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A New Method to Visualize Geometric Scatter from Stochastic Simulation Studies

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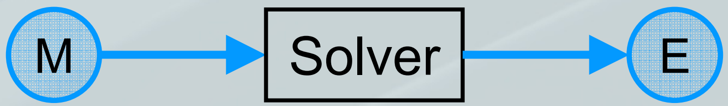
Content

- Introduction to Stochastic Simulation
- Development of Visualisation Method
- Application Examples
- Conclusion

Deterministic Simulation

Problem definition as idealized Model with fixed system properties

Exact numerical result of the simulation



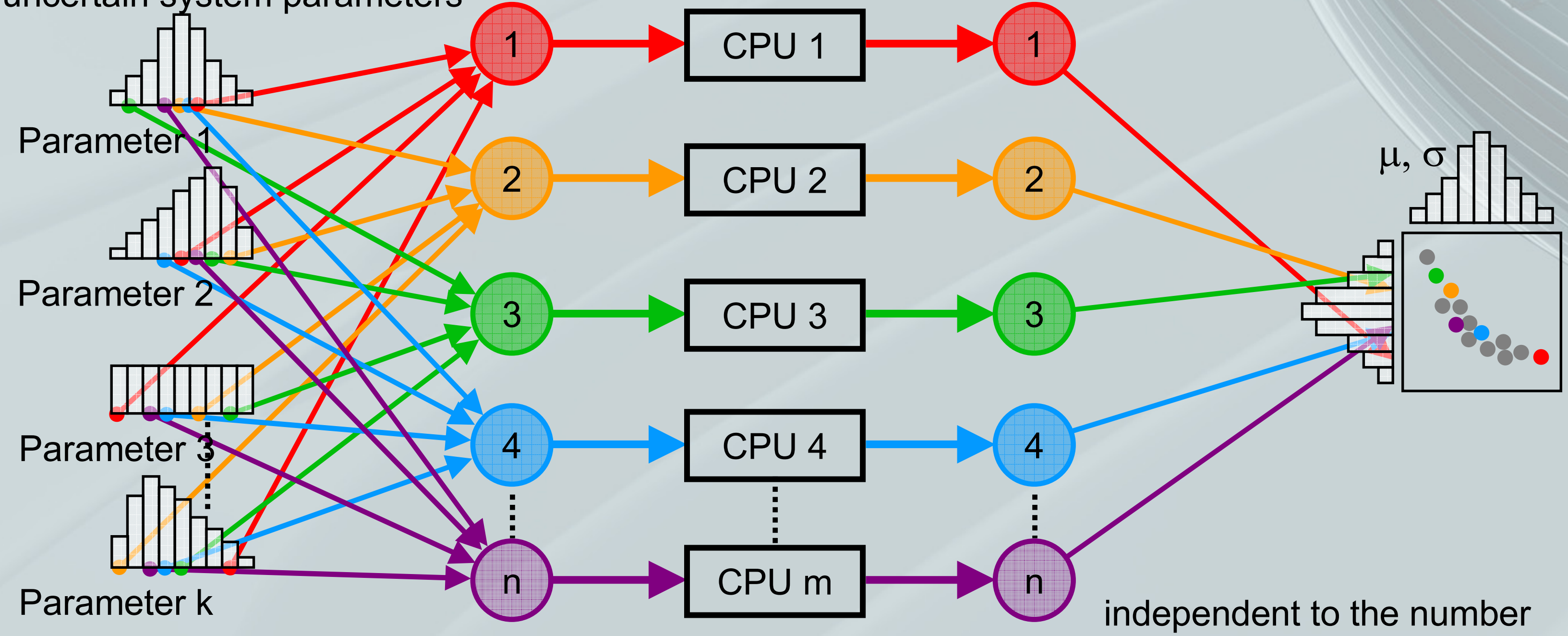
Calculation (Analysis)

- Fixed link between Model and numerical analysis result
- Disadvantages:
  - Cause-effect relationships of the system may remain concealed
  - Influence of scatter due to production and usage tolerances not quantifiable
  - No information about system robustness

Stochastic Simulation (Monte Carlo Method)

generation of n random samples according to k Input PDFs modelling all uncertain system parameters

sequential or parallel computation of n simulations on m CPUs

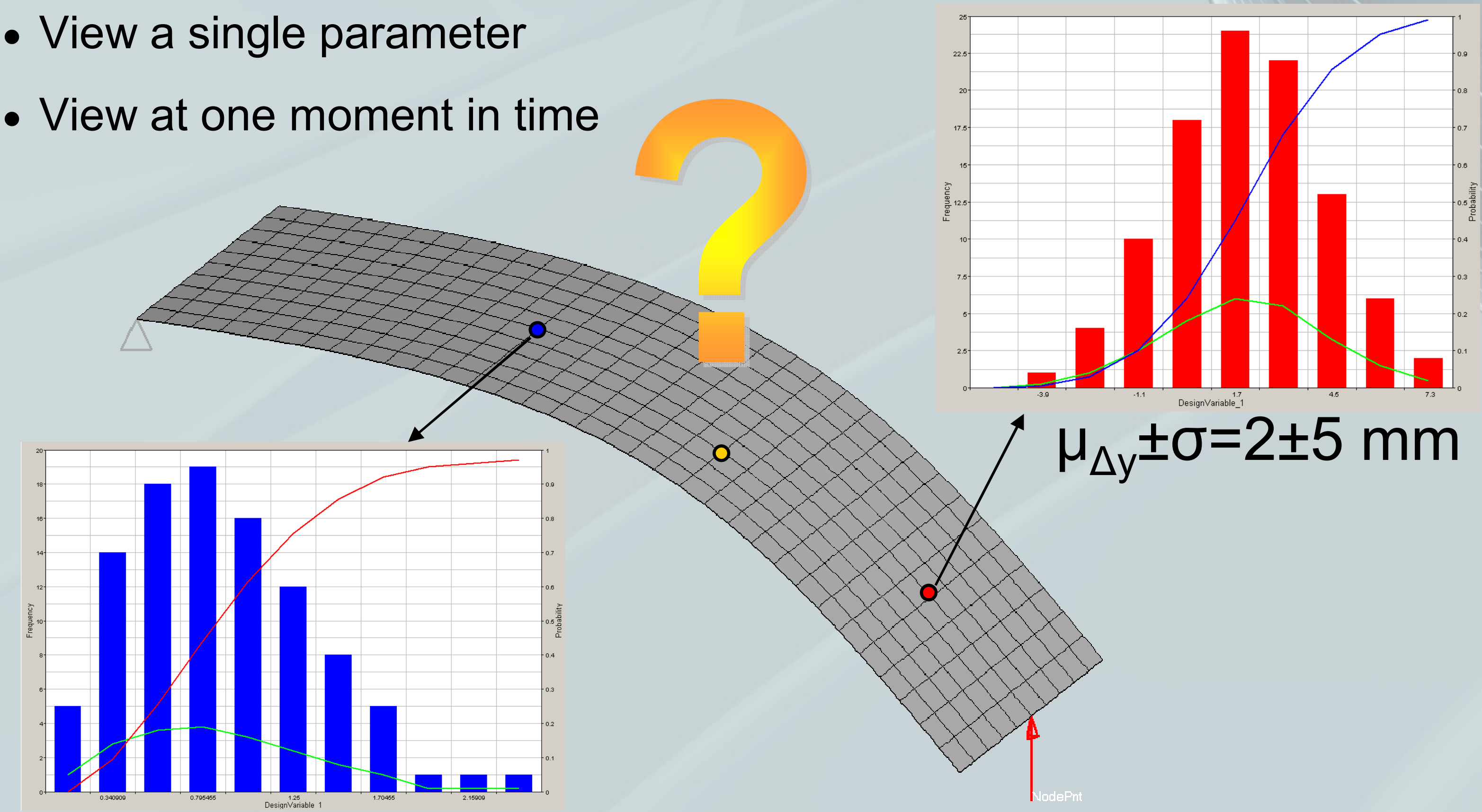


create duplicates of the model for each set of the n random samples

independent to the number of inputs 50 to 150 random samples are required to estimate the global population behaviour

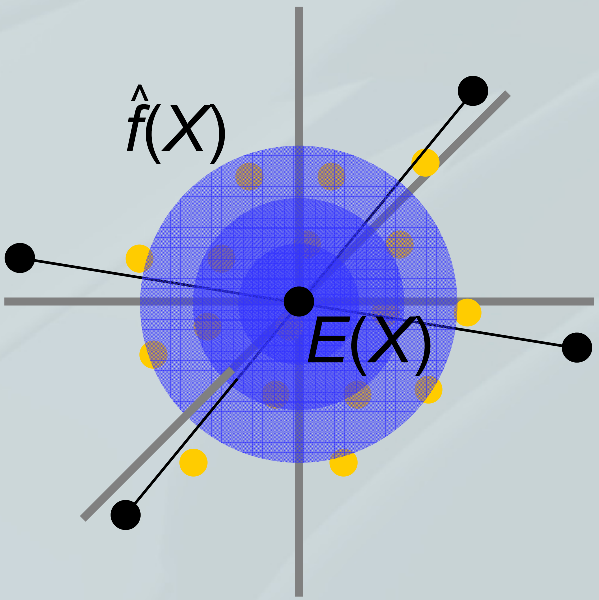
Limitations of today's statistic visualisation in CAE

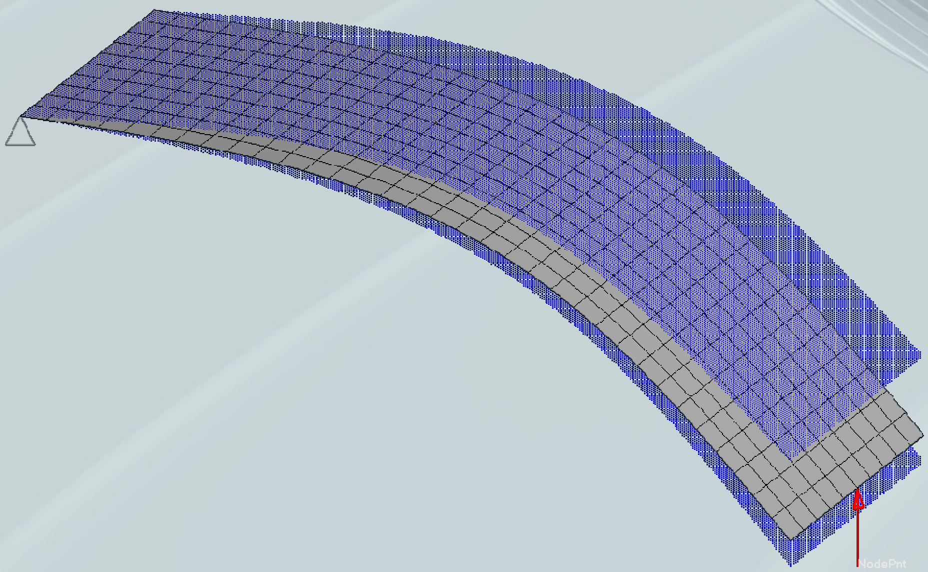
- View a single point in space
- View a single parameter
- View at one moment in time



New method to visualise geometric scatter

- Density estimation of three-dimensional density function from the samples
- Calculation of the expected value per each node of the mesh
- Assembly of the expected value geometry by connection of these nodes
- Derivation of convex hulls with regard to user defined *α*-levels of maximum probability density





Non-parametric density estimation

- Kernel density estimator

$$\hat{f}(x) = \frac{1}{n \cdot h} \sum_{i=1}^{n} K(u)$$

- Epanechnikov-Kernel

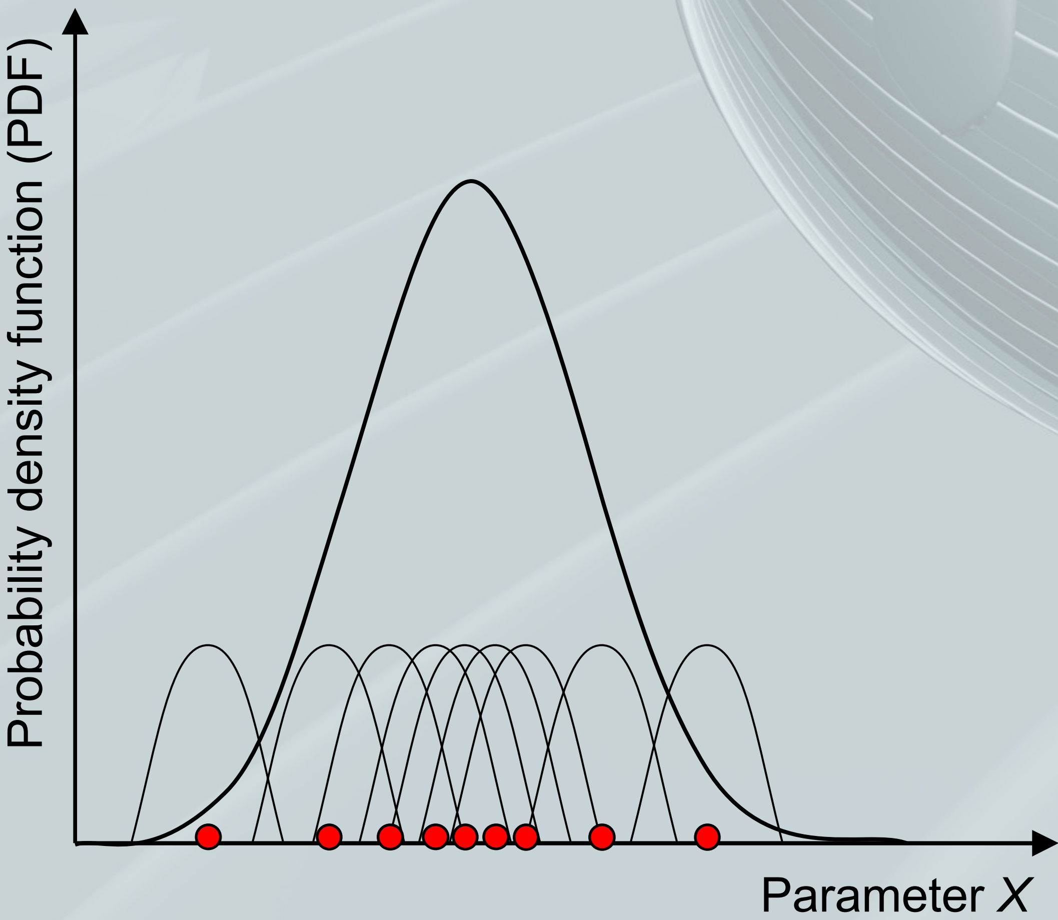
$$K_{\mathrm{Epa}}(u) = \frac{3}{4}\left(1 - u^2\right)$$

for $-1 \leq u < 1$,

outside $u = 0$

and $u = \dfrac{x - x_i}{h}$

- Trade-off between variance and bias depending on bandwidth h



Non-parametric density estimation

- General multivariate kernel density estimator

$$\hat{f}(\mathbf{x}) = \frac{1}{n}\sum_{i=1}^{n}\left[\prod_{j=1}^{d}\frac{1}{h_j}K\left(\frac{x_j - x_{ij}}{h_j}\right)\right] \quad \text{mit } x_j \in \mathbf{x}$$

- For three dimensions with Epanechnikov-Kernel

$$\hat{f}(x,y,z) = \frac{3}{4n}\cdot\frac{\sum_{i=1}^{n}\left[1-\left(\frac{x-x_i}{h^{opt}_{\text{Epa},\,x}}\right)^2\right]\cdot\left[1-\left(\frac{y-y_i}{h^{opt}_{\text{Epa},\,y}}\right)^2\right]\cdot\left[1-\left(\frac{z-z_i}{h^{opt}_{\text{Epa},\,z}}\right)^2\right]}{h^{opt}_{\text{Epa},\,x}\cdot h^{opt}_{\text{Epa},\,y}\cdot h^{opt}_{\text{Epa},\,z}}$$

- Optimum asymptotic bandwidth h

$$\text{with } x_i \in \left(x - h^{opt}_{\text{Epa},\,x}, x + h^{opt}_{\text{Epa},\,x}\right], \quad h^{opt}_{\text{Epa},\,x} = \tilde{s}_x\left(\frac{24\sqrt{\pi}}{5n}\right)^{\frac{1}{7}} \text{ and } y_i, z_i \text{ analog.}$$

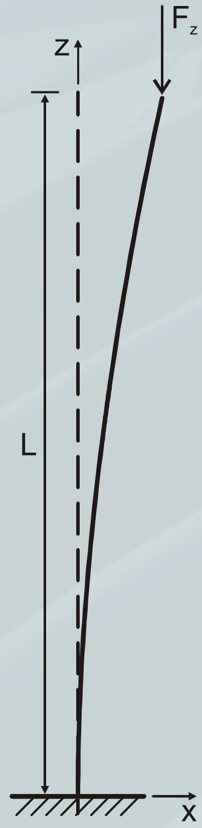
Example: Stochastic Simulation of 1st Euler buckling mode

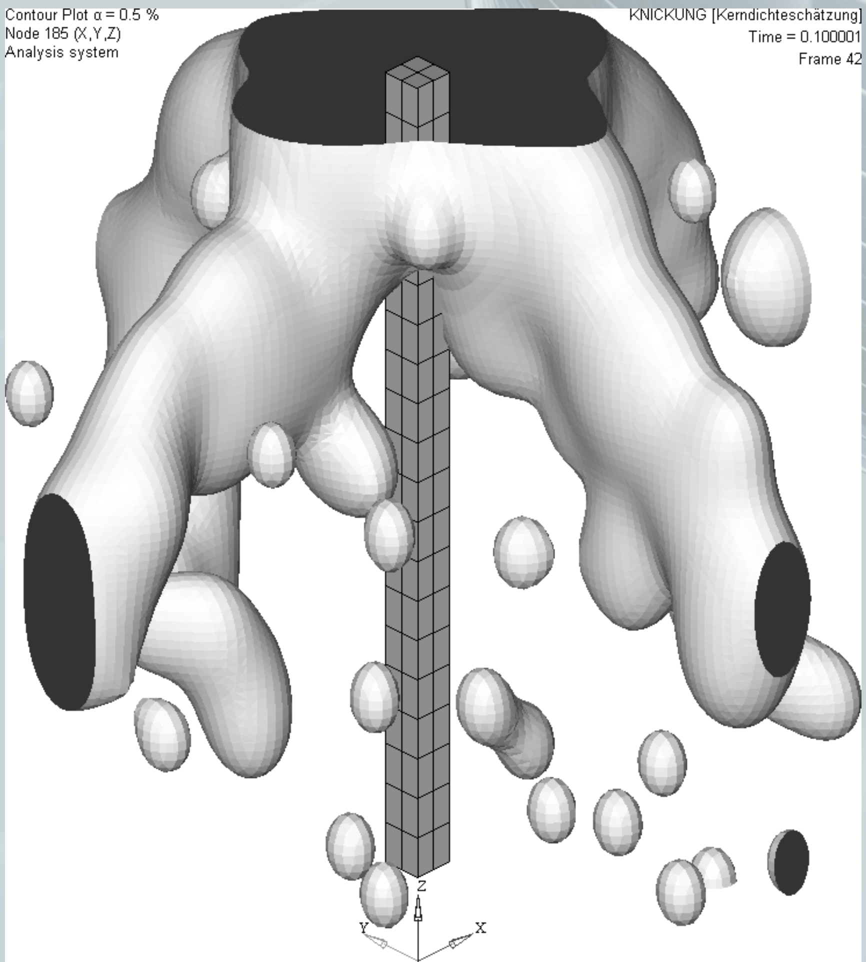
Stochastic parameters:

- Length
- Edge lengths
- Force
- Young's modulus

Isoprobability surface of column tip:

- User defined *α*-level of max PDF
- Marching cube algorithm for convex hull

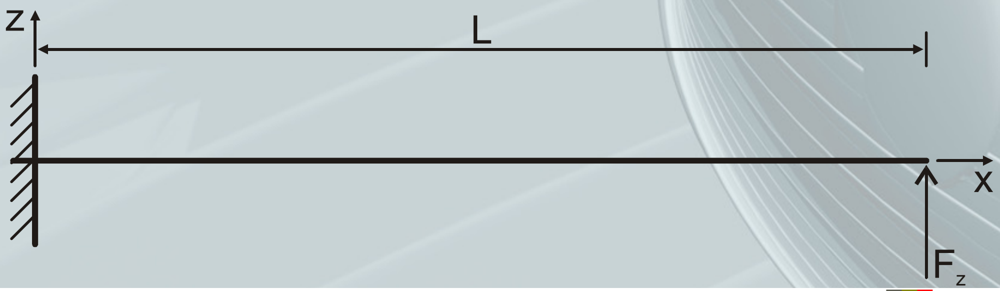




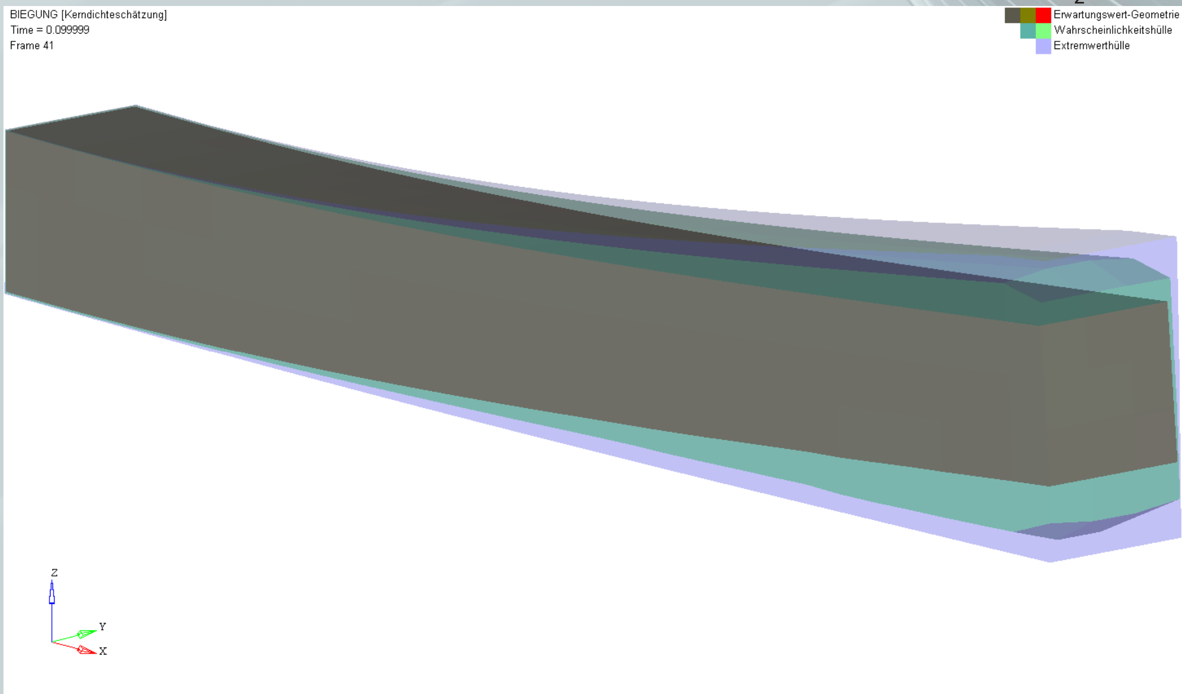
Example: Cantilever with uncertainties

Stochastic parameters:

- Length
- Edge lengths
- Force
- Young’s modulus



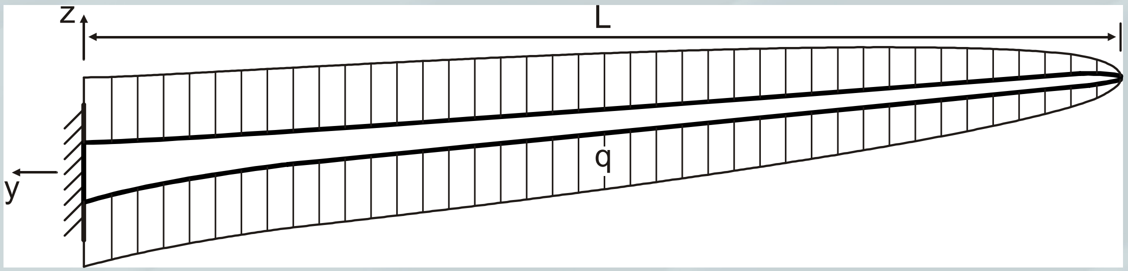
- Expected value geometry with surrounding convex hulls of isoprobability

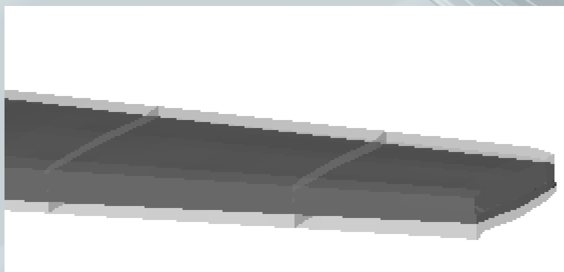


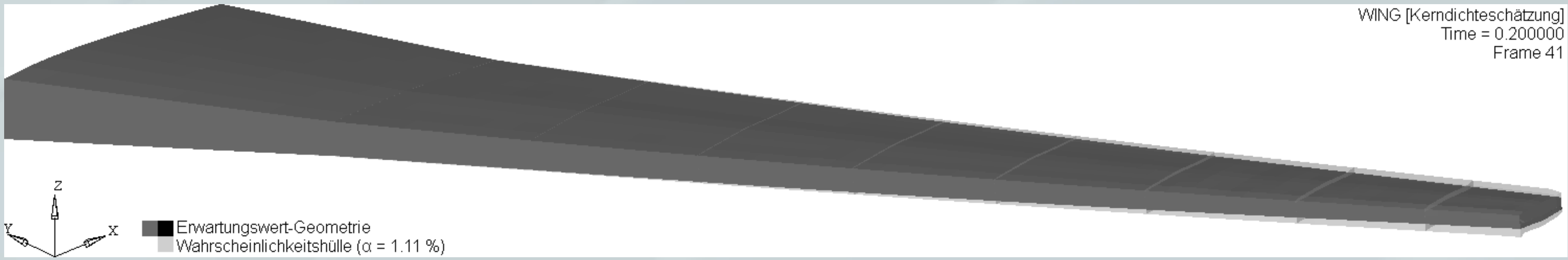
Example: Aircraft wing under varying load conditions

Variation of air loads caused by:

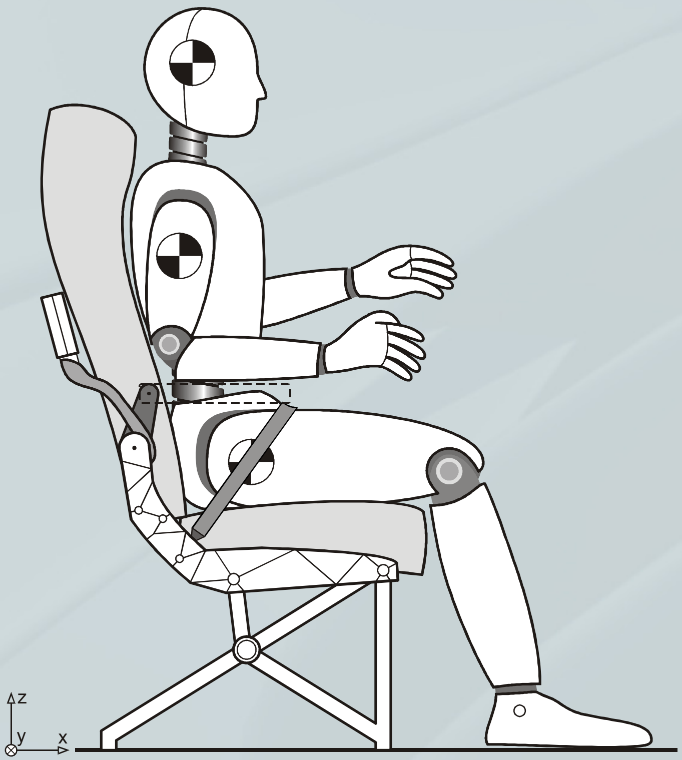
- Turbulence
- Altitude
- Flight conditions

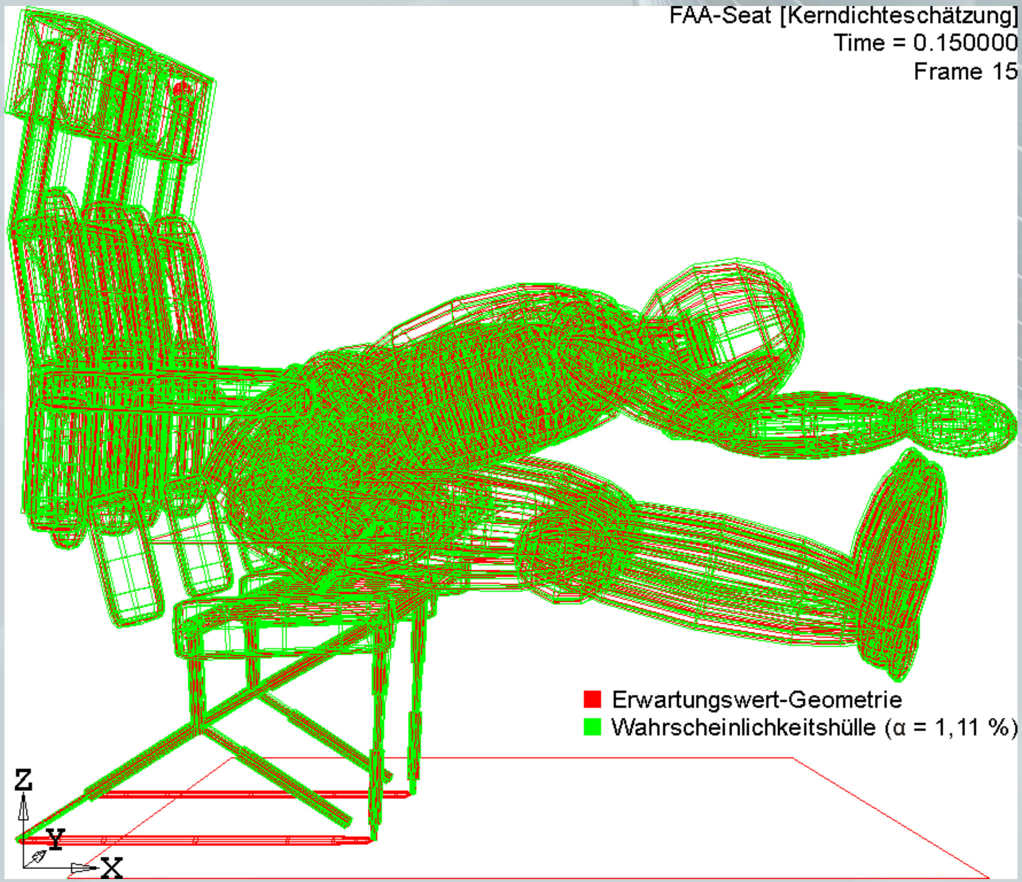






Example: Occupant safety simulation of an aircraft seat





Conclusion

- Assessment of uncertainties important for system reliability and robustness
- Conventional analysis methods limited exploitation of Stochastic Simulation studies

Developed method:

- Relies on non-parametric multivariate density estimation
  - Expected value geometry (most probable system behaviour)
  - Convex hulls of isoprobability considering user defined *α*-levels
- Provides holistic way to visualise geometric scatter
- Allows for statistic collision detection

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Thank you for your attention.

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