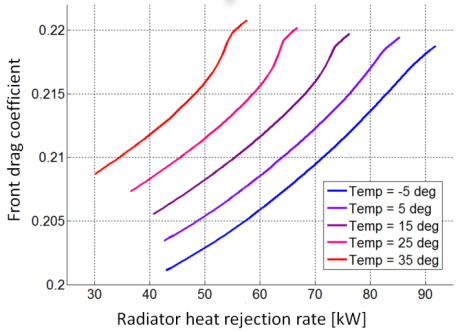
Main Applications
Thermal Packaging



Design Quality Morphing

Discrete Cooling Package Options





- Complex system models
- Performance maps
- Tolerance studies

- Project Success
  - *~ 25 production projects*
  - *~ 25-50 runs for 5-15 parameters*
  - ***~ 2% - 12% performance increase***

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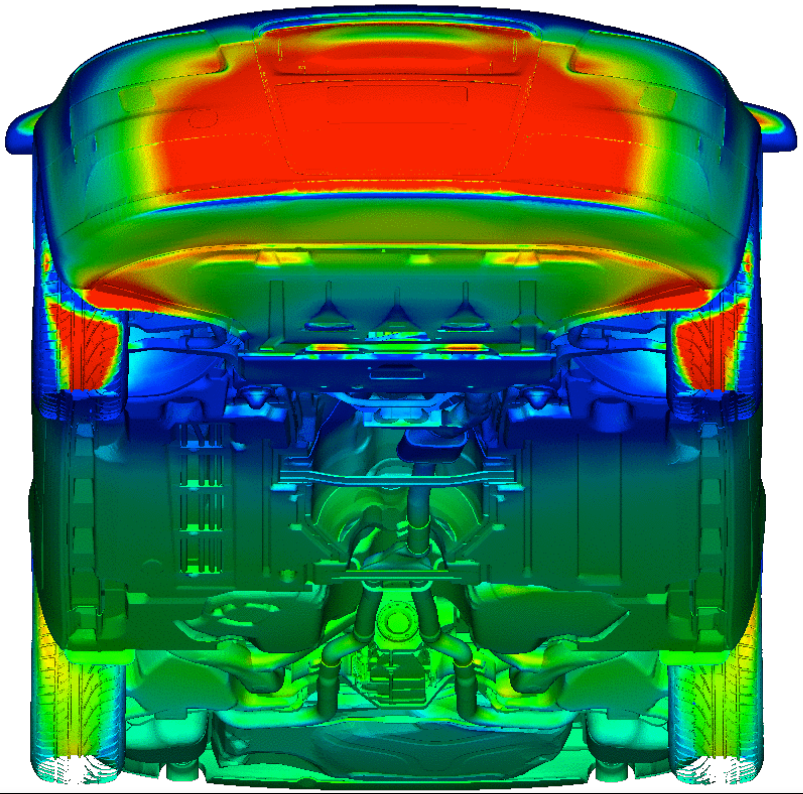
Objectives

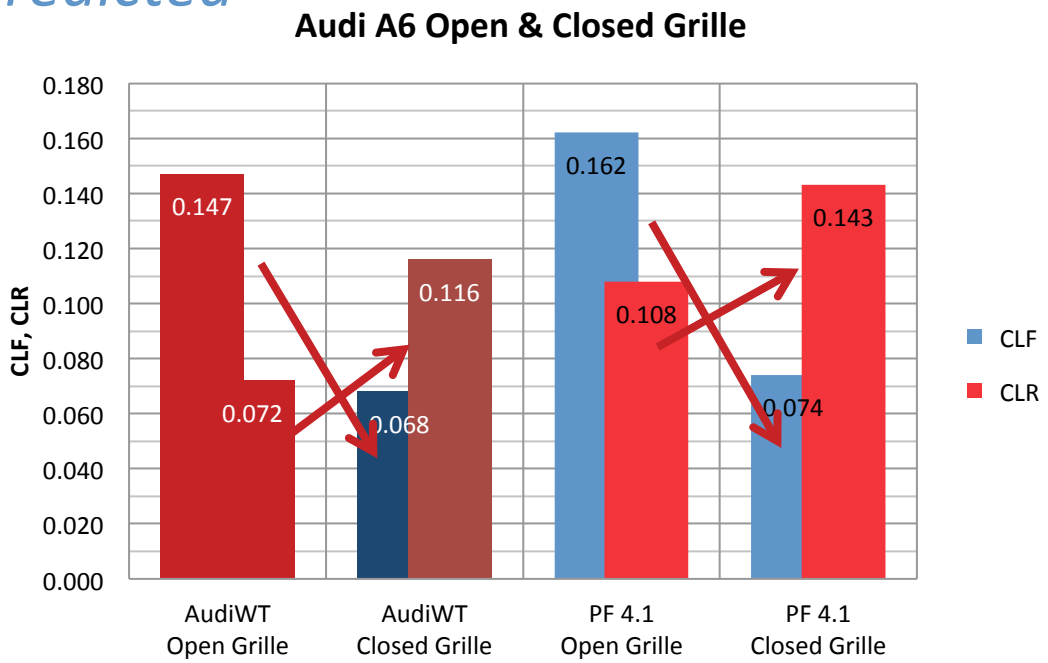
- Share some of our studio experience
  - *Explain the Designers point of view*
- Describe our freeform methods
  - *Think beyond analysis – consider how to design*
- Connect Design to Simulation Accuracy
  - *Theoretical skills are still needed*
- Speculate on what comes next

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Audi Lift Balance Study
A6 Sedan

- Open Grille Lift
  - *Correlation similar to closed grille*
  - *Lift Change is well-predicted*



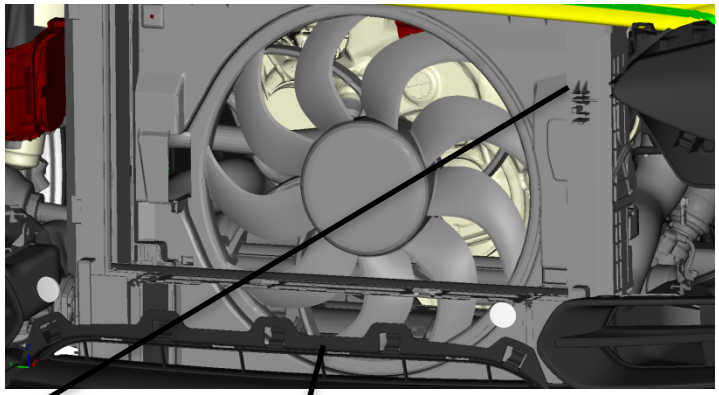


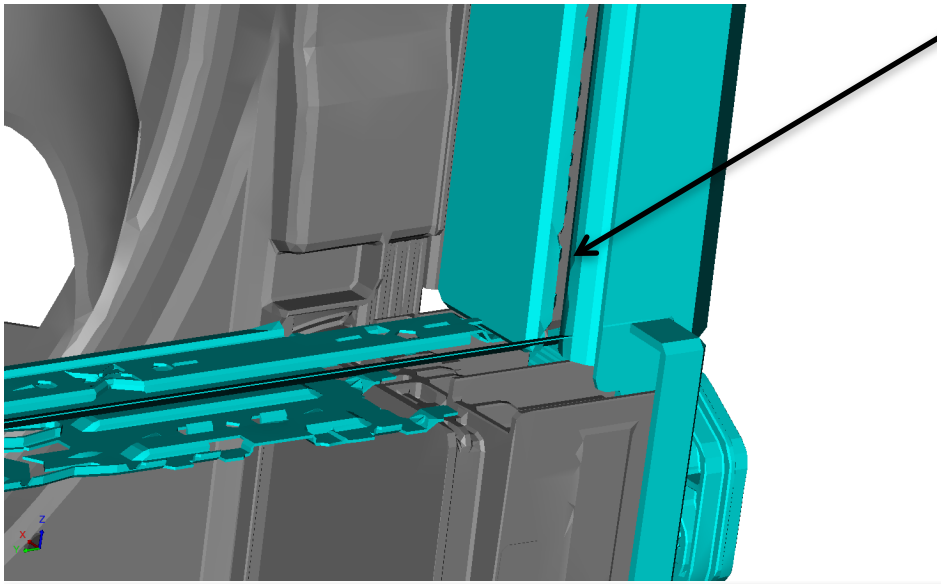
Audi WT vs. PF, Effect of Closing Grille
- CLF 13 counts different, CLR 9 counts
  - Balance change exactly matches

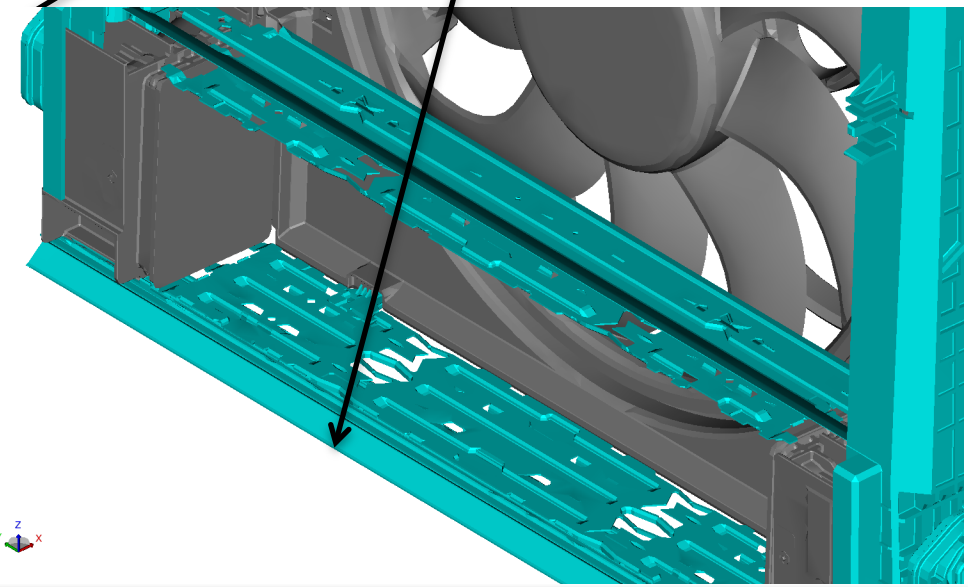
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Geometry
Under hood –Cooling Frame/ Fan

- Represent
  - *Gaps in the cooling frame*
  - *Fan geometry*
- Preserve
  - *Clearances between parts*

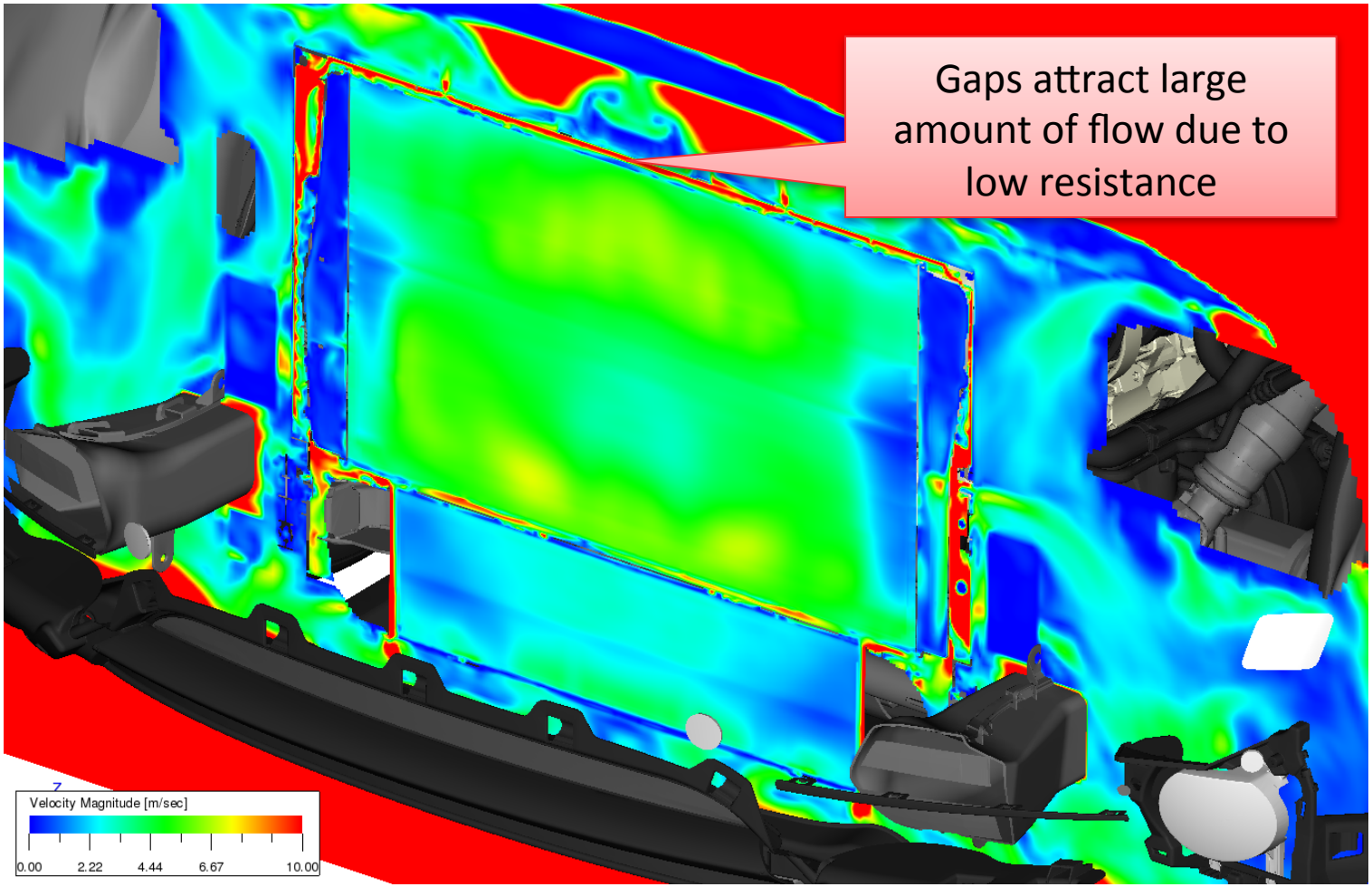






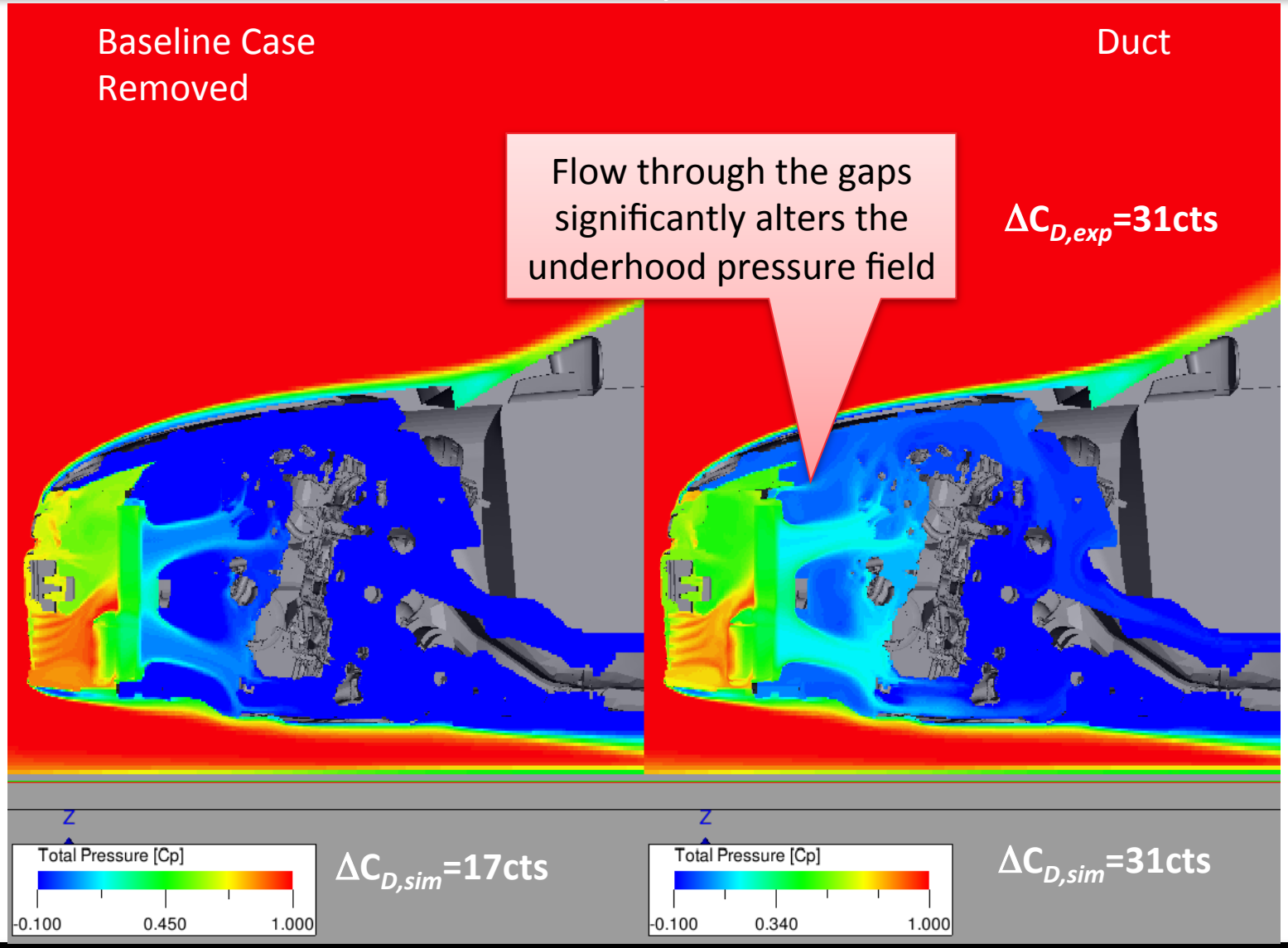
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Geometry
Under hood –Cooling Frame/ Fan



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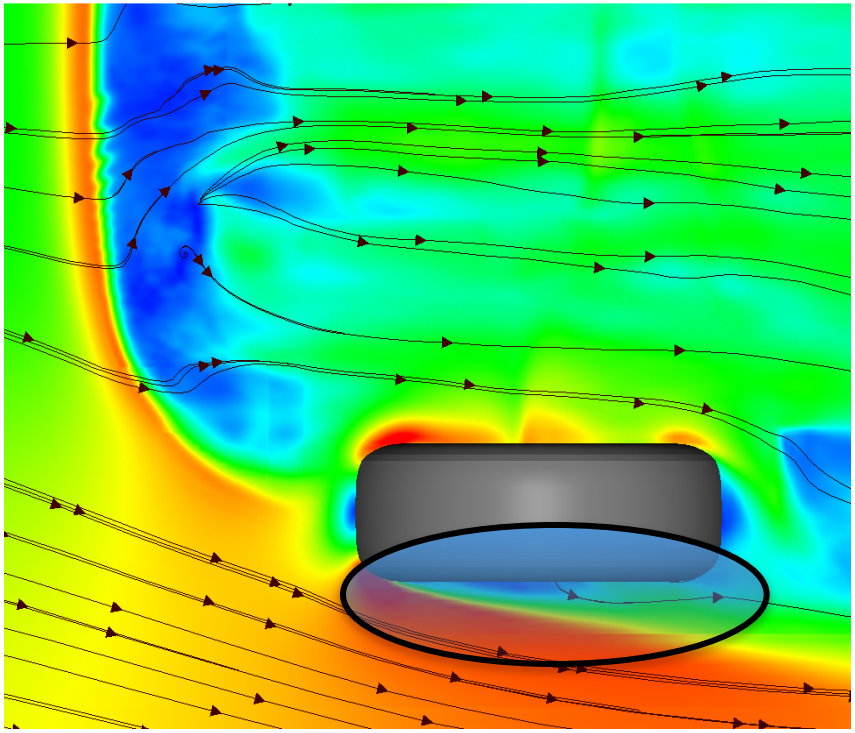
Cooling Drag Physics
Leakage Investigations - C_{pt}

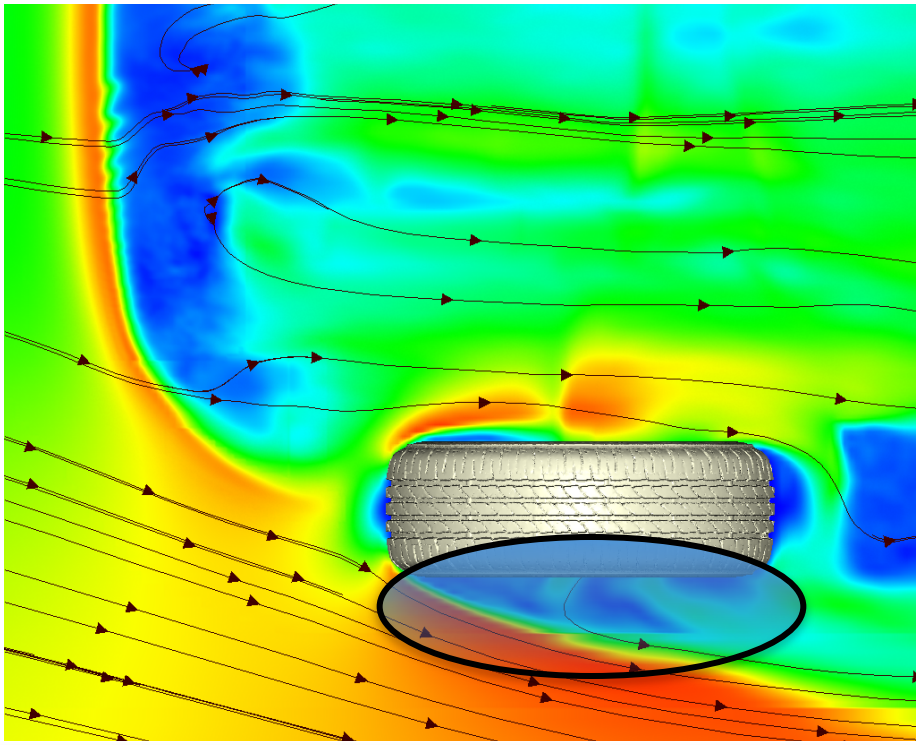


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Geometry
Realistic Tires

- Realistic Tires
  - *Change in Stagnation/Wake*
  - *Alters flow direction*
    - At the tires/wheels

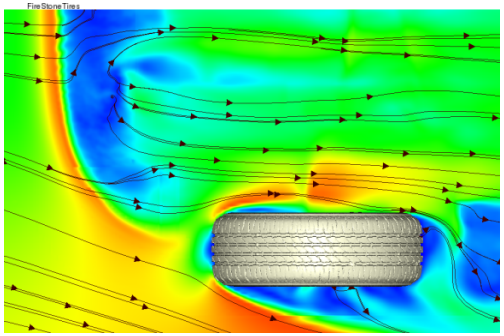


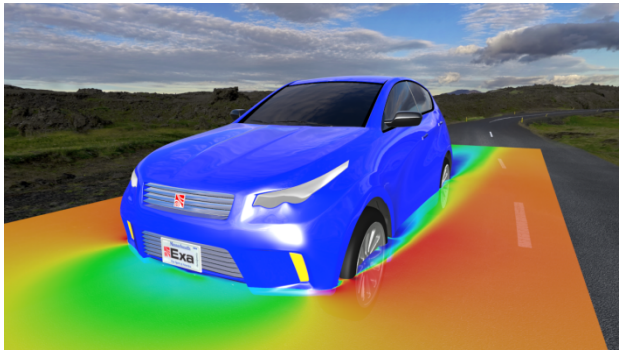


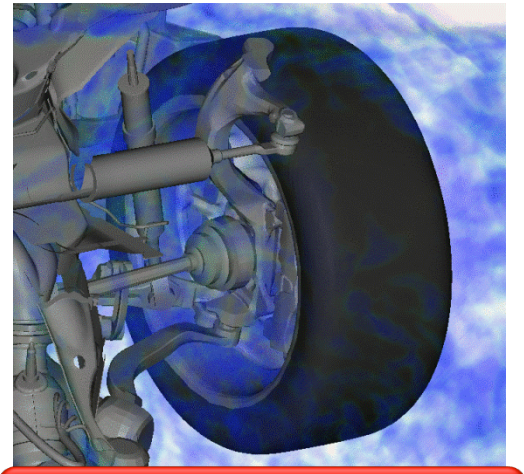
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Geometry
Realistic Tires

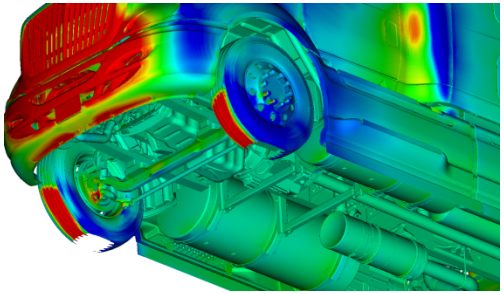
- Flow around the tires impacts the performance of the vehicle in various ways



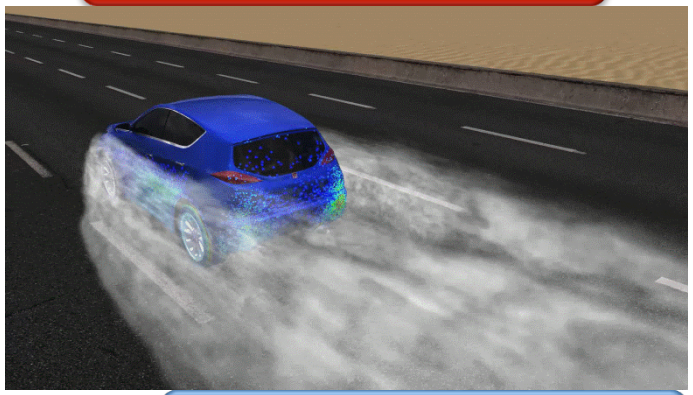




Brake Cooling



Aerodynamics



Soiling

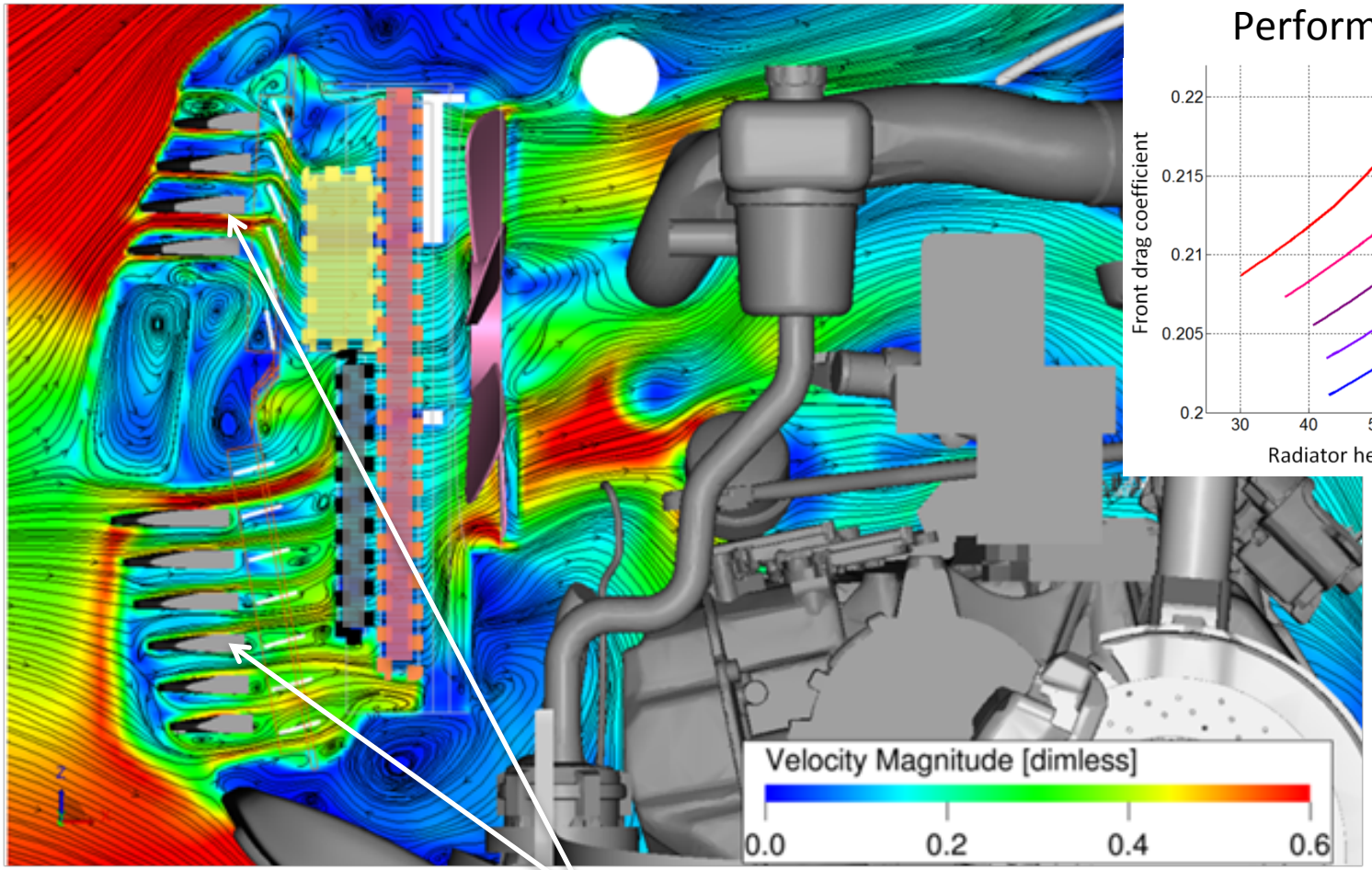
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Objectives

- Share some of our studio experience
  - *Explain the Designers point of view*
- Describe our freeform methods
  - *Think beyond analysis – consider how to design*
- Connect Design to Simulation Accuracy
  - *Theoretical skills are still needed*
- Speculate on what comes next

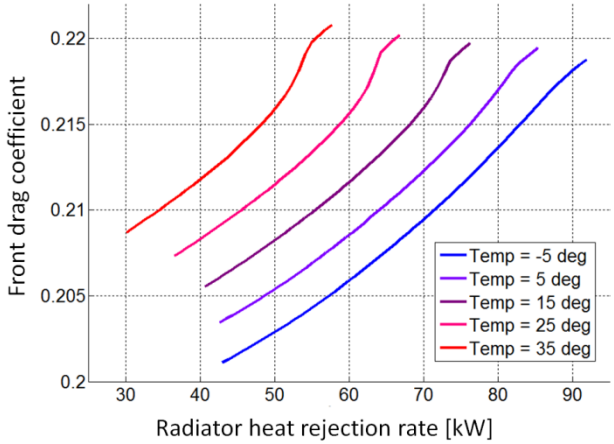
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Active Devices
Less compromise



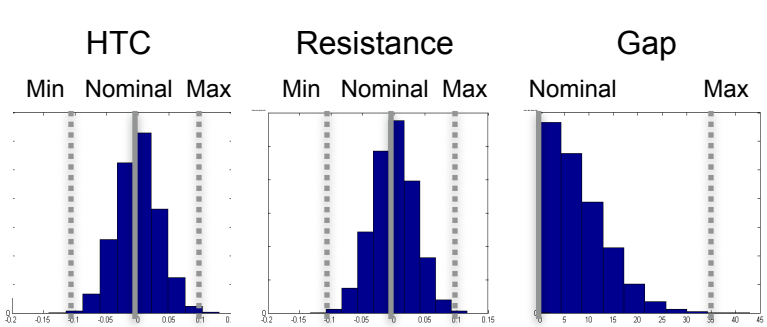
Upper and lower active grille shutters

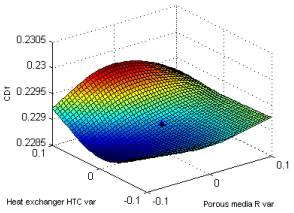
Performance Trade-Offs



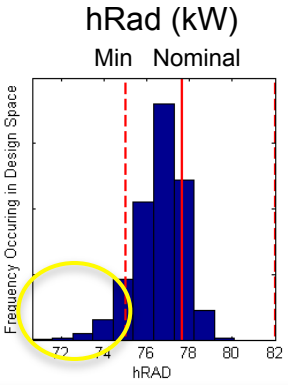
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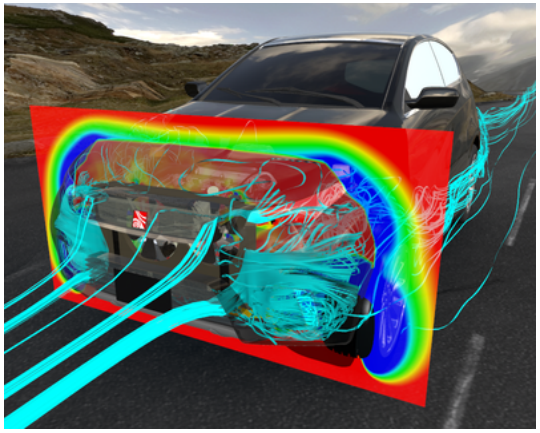
Variance in Geometries
Manufacturing Tolerances, Aging Vehicles

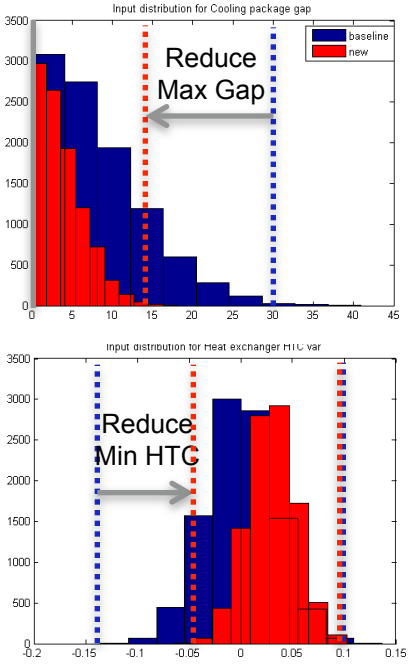




Tolerance Failures

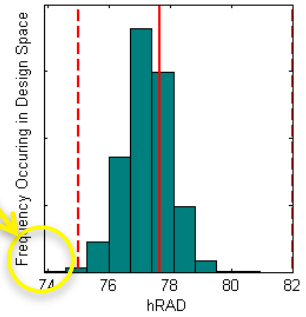




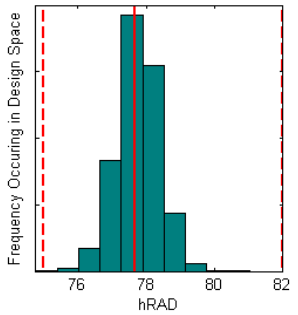


Modified Input Tolerances

Tolerance Failures



No Failures



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True Optimization
Motorsports – 1990's



A few components



A lot of straight edges

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True Optimization
Motorsports - Today





No parallel lines

Complex systems



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A Stylist’s Canvas?







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