Workshop on Bayesian calibration using UQLab

WINDTRUE: WP2

Vinit Dighe & Benjamin Sanderse

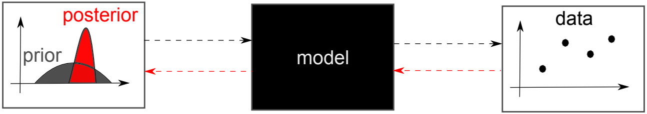
September 09, 2020

CWI

UQLab and Aeromodule installation test

- UQLab
  - Set the Matlab layout to **Default**.
  - Type **uqlab** in command window.
  - Change the path in **config.m** file located in the **sensitivity_analysis** folder. The path will be where your personal UQLab licence is stored.
  - Type **uqlab** in command window.
- Aeromodule
  - Run the **ECNAero** executable to check whether your Aeromodule licence is activated.
    Folder: sensitivity_analysis/AEROmodule/NM80_calibrate

Ingredients to perform Bayesian calibration

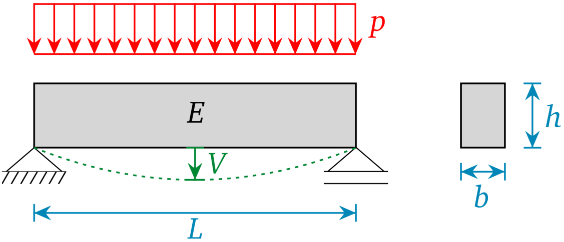


- Experimental data
- Forward model
- Likelihood/Discrepancy
- Prior

Examples

- Simple beam model calibration
- ECN AeroModule calibration
- Exercise

Simple beam model calibration



Calibration/surrogate_beam.m

Calibration/uq_SimplySupportedBeam.m

Problem setup

Ingredients for Bayesian calibration

- Data ($\mathbf{y}$): {12.84, 13.12, 12.13, 12.19, 12.67} (mm)
- $\boxed{\text{Forward model}}$: $V = \frac{5}{32}\frac{pL^4}{Ebh^3}$
- Likelihood: $\pi(\mathbf{y}|\theta)$: $\sigma^2 = 10^{-6}$
- Prior distribution:

θ	$\pi(\theta)$
b (m)	0.15
h (m)	0.3
L (m)	5
p (kN/m)	$\mathcal{N}(0.012, 0.0006)$
E (MPa)	$\mathcal{LN}(30000, 4500)$

Problem setup

Ingredients for Bayesian calibration

```
myData.y = [12.84; 13.12; 12.13; 12.19; 12.67]/1000;  % (m)
myData.Name = 'Mid-span deflection';
```

```
ModelOpts.mFile = 'uq_SimplySupportedBeam';
ModelOpts.isVectorized = true;
myForwardModel = uq_createModel(ModelOpts);
```

```
DiscrepancyOpts.Parameters = 1e-6; % known discrepancy variance
BayesOpts.Discrepancy = DiscrepancyOpts;
```

```
PriorOpts.Marginals(1).Name = 'b';               % beam width
PriorOpts.Marginals(1).Type = 'Constant';
PriorOpts.Marginals(1).Parameters = [0.15];      % (m)

PriorOpts.Marginals(2).Name = 'h';               % beam height
PriorOpts.Marginals(2).Type = 'Constant';
PriorOpts.Marginals(2).Parameters = [0.3];       % (m)

PriorOpts.Marginals(3).Name = 'L';               % beam length
PriorOpts.Marginals(3).Type = 'Constant';
PriorOpts.Marginals(3).Parameters = 5;           % (m)

PriorOpts.Marginals(4).Name = 'E';               % Young's modulus
PriorOpts.Marginals(4).Type = 'LogNormal';
PriorOpts.Marginals(4).Moments = [30000 4500];   % (MPa)

PriorOpts.Marginals(5).Name = 'p';               % uniform load
PriorOpts.Marginals(5).Type = 'Gaussian';
PriorOpts.Marginals(5).Moments = [0.012 0.012*0.05]; % (kN/m)

myPriorDist = uq_createInput(PriorOpts);
```

Prior and posterior distribution

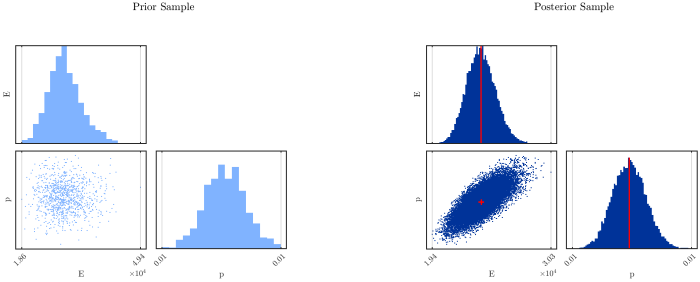


Figure: Prior and posterior samples.

MAP estimate

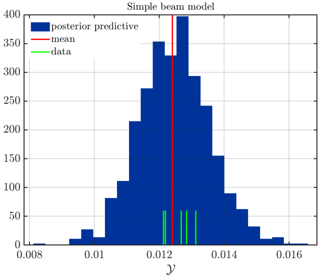
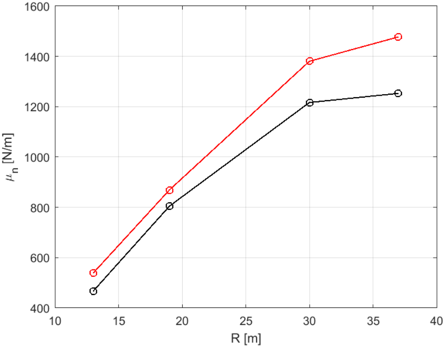


Figure: Bayesian estimate using posterior distribution against the experimental data.

MAP estimate: $\mathbb{E}[\theta|\mathbf{y}]$

p	E
2.4×10^4	0.0012

ECN AeroModule calibration



sensitivity_analysis/cases/aero_module/NM80_calibrate.m

sensitivity_analysis/cases/aero_module/initialize_calibration.m

sensitivity_analysis/testCalibration.m

Problem setup

Ingredients for Bayesian calibration

- Axial force data $(\mathbf{y}) = \{\mathbf{y}_1, \mathbf{y}_2, \mathbf{y}_3, \mathbf{y}_4\}$
- $\boxed{\text{Forward model}}$: ECN Aero-Module
- Likelihood: $\pi(\mathbf{y}|\theta) = \prod_{i=1}^{n} \mathcal{N}[\mathbf{y}_i - f_i(\theta)]^2$
- Prior distribution:

θ	$\pi(\theta)$
P	Constant
C_L	Uniform
σ^2	Uniform

Problem setup

Marco's (ECN) script for reading the data in N/m

```
filename_exp = ('../../../Experimental/WINDTRUE/raw.dat');
output_raw = read_exp_data(filename_exp, 2);
% Because the model has different discrepancy options at different
 radial locations,
% the measurement data is stored in four different data structures:
Data(1).y = mean(output_raw.Fy03); % [N/m]
Data(1).Name = 'Fy03';
Data(1).MOMap = 1; % Model Output Map 1
```

Name of Matlab file representing the model

```
Model.mHandle = @aero_module_calibration;
% Optionally, one can pass parameters to model stored in the cell
 array P
P - getParameterAeroModule(turbineName);
Model.Parameters = P;
Model.isVectorized = false;
```

```
DiscrepancyPriorOpts1.Name = 'Prior of sigma 1';
DiscrepancyPriorOpts1.Marginals(1).Name = 'Sigma1';
DiscrepancyPriorOpts1.Marginals(1).Type = 'Uniform';
DiscrepancyPriorOpts1.Marginals(1).Parameters =
 [0.5*std(output_raw.Fy03), 1.5*std(output_raw.Fy03)];
DiscrepancyPrior1 = uq_createInput(DiscrepancyPriorOpts1);

DiscrepancyOpts(1).Type = 'Gaussian';
DiscrepancyOpts(1).Prior = DiscrepancyPrior1;
```

```
uncertain_params = {{'CL',1, 0.2}, {'CL',2, 0.2}, {'CL',3, 0.3},
{'CL',4,0.3}};
QoI = 'force'; % Force at different radial stations
aero_module_outputfile = 'B1n_BEM.txt'; % Aero-Module data to be
 calibrated
```

Problem setup

Switch for Bayesian analysis with the AeroModule or with the surrogate model

```
Bayes_full = 0; % 0: use surrogate model (PCE); 1: run full model for
 Bayes (Computationally expensive!)

% If Bayes_full = 0, we need to specify options for loading a
 surrogate model
Surrogate_model_type = 0; % 0: Uses a stored PCE surrogate model, 1:
 create surrogate model

% Options for loading a surrogate model
Surrogate_model_filename = 'surrogate/PCE_60.mat'; % Specify the
 surrogate model file to be used

% Options for creating a surrogate model
% These are used if Bayes_full = 0 and Surrogate_model_type = 1
MetaOpts.Type = 'Metamodel';
MetaOpts.MetaType = 'PCE';
MetaOpts.Method = 'LARS'; % Quadrature, OLS, LARS

MetaOpts.ExpDesign.Sampling = 'LHS';
MetaOpts.ExpDesign.NSamples = 60;
MetaOpts.Degree = 1:4;
MetaOpts.TruncOptions.qNorm = 0.75;
```

MCMC parameters

```
Solver.Type = 'MCMC';
% MCMC algorithms available in UQLab
MH = 0; % Metropolis-Hastings
AM = 0; % Adaptive Metropolis
AIES = 1; % Affine invariant ensemble
HMC = 0; % Hamilton Monte Carlo
```

Convergence diagnostics

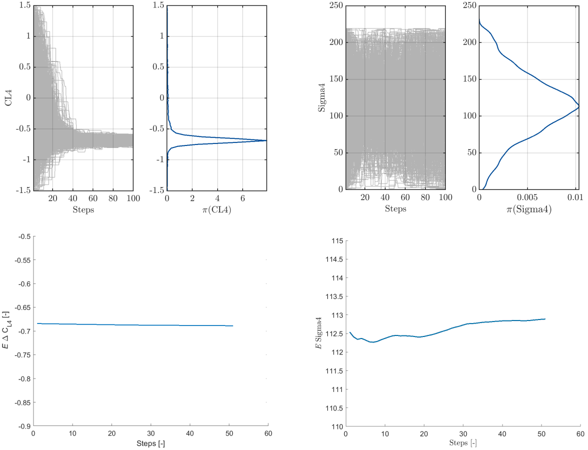


Figure: Trace plots and convergence for y4

Prior and posterior distribution

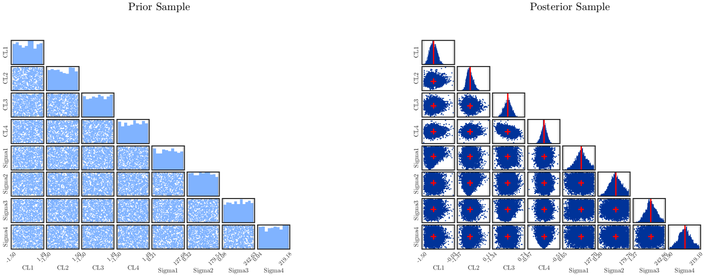


Figure: Prior and posterior samples.

MAP estimate

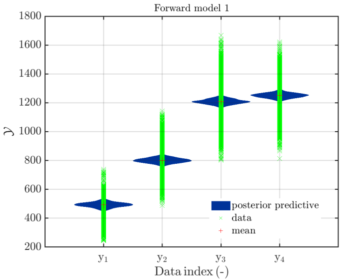


Figure: Violin plot showing distributions of Bayesian prediction against the DANAERO data.

MAP estimate: $\mathbb{E}[\theta|\mathbf{y}]$

ΔC_{L1}	ΔC_{L2}	ΔC_{L3}	ΔC_{L4}	σ_1^2	σ_2^2	σ_3^2	σ_4^2
-0.2025	-0.1604	-0.1087	-0.2067	73.7666	100.2012	138.4856	112.8861

Calibrated polars

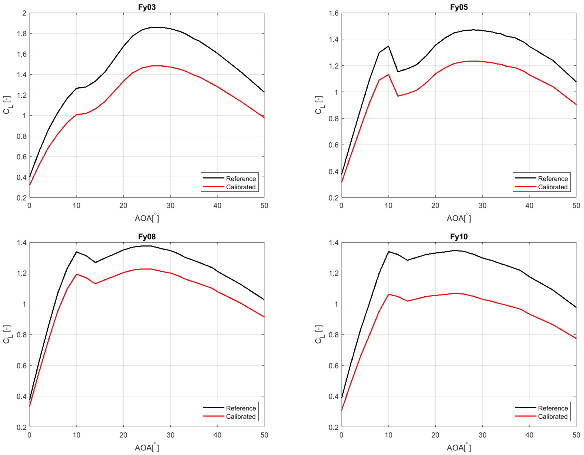


Figure: C_L polars comparison.

QoI validation

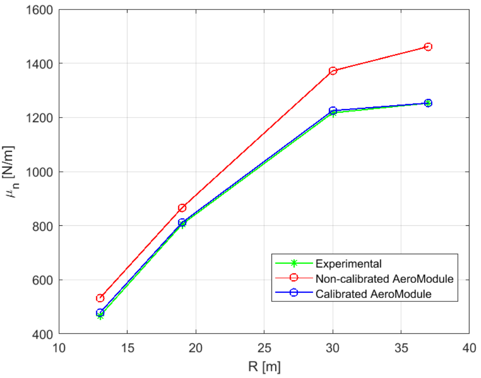
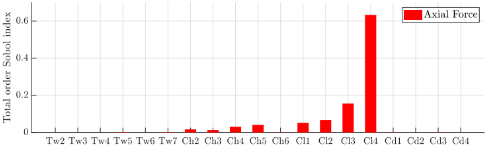


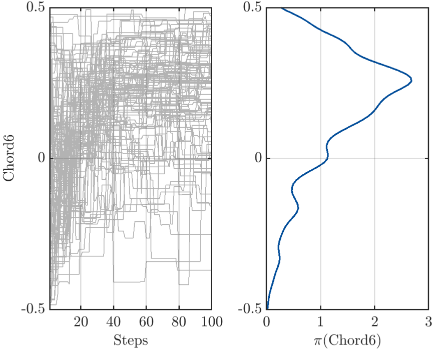
Figure: Comparison of axial force obtained using: experimental, non-calibrated Aero-Module run and calibrated Aero-Module run.

Exercise



1. Calibrate Aero-Module using **Cl** and **Ch** as the uncertain parameters
2. Create a surrogate model using 50 samples and save the model in the surrogate folder

Note



Ch6 calibrated = **Ch6** reference $(1 + (0.264 \times 0.2))$

Relevant cases?

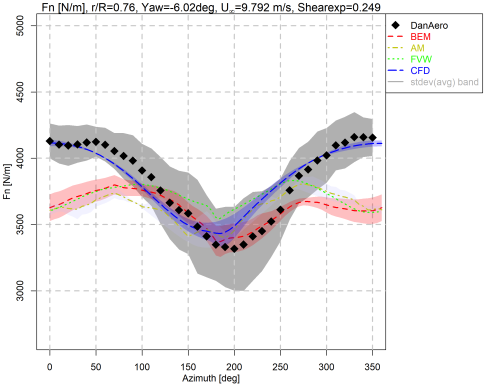


Figure: Comparison of axial force in the azimuthal direction.