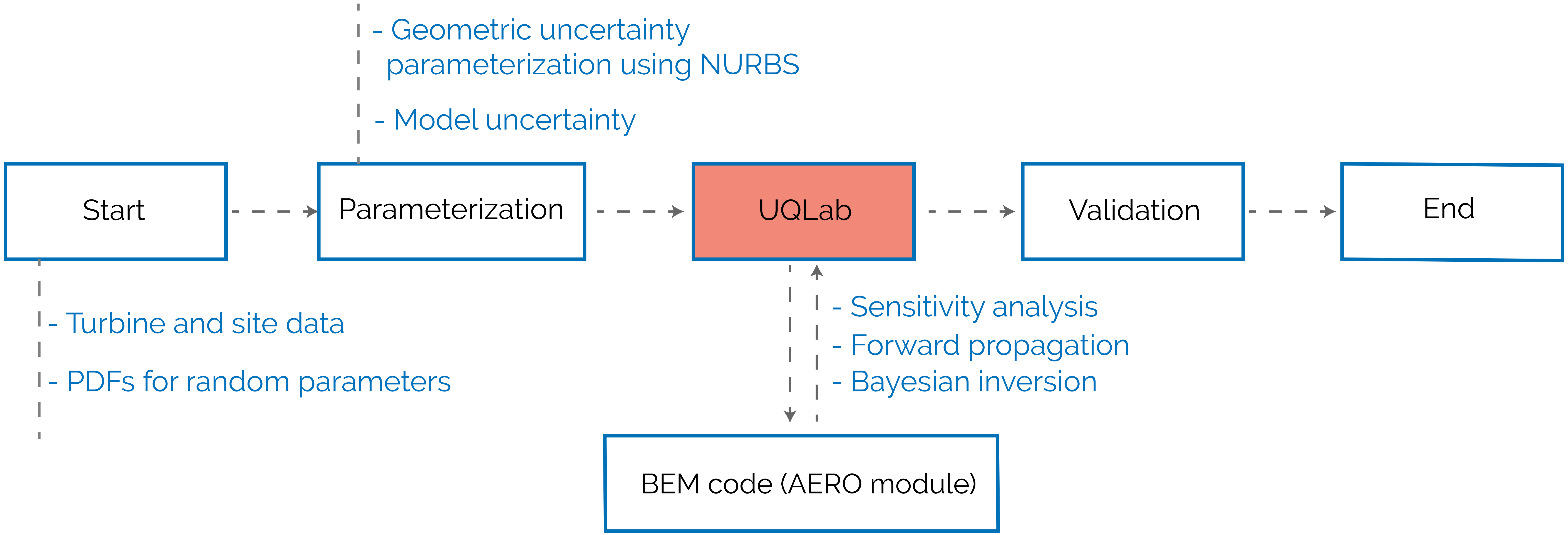
WindTrue: Sensitivity analysis applied to DANAERO wind turbine

Prashant Kumar

Benjamin Sanderse

CWI

Workflow

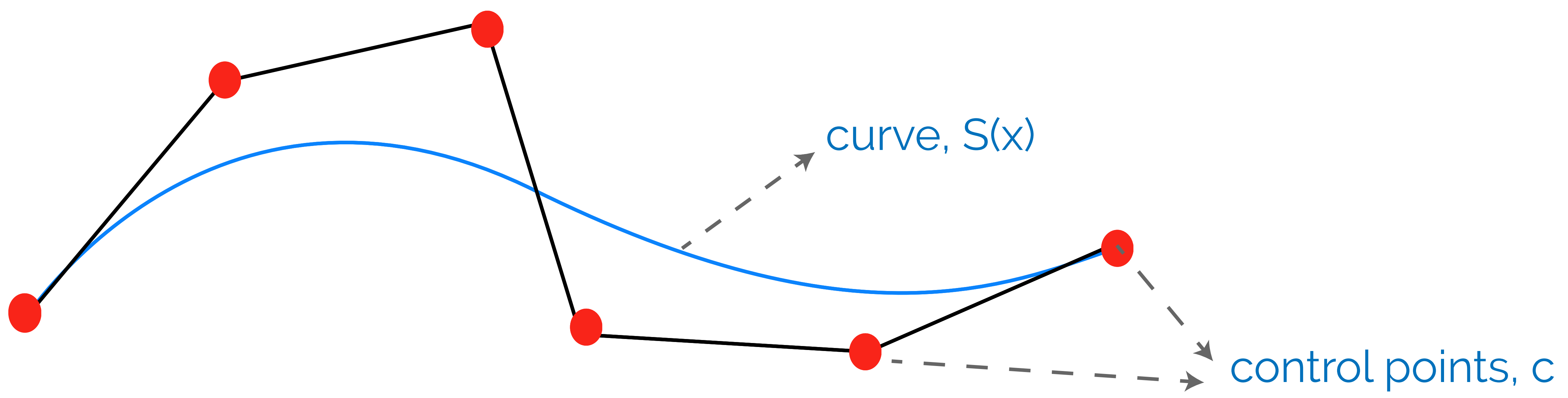


- Geometric uncertainty parameterization using NURBS
- Model uncertainty
Start
Parameterization
UQLab
Validation
End
- Turbine and site data
- PDFs for random parameters
- Sensitivity analysis
- Forward propagation
- Bayesian inversion
BEM code (AERO module)

NURBS based parametrization

Obtain perturbed chord/twist/thickness curves from given reference curves

Non-Uniform Rational Basis Spline (NURBS)



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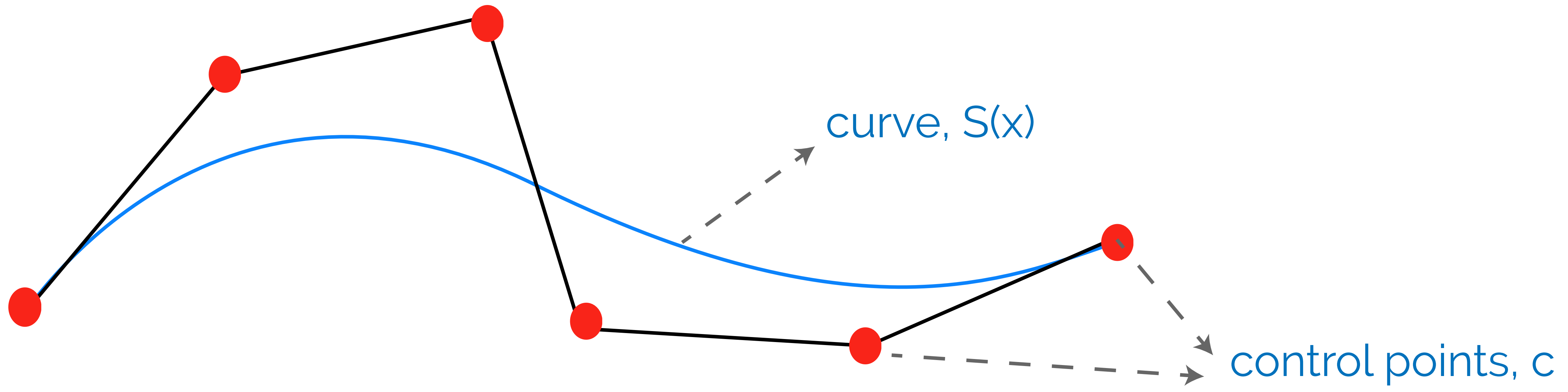

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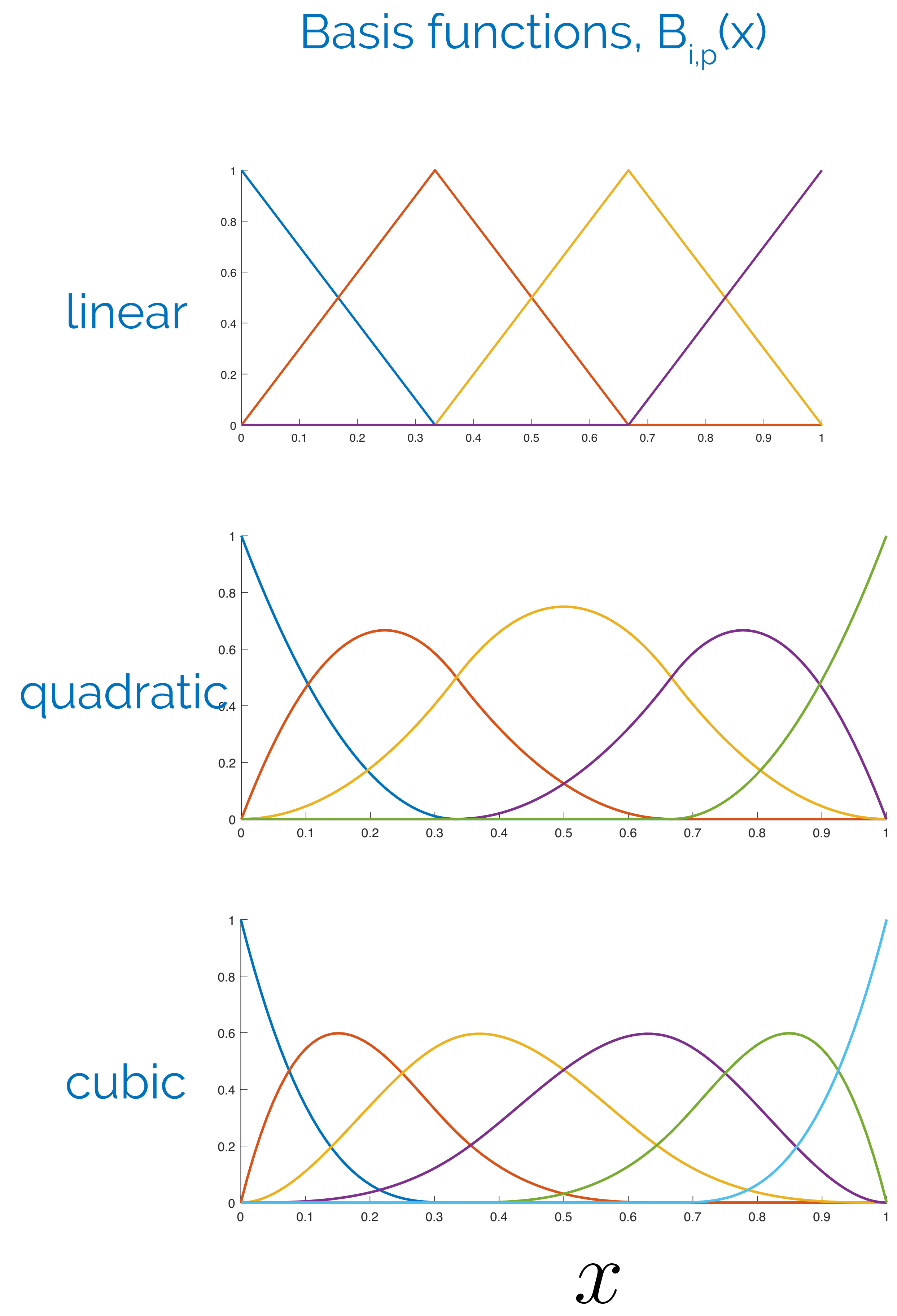

Why NURBS?

-> Represent complex shapes with very few points

-> Flexibility to design a large variety of shapes

-> Easy to obtain high-order polynomials

Parameterization using NURBS

Goal: Obtain perturbed chord curves from a given reference chord

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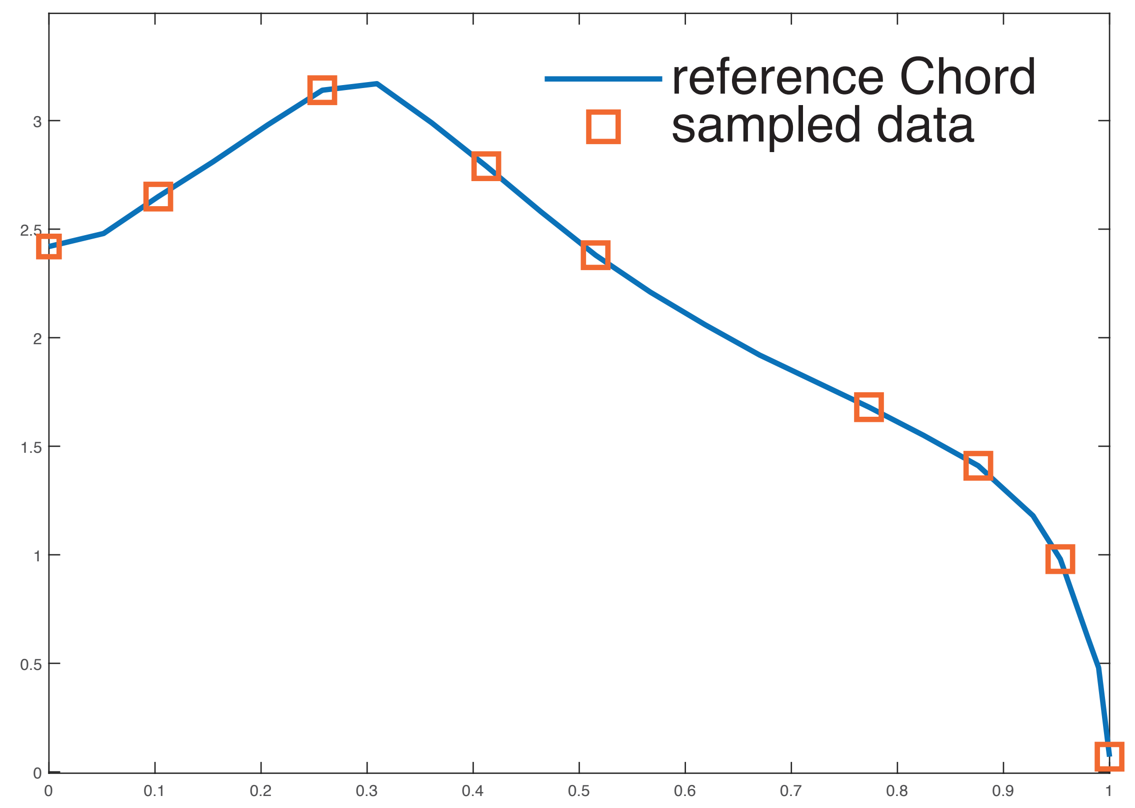
Step 1: Sample locations from the reference curve



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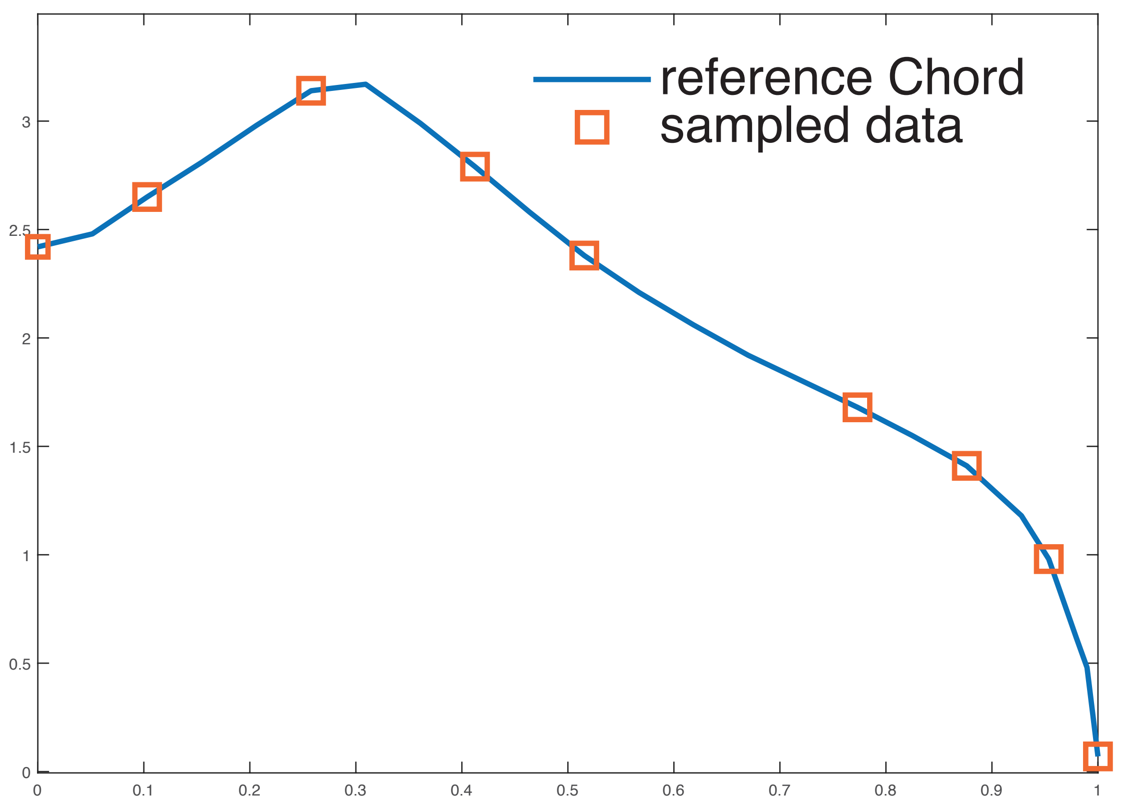

Step 2: Compute control points at sampled location via inversion

$$\underbrace{S(x)}_{\text{known}} = \sum_{i=0}^{N-1} c_i \underbrace{B_{i,p}(x)}_{\text{known}} \implies \mathbf{B}\mathbf{c} = \mathbf{S}$$

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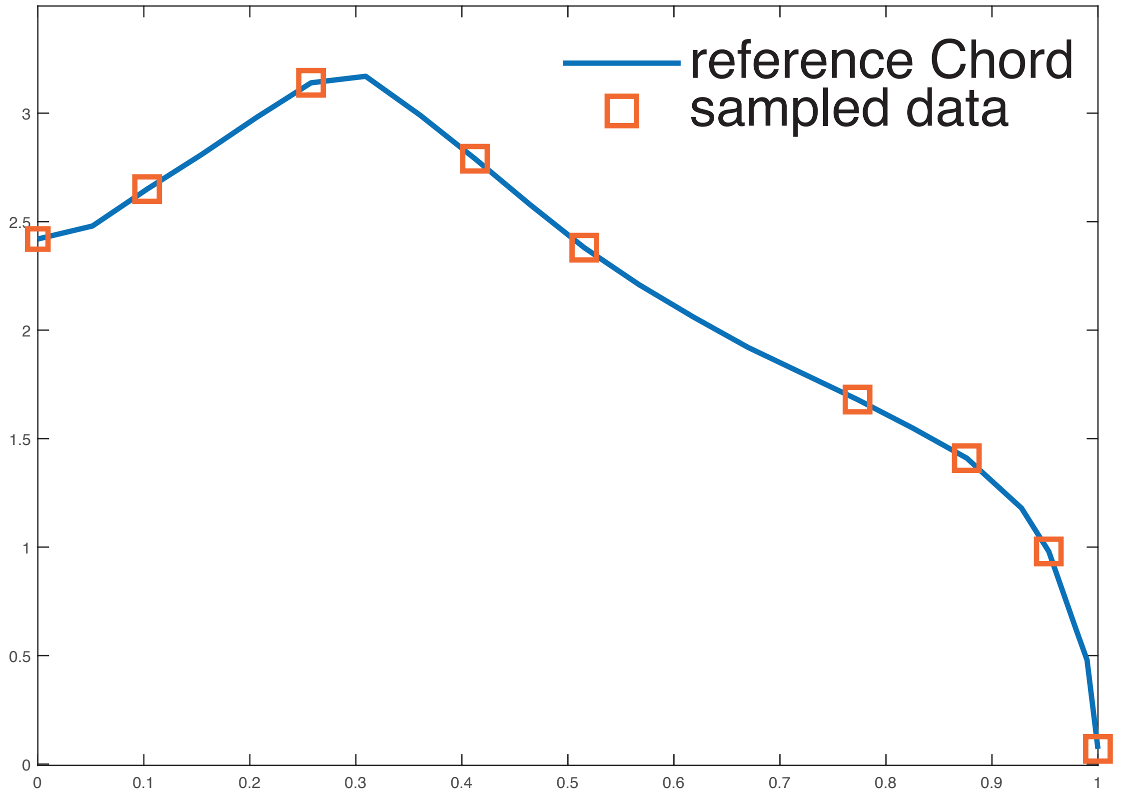

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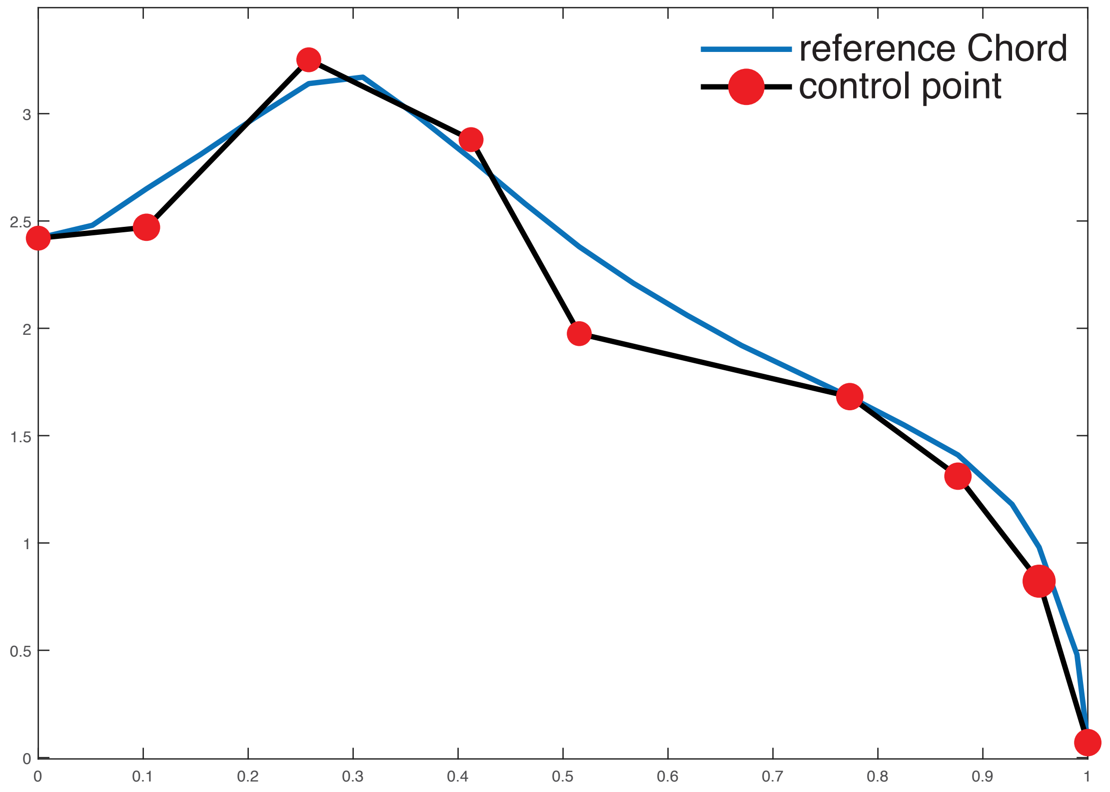
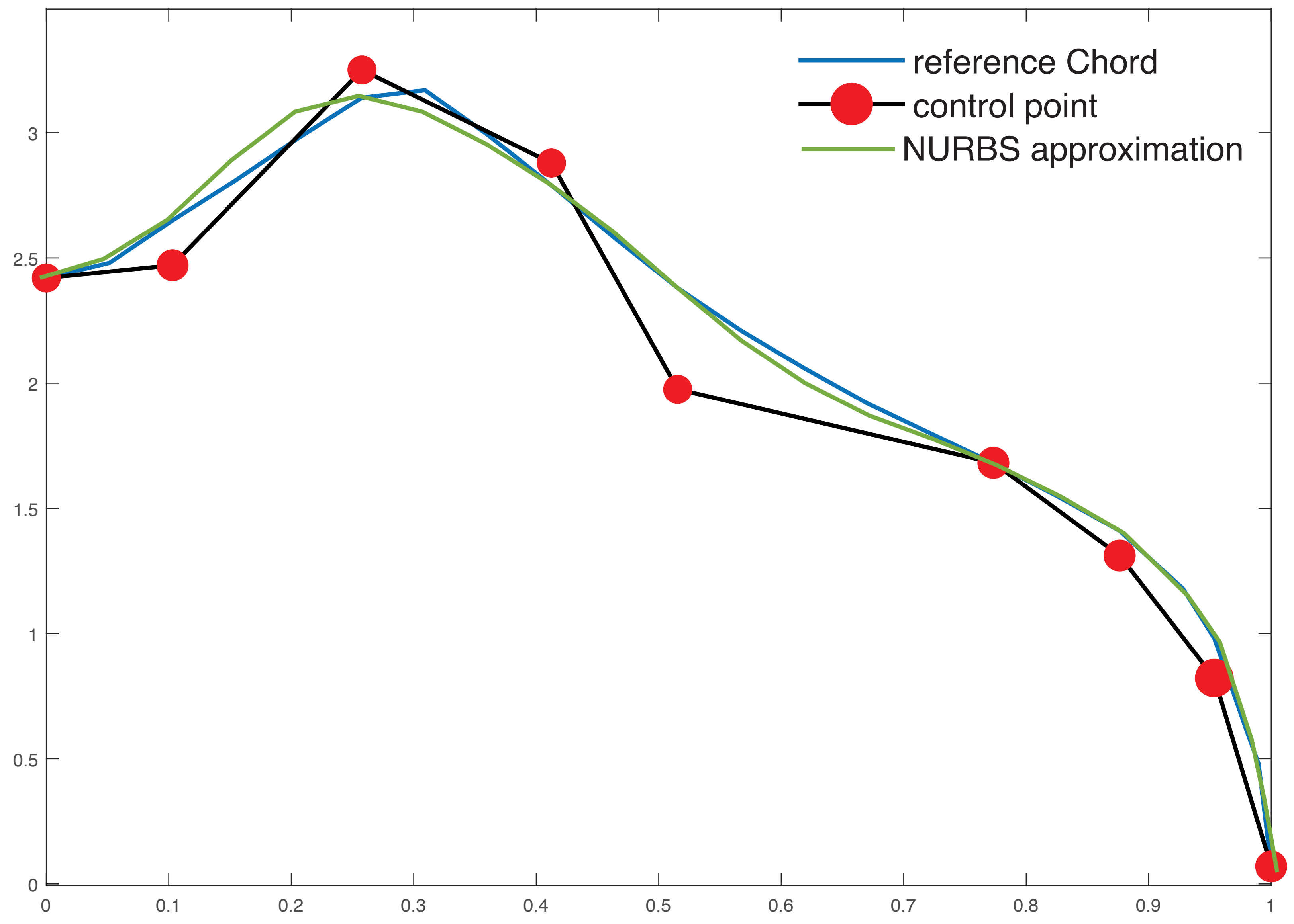
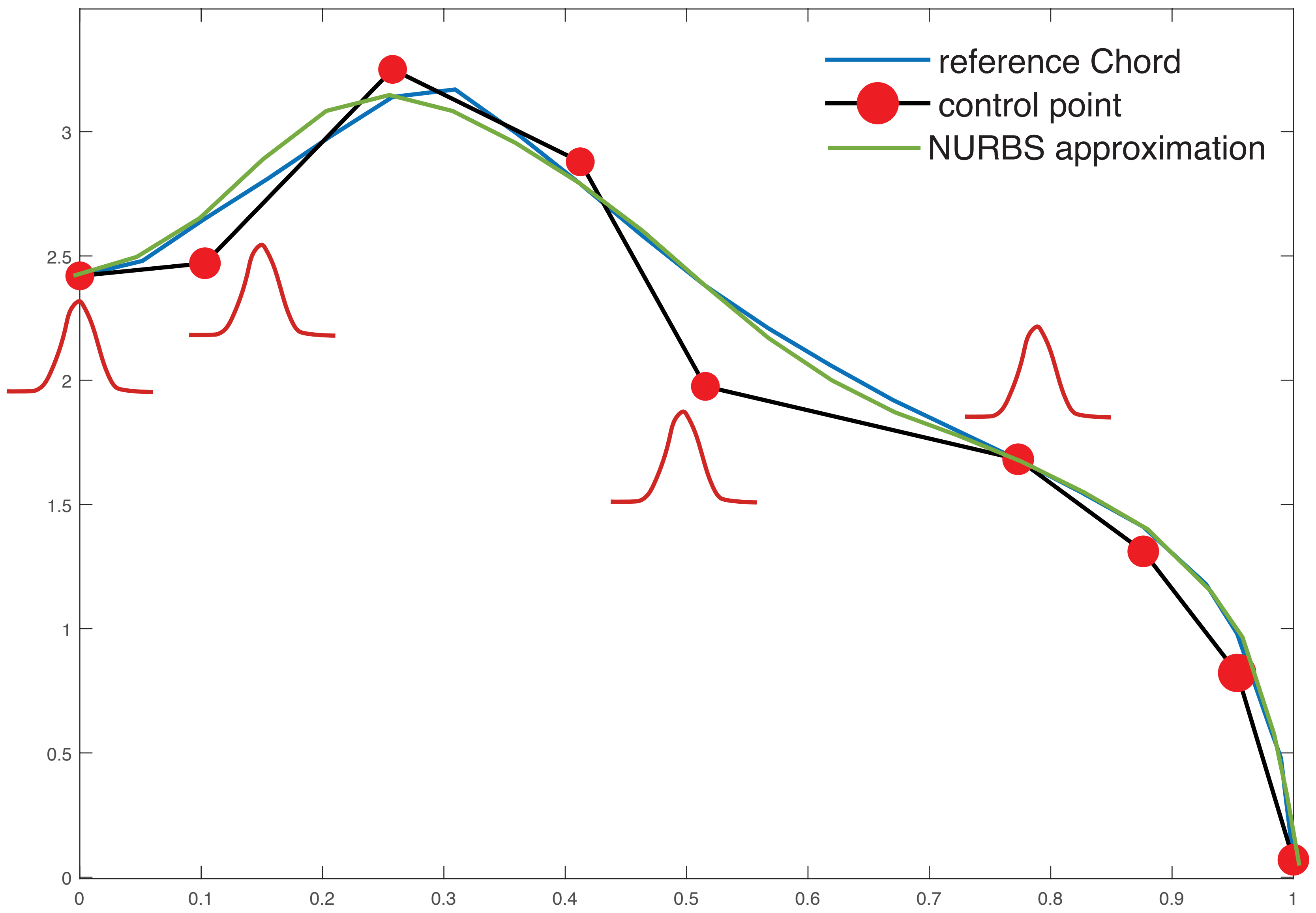


Parameterization using NURBS



Parameterization using NURBS

Step 3: Perturb control point values using some PDFs



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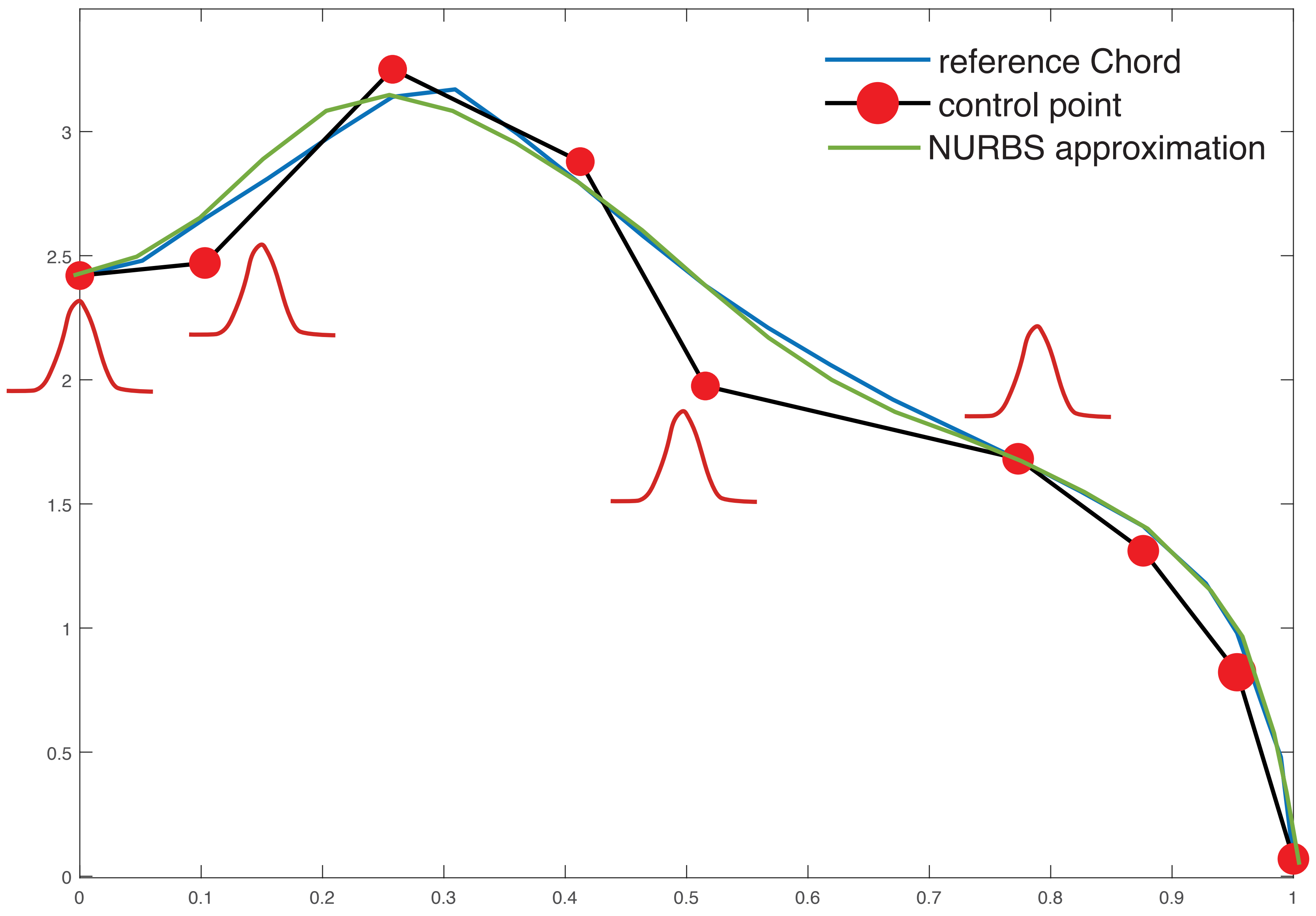
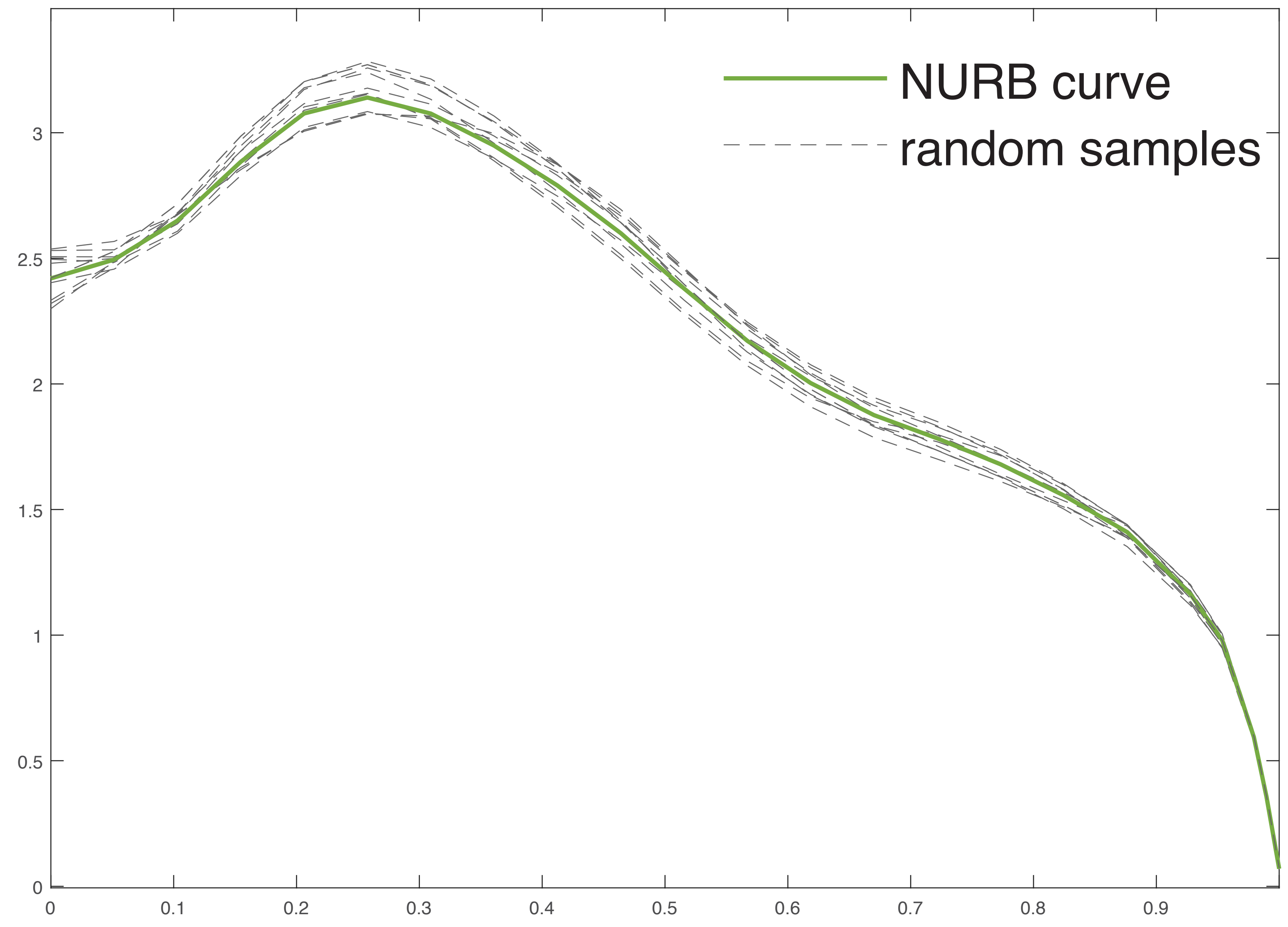


Step 4: Sample perturbed curves



Global sensitivity analysis

Global sensitivity analysis

-> Goal is to rank the uncertain parameters in the order of importance

-> Global approaches cover the uncertainty spaces more exhaustively
than local approches

-> Better able to capture uncertainty in the model output

Sobol sensitivity indices

Main idea: Decompose the variance of model output in terms of contribution from individual input parameters and their combinations.

$$V(y) = \sum_i V_i + \sum_{i,j} V_{i,j} + \text{higher order terms}$$

First order indices

$$S_1 = \frac{V_1}{V}, S_2 = \frac{V_2}{V}, ...$$

Second order indices

$$S_{1,2} = \frac{V_{1,2}}{V}, S_{1,3} = \frac{V_{1,3}}{V}, ...$$

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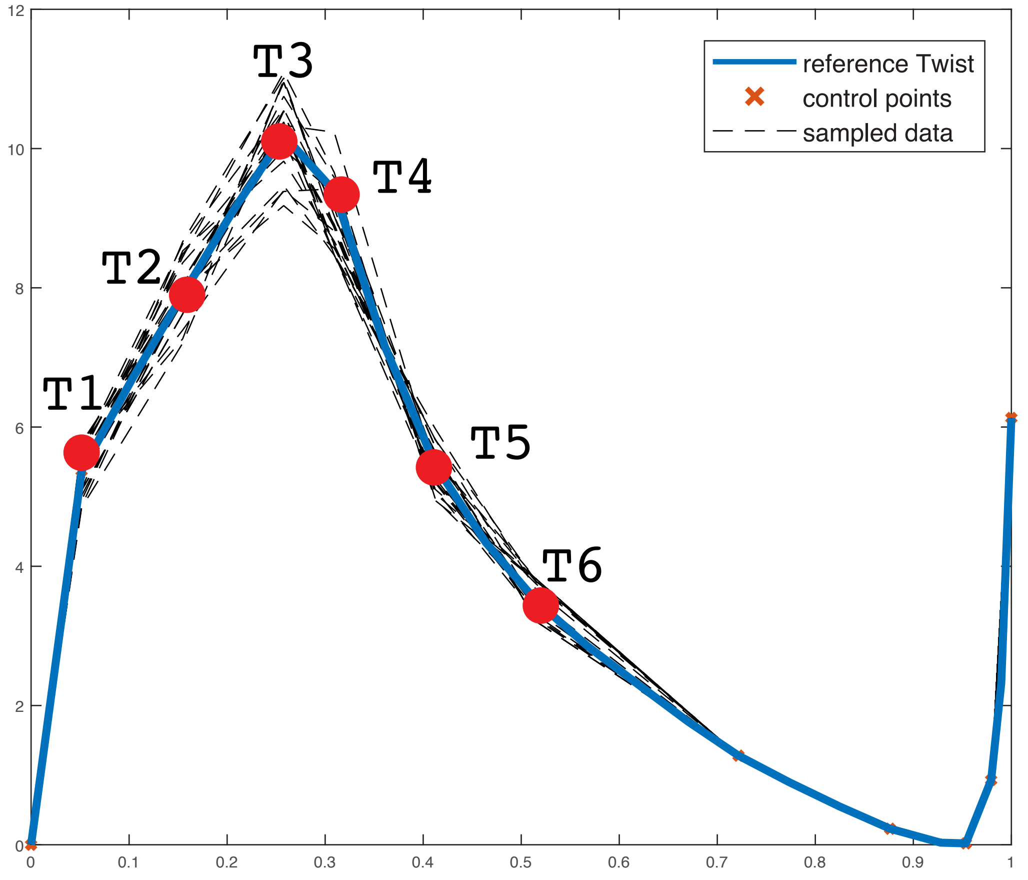
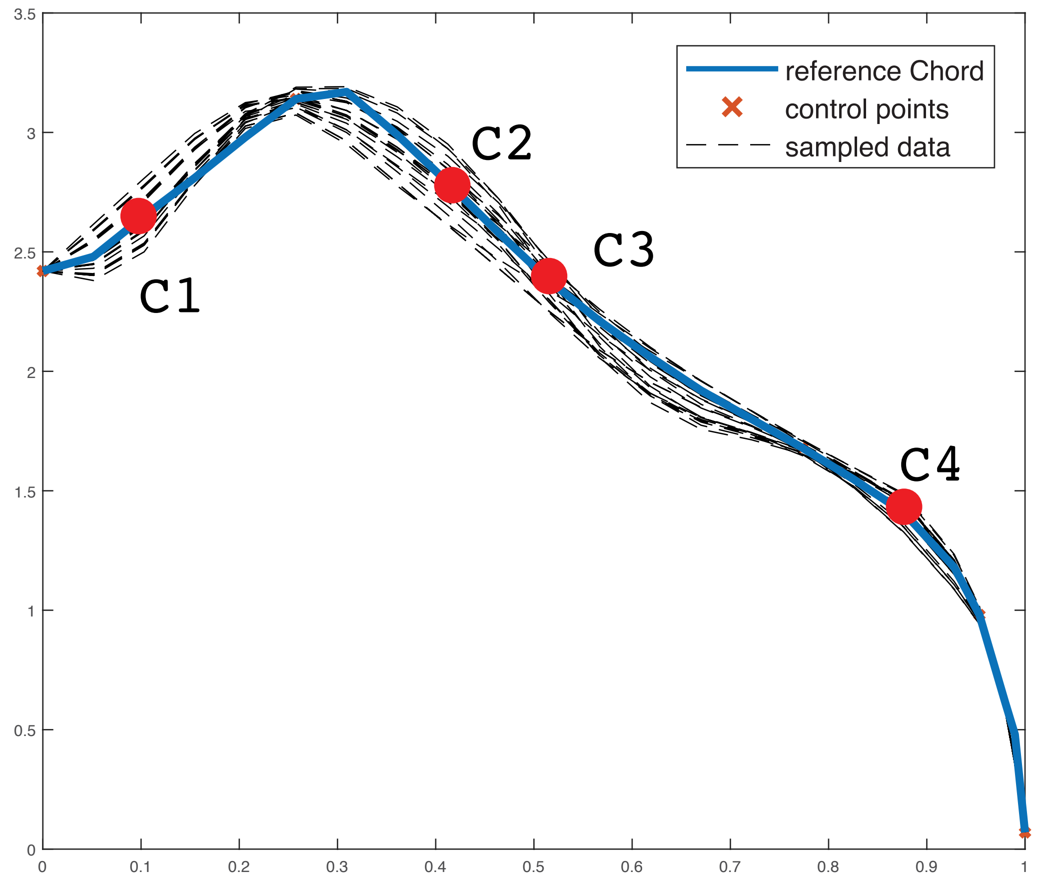
We use **adaptive Polynomial Chaos Expansion** (Least angle regression) to compute variances

Sensitivity analysis results

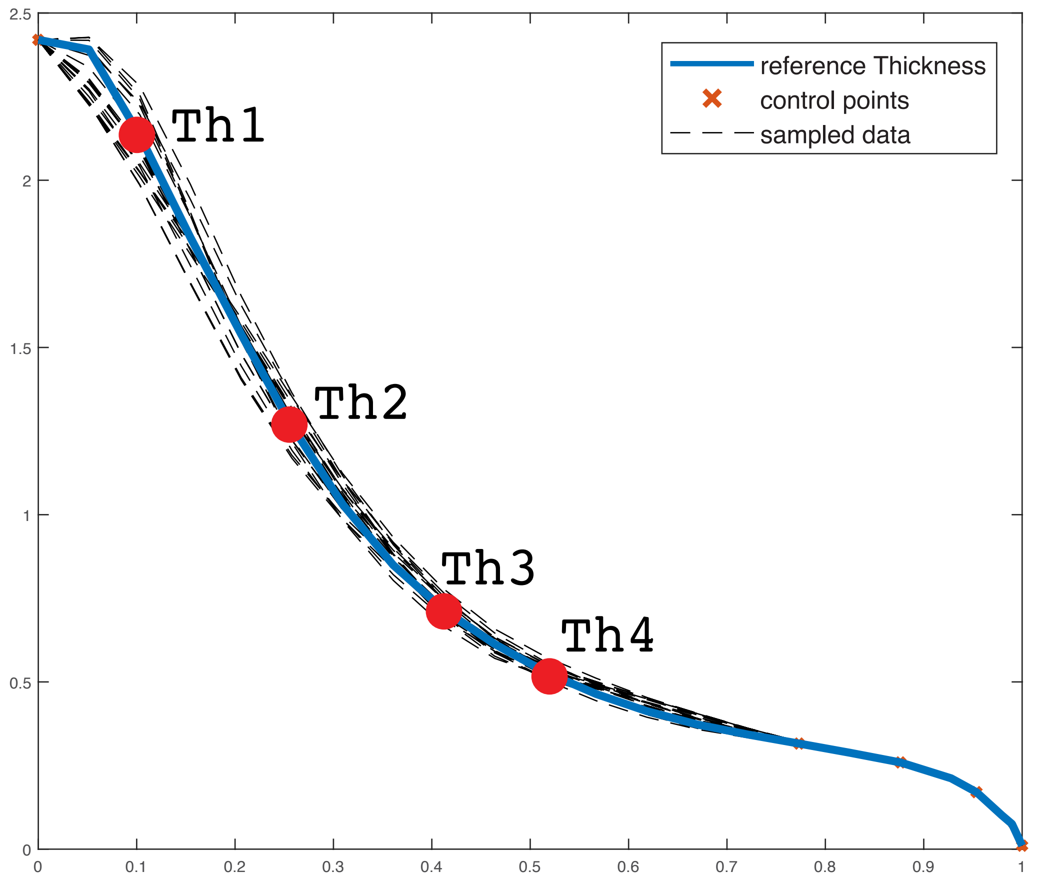
Geometric Uncertainty



Twist



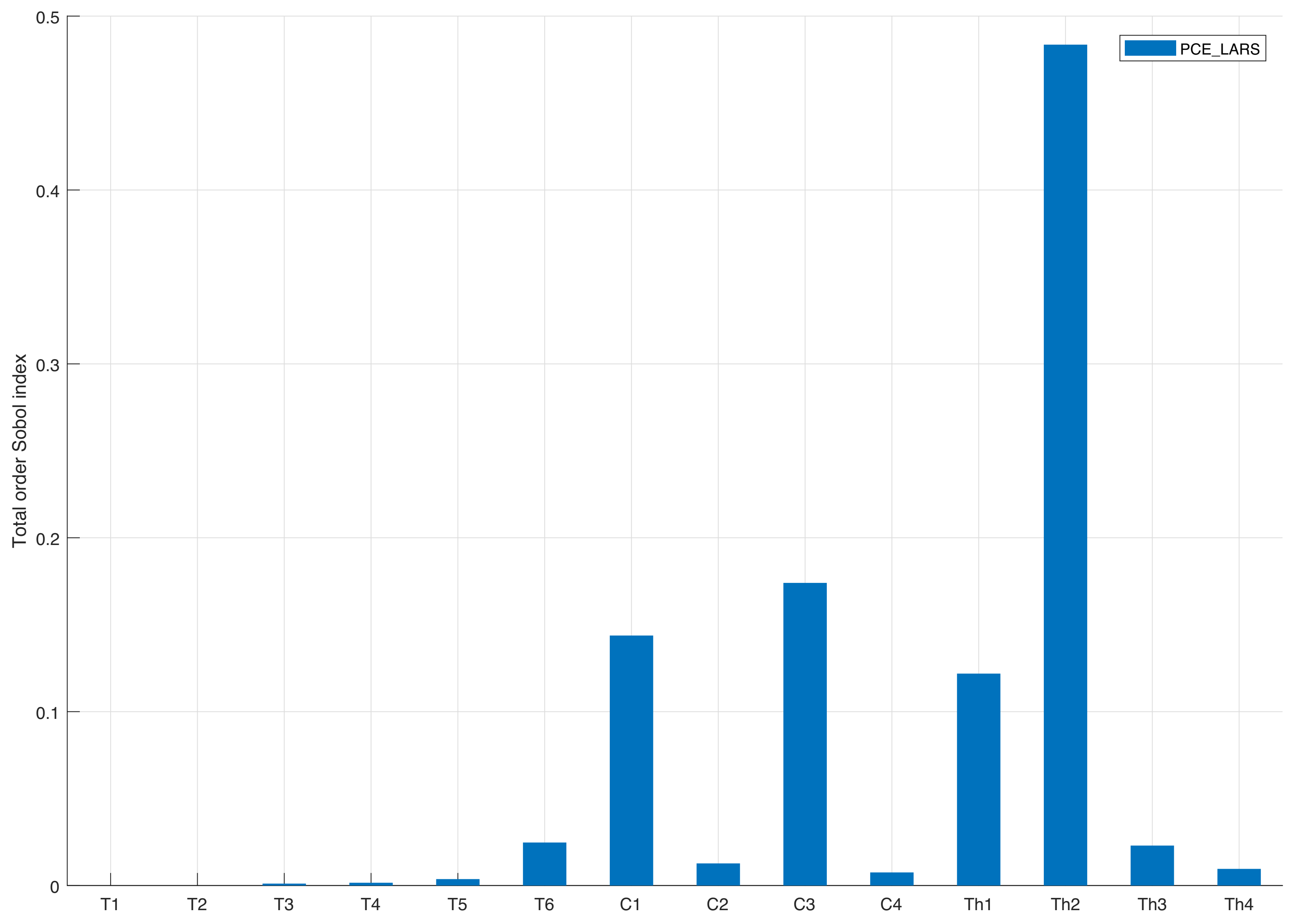
Chord



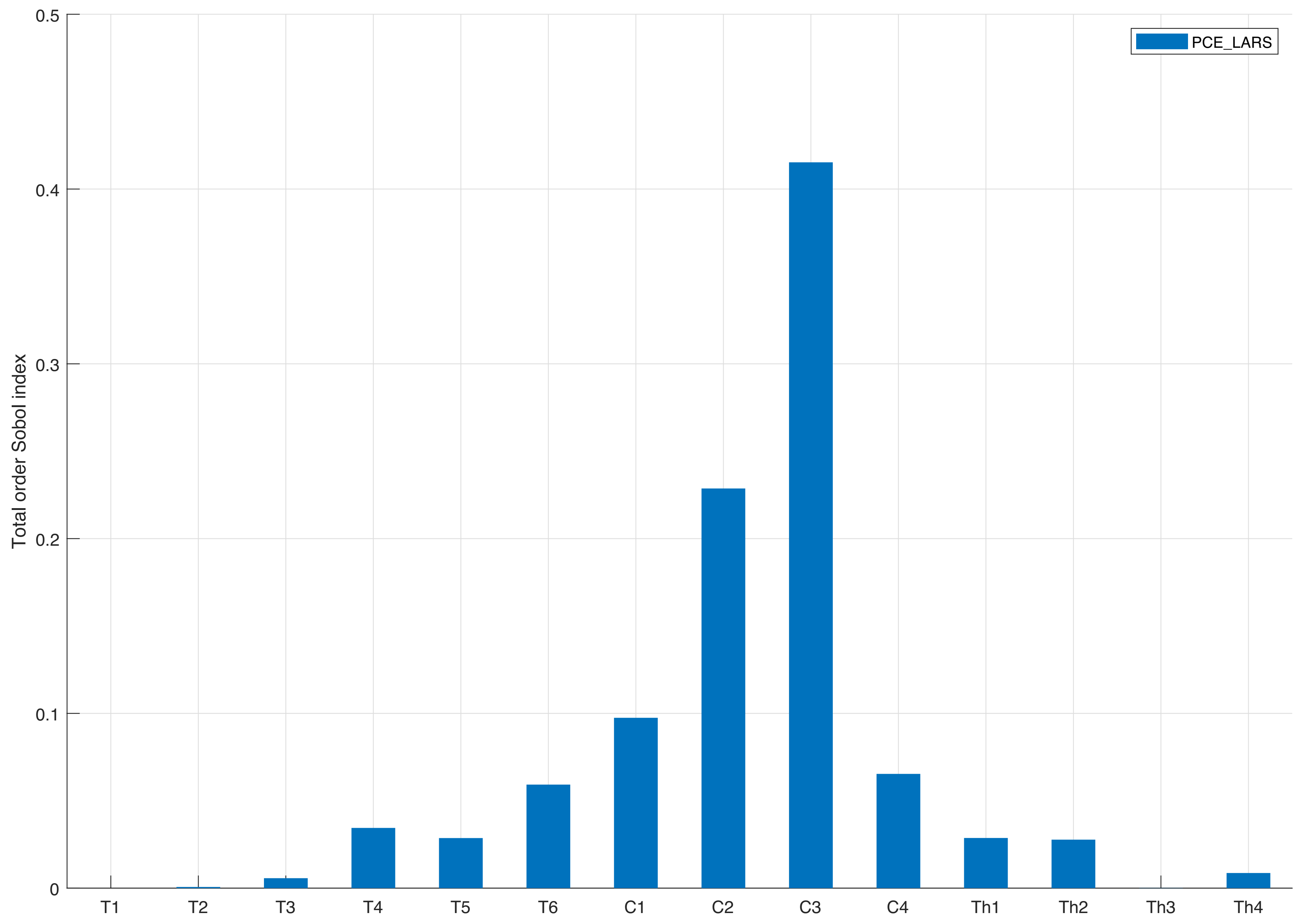
Thickness

10% (uniformly distributed) uncertainty in chosen control point

Sobol indices



Power



Axial Force

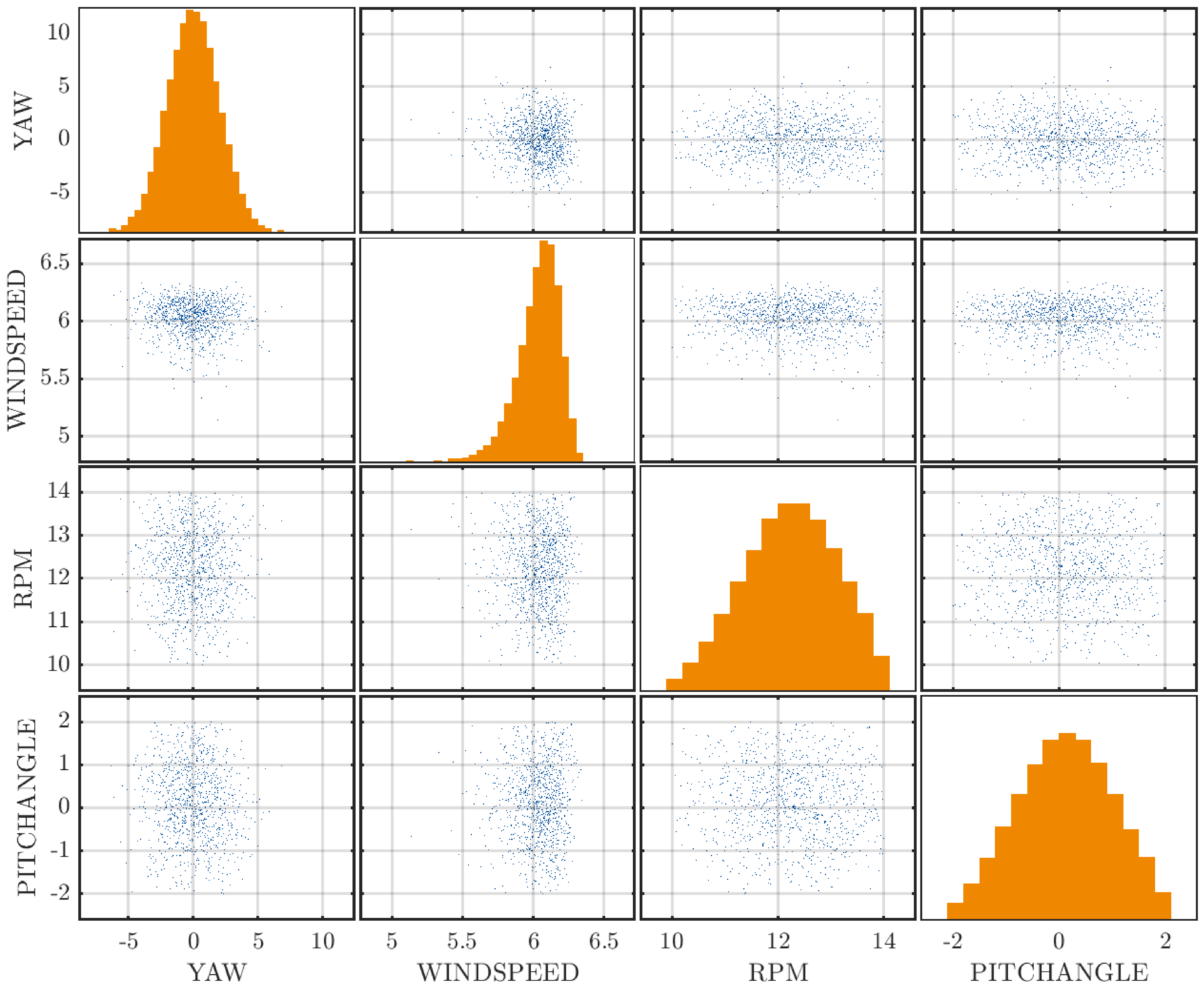
Operational Uncertainty

Yaw
Truncated Gaussian [mean = 0, std = 2, LB = -10, UB = 10]

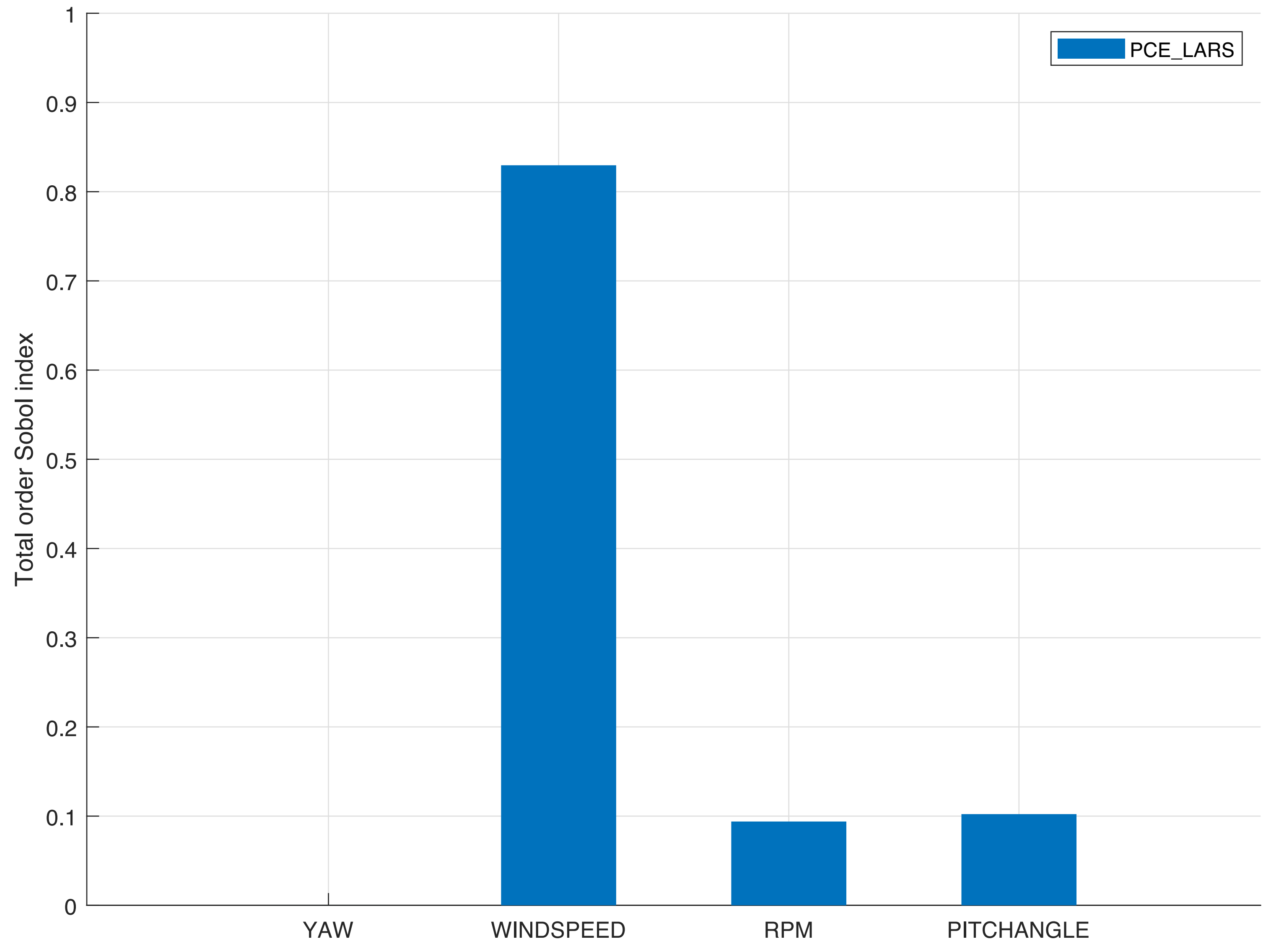
WindSpeed
Weibull distribution [Scale = 6.1, Shape = 50]

RPM
Truncated Gaussian [mean = 12.3, std = 1, LB = 10, UB = 14]

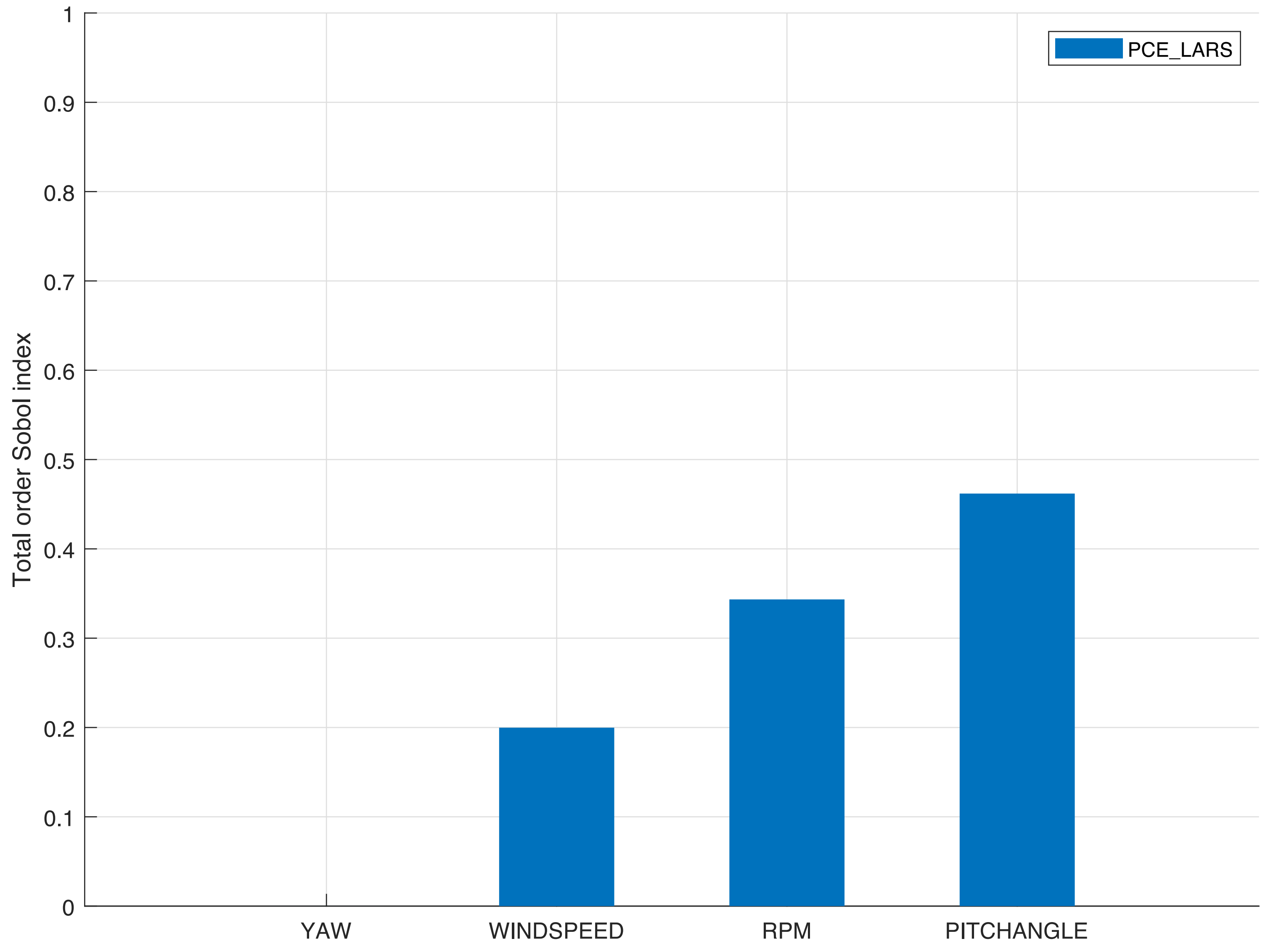
PitchAngle
Truncated Gaussian [mean = 0.15, std = 1, LB = -2, UB = 2]



Sobol indices



Power



Axial Force

Conclusions

-> Global SA is a powerful method to analyze uncertainties in BEM models

-> Chord and Thickness more sensitive compared to Twist

-> Yaw angle is least sensitive parameter compared to WindSpeed, RPM and Pitch

Next Steps

-> Determine realistic amount of perturbations for uncertain parameters

-> Parameterization for other random inputs, model-form uncertainty

-> Include other BEM codes in the workflow and perform comparisons