WOST – 2016
Design Optimization and Robustness of a Passenger Car Brake Rotor

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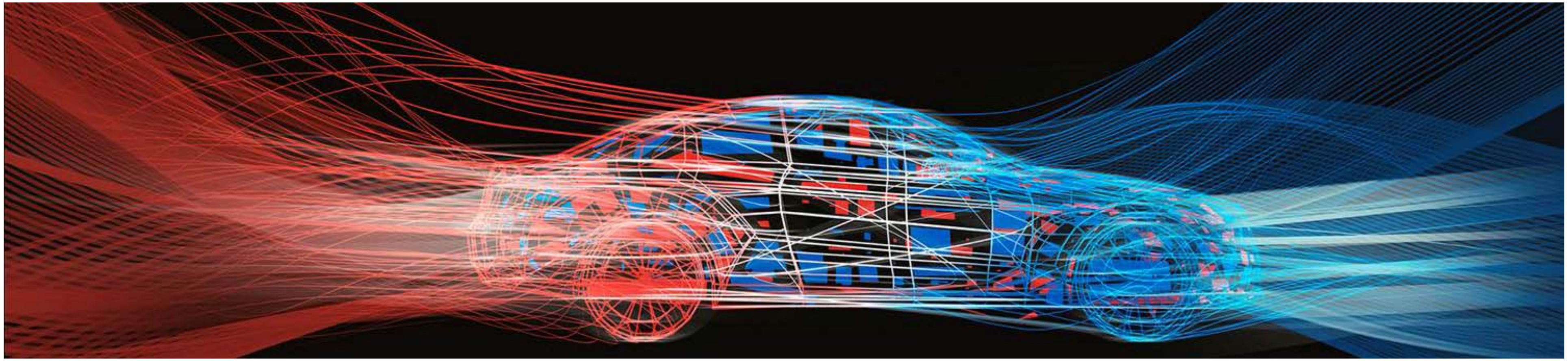


Contents

Background: Focus of Work

Function / Performance

Weight / Design Space

Noise and Vibration

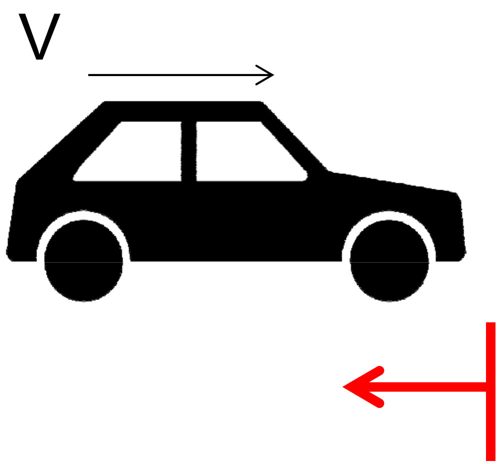
Design / Appearance

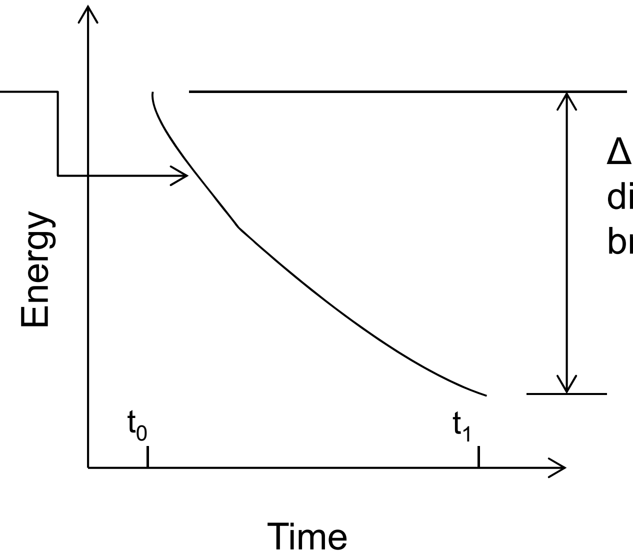
Pad Wear / Dust Emission

Reduced CO_2 Emission / Residual Drag

Background: Brake Rotors – Performance Requirements

Kinetic energy : ½ m V^2





Δ E – Energy is dissipated through brake - rotor

Decel – 'x' g

Begin decel at time t_0
Stop decel at time t_1

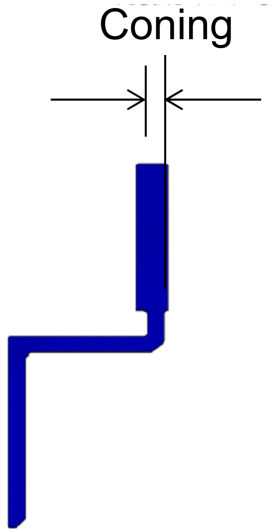
Brake system, particularly rotor is subjected to mechanical and thermal loading

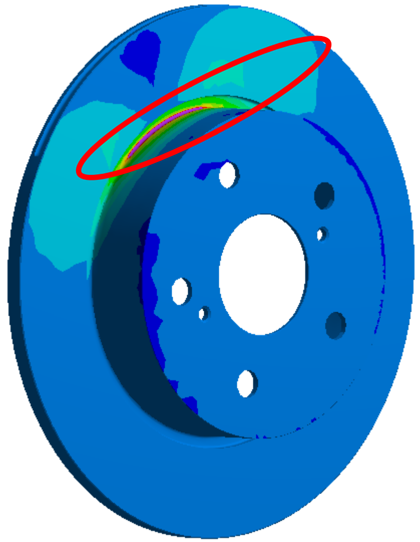
X % of Δ E

Y % of Δ E

X + Y = 100% of Δ E

Background: Thermo Mechanical Loading of Rotor



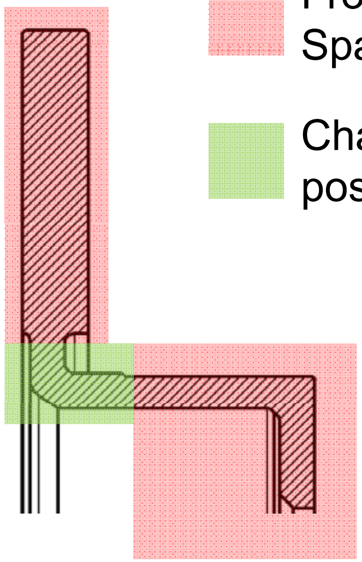


Thermal loading leads to thermal deflections => thermo mechanical stress. Large differential deflection may lead to BTV (Brake Torque variation) issues

Deceleration leads to mechanical loading and material stress – critical for component durability

Both characteristics should be evaluated in rotor design

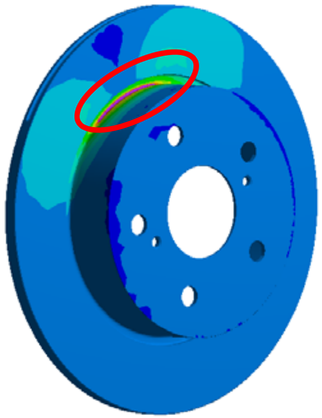
Motivation: Design Restrictions



Frozen Design Space

Change in design possible

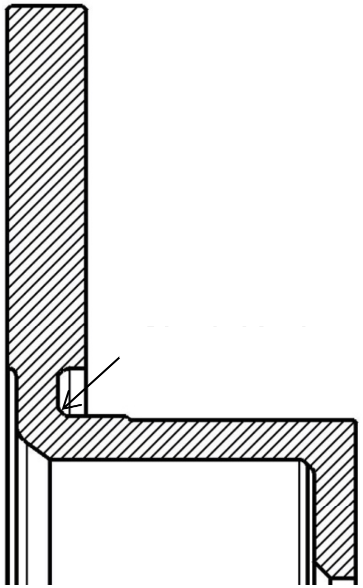
Initial Design

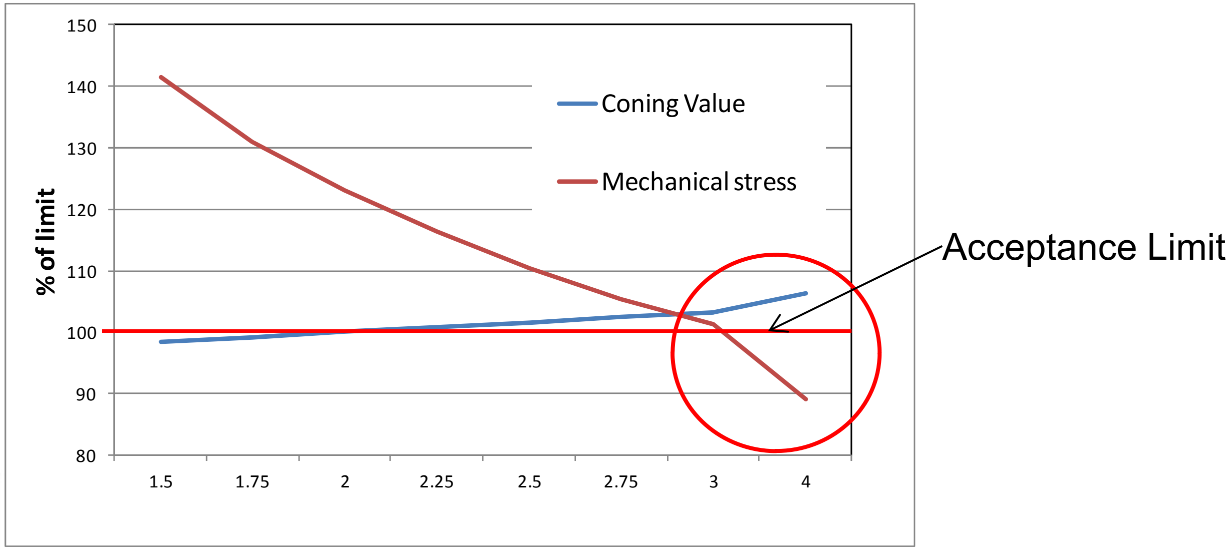


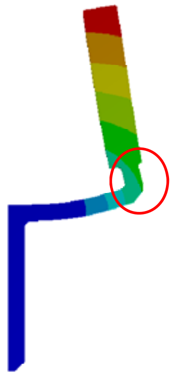
Mechanical stress over limit in initial design

Initial design based on available design space did not meet either mechanical or coning requirement

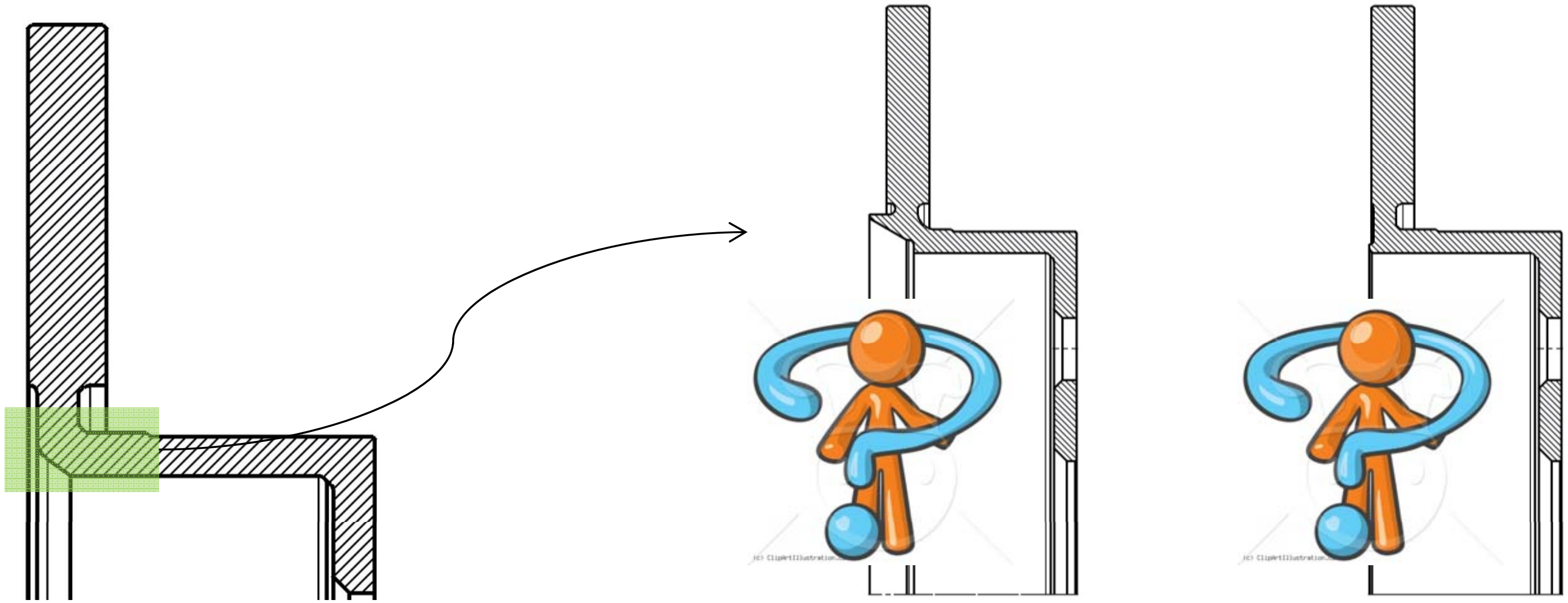
Motivation: Problem Statement







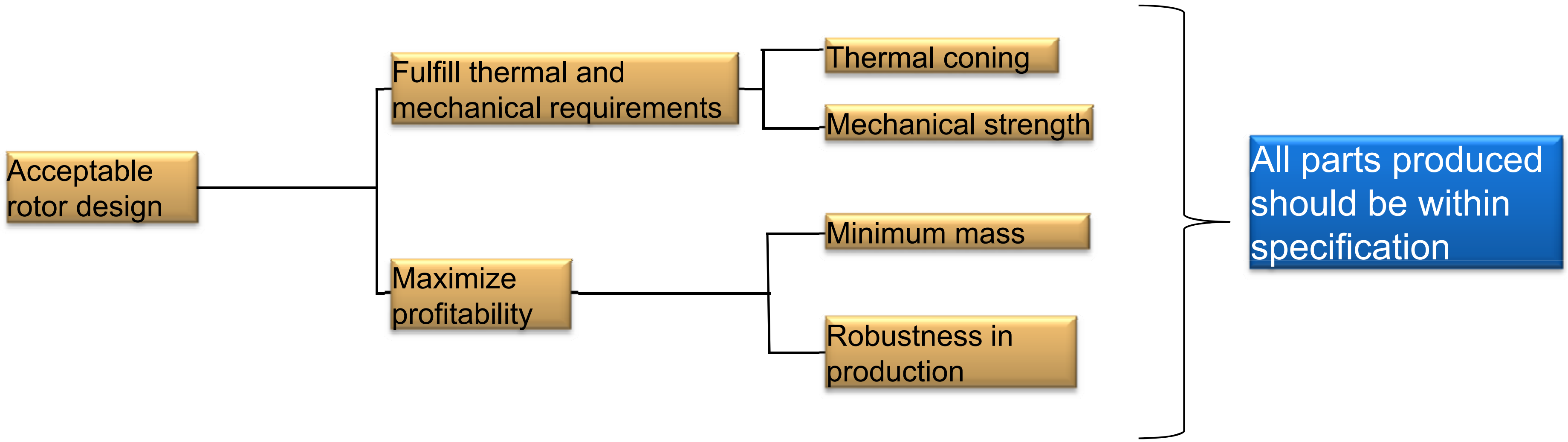
Motivation: Best Design



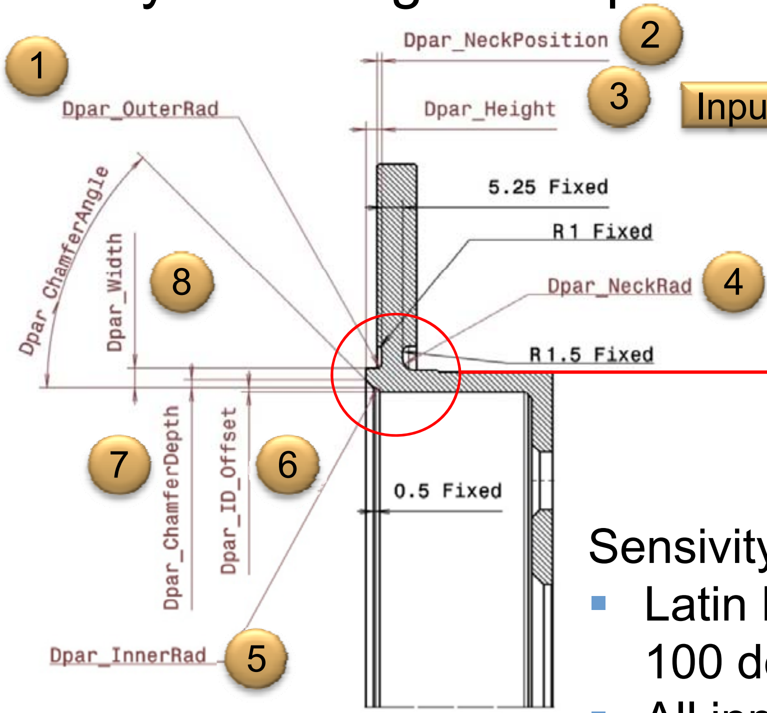
How to design stiffening rib?
What shape would fulfill function and be robust against process variations?
How to reduce mass due to addition of new feature?

Motivation: Functional and Robust

Functional component → **Meet specifications under production variation** → **No scraps – no warranty costs**



Analysis: Design of Experiments

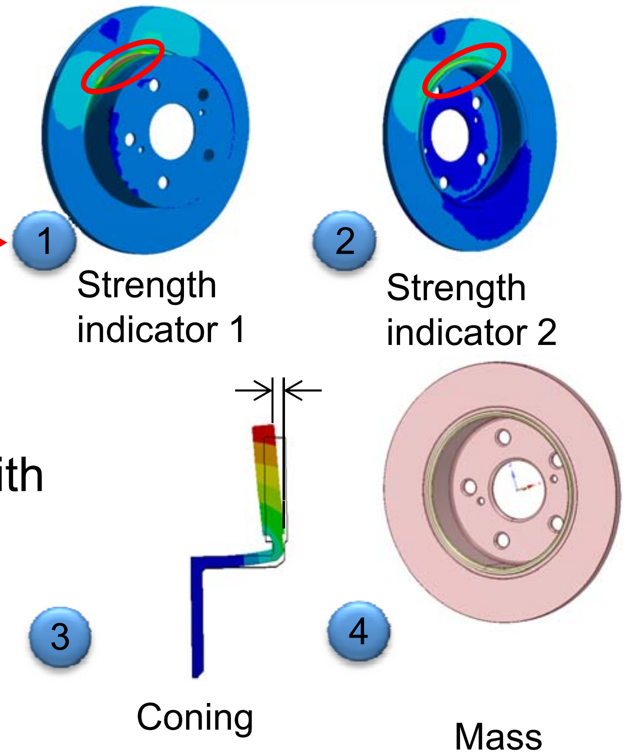


Defined Parameters

Input Parameters - 8

Sensitivity Analysis

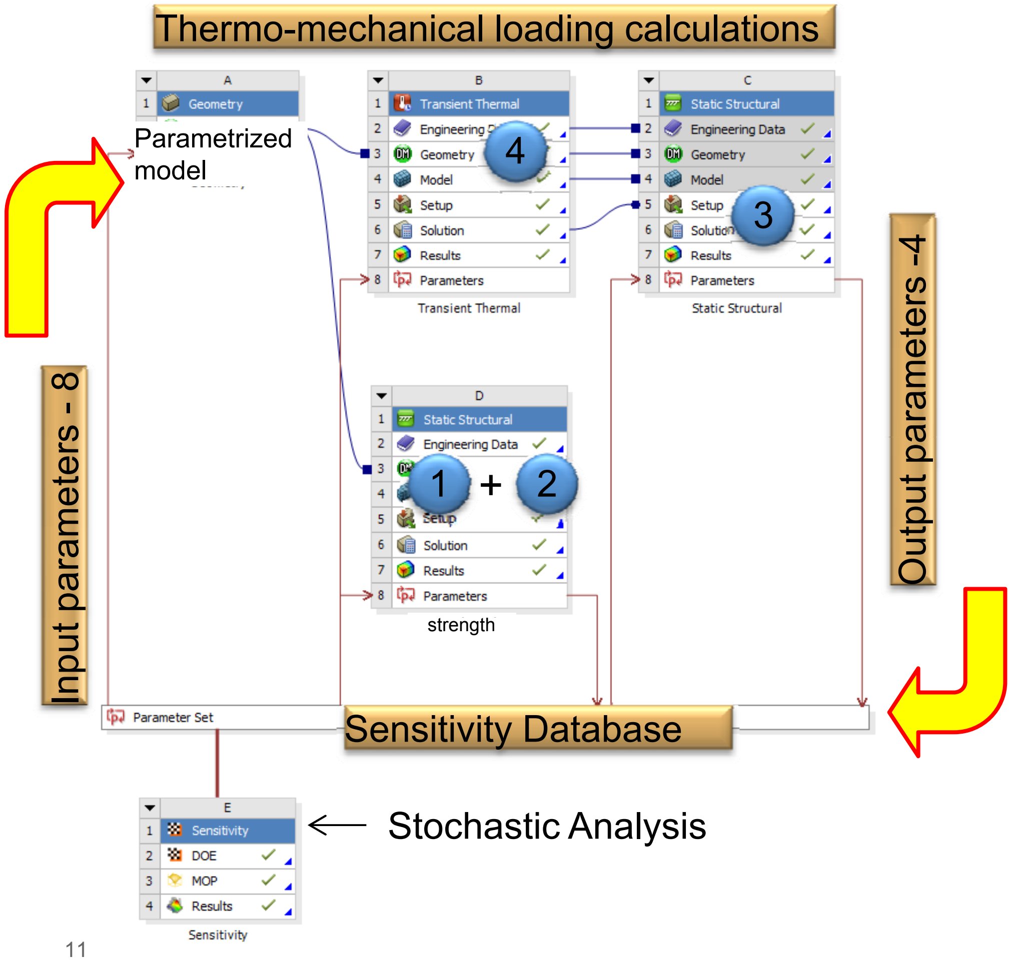
Output Parameters - 4



Sensivity Analysis:

- Latin Hypercube Sampling with 100 design points
- All input parameters were varied continuously

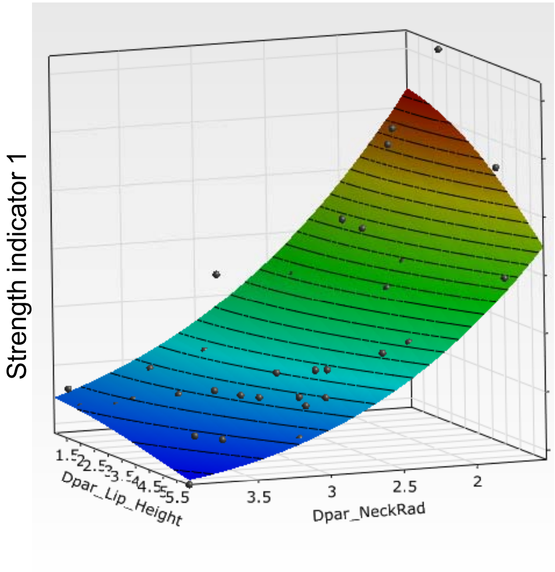
Analysis: Schematic for Stochastic Response Analysis



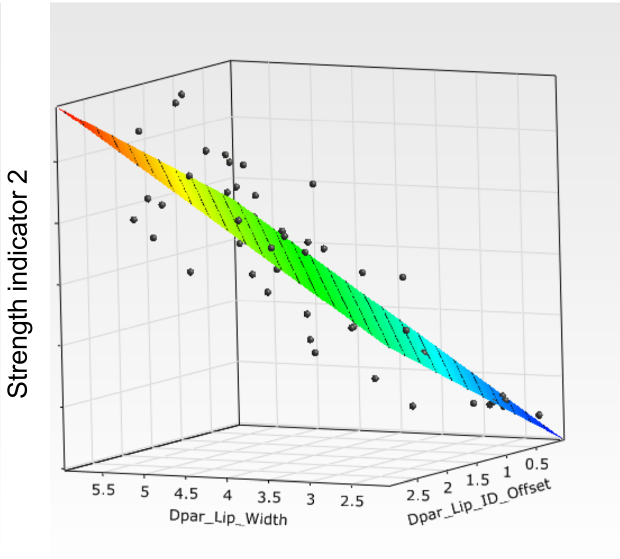
- Geometry parametrization in Catia + CADNexus
- FE calculation using Ansys workbench
- Sensitivity analysis using Optislang inside workbench
- Run time for single run ~ 1 hour

Analysis: Results

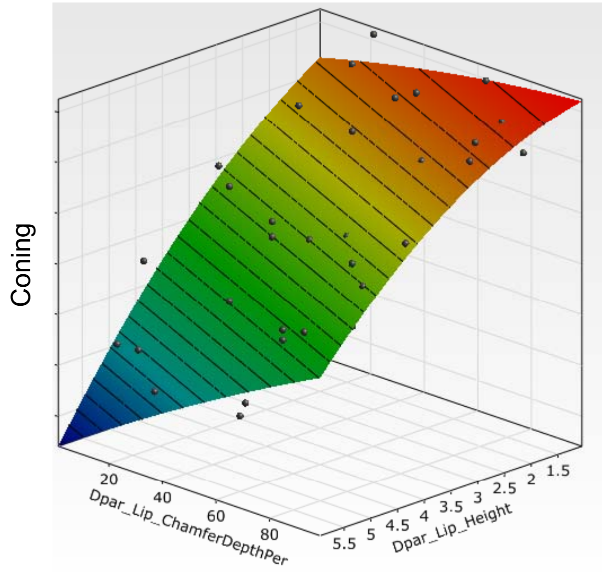
CoP – 93%



CoP – 90%



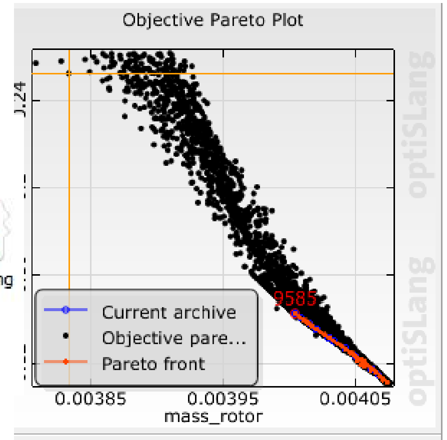
CoP – 95%

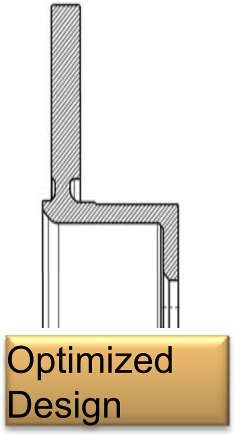


DoE provided an analytical model with desired level of accuracy => Optimization can be done on analytical model to save FE calculation time

Solution: Optimization

Optimization is carried out based on MoP model obtained using DoE
Cross check of optimized design is done by confirmation FE calculation





Optimized design nominal limit to margin:
Mechanical strength indicator 1: 19 %
Mechanical strength indicator 2: 25 %
Coning: 27 %
No significant increase in mass but improved robustness

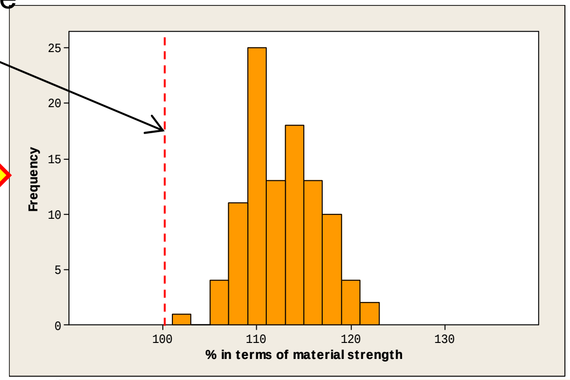
Robustness: Process Variation

Casting process

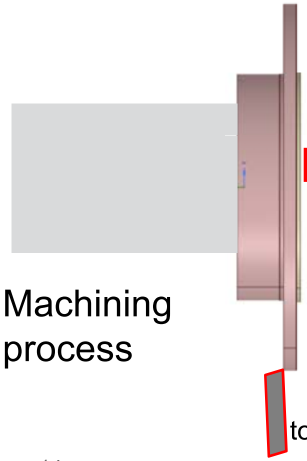
Variation in material properties:

- Position in casting palette
- Variation in material
- Variation in cooling time

Worst case material



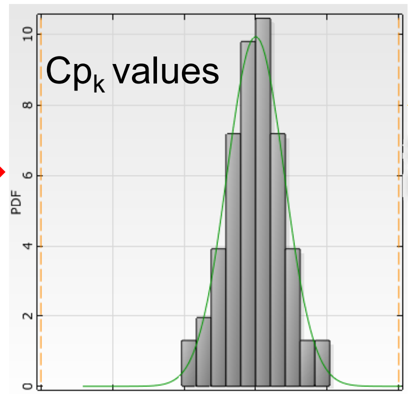
Variation in material strength



Machining process

Variation in Geometry:

- Tool wear
- Accuracy of machine

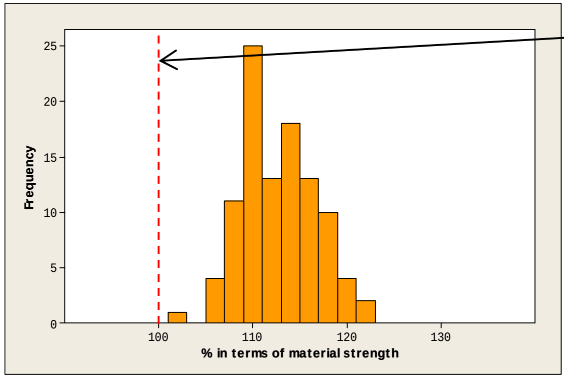


Specification limits

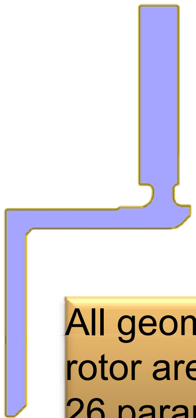
Variation in Geometry

Rotor design should be robust against all process variations

Robustness: Simulation of Product Robustness



Rotor design is always evaluated using worst case material to ensure robustness due to material properties



All geometric features of rotor are parametrized ~ 26 parameters

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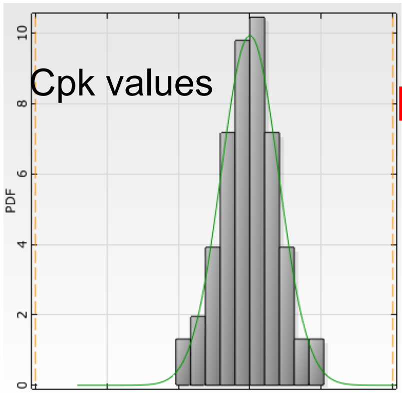


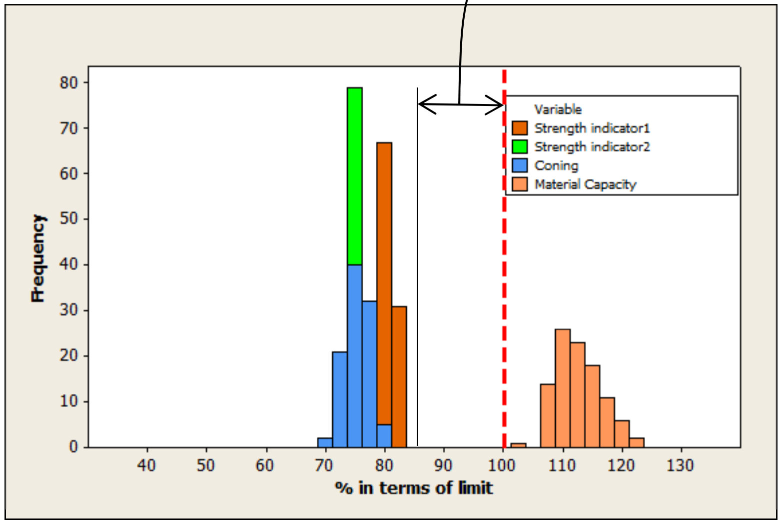
	Name	Parameter type	Reference value	Constant	PDF	Type	Mean	Std. Dev.	CoV	Distr
1	Dpar_OD	Stochastic	274			NORMAL	274	0.040161	0.0146573 %	274; (
2	Dpar_ID	Stochastic	182			NORMAL	182	0.040161	0.0220665 %	182; (
3	Dpar_Thickness	Stochastic	10			NORMAL	10	0.023256	0.23256 %	10; 0.
4	Dpar_BellHeight	Stochastic	39			NORMAL	39	0.0251	0.064359 %	39; 0.
5	Dpar_BellOD	Stochastic	169			NORMAL	169	0.060241	0.0356456 %	169; (
6	Dpar_BellEnd_Thickness	Stochastic	5.25			NORMAL	5.25	0.050201	0.95621 %	5.25;

Simulation of product robustness

Robustness: Prediction vs Test Results

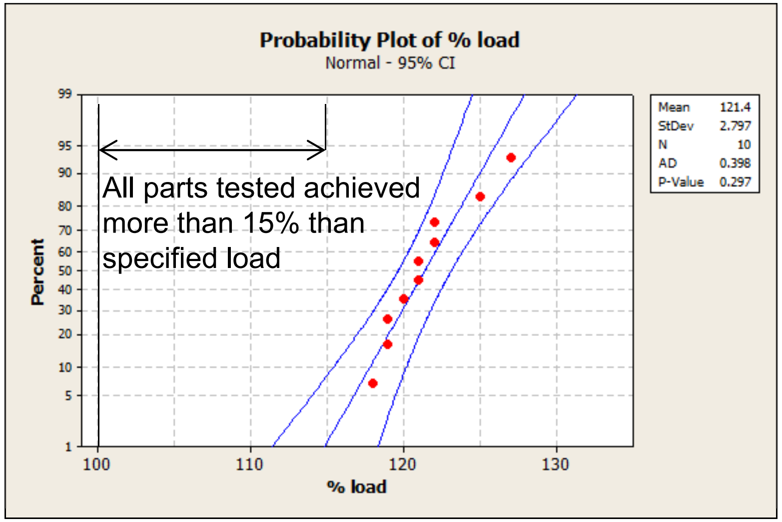
Prediction

15 % more load possible



Worst case margin to limit
Strength indicator 1: 15%
Strength indicator 2: 22%
Coning: 19%

Verification by sample testing



High probability of parts meeting specification

Key driving dimensions for strength and coning characteristics identified for production control to ensure product quality

Summary

- Product requirements presented a design challenge
- Detailed analysis was performed to understand key parameters driving product performance
- The product design was optimized to increase profit while meeting requirements
- Proposed optimized design to was analyzed to ensure robustness of design
  - Dimensions critical to quality were defined to ensure performance under variation in production conditions

Thank you for your attention

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driving motion, mobility and safety