Research directions in Engineering Dynamics

Swansea University
Prifysgol Abertawe

COPPE/UFRJ and Swansea Workshop
November 2014

Sondipon Adhikari

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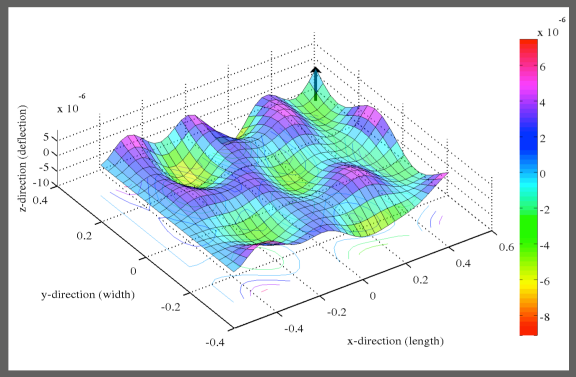

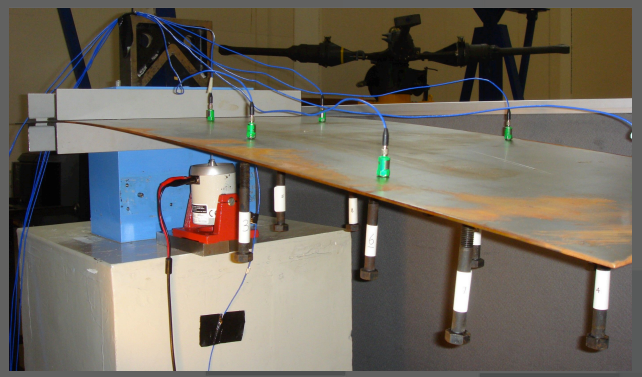

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Engineering Dynamics

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- Principal investigators: Prof Friswell, Prof Adhikari, Dr Haddad
- Main research areas
- Summary of current research works
  - Morphing Aircraft and Nonlinear dynamics
  - Vibration energy harvesting
  - Uncertainty quantification
  - Model updating
- Future works

Michael I. Friswell: Morphing Aircraft and Dynamics

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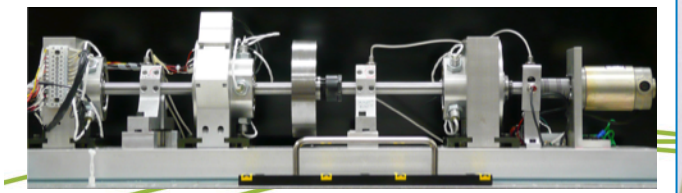
Modelling, analysis, simulation, identification & optimisation of engineering structures

Morphing Aircraft

MORPHLET – Morphing Winglet

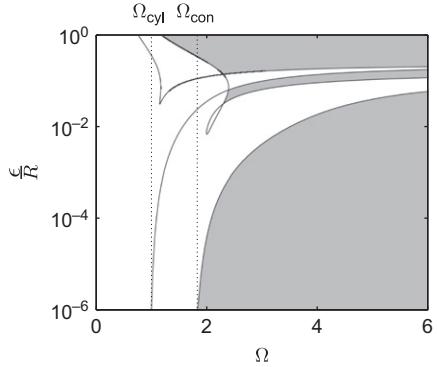
FishBAC Active Camber



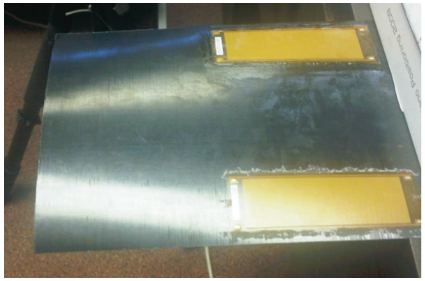
Rotating Machine Diagnostics

Corrugated Skins

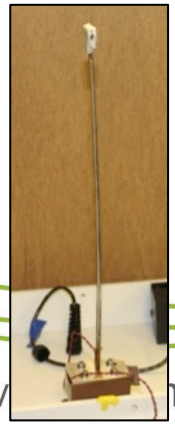
Nonlinear Structural and Rotor Dynamics

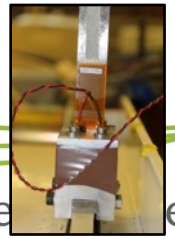


Automatic Rotor Balancing



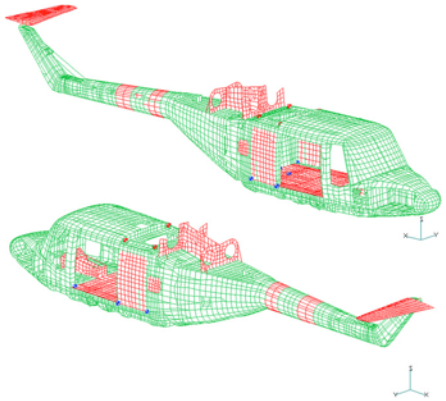
Bistable Plates





Energy Harvesting

Model Updating and Inverse Problems



FE Model Identification

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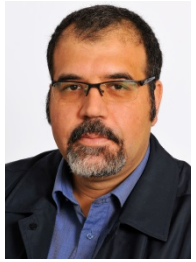
Hamed Haddad Khodaparast : Uncertainty analysis in aircraft structures



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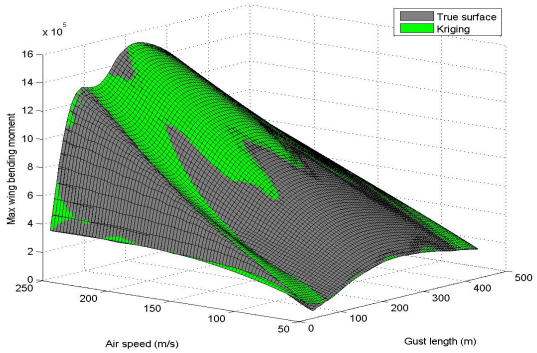
Using non-probabilistic models for uncertainty analysis and robust design in aircraft structures

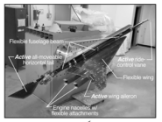
Uncertainty Quantification of Aeroelastic Stability

Surrogate modelling (Kriging and Polynomial Chaos Expansion)

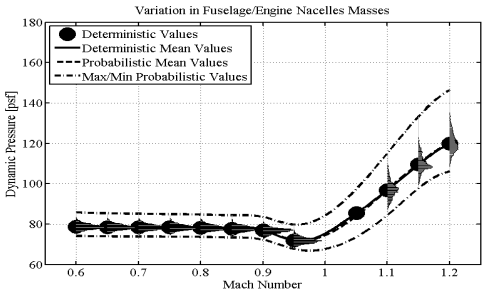


Rapid perdition of worst case gust loads

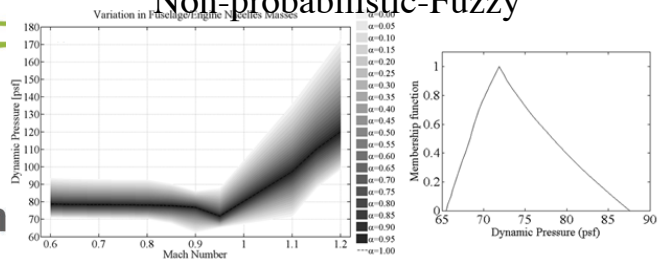
Variations in the fuel load and its effect on the aeroelastic behavior of the Semi-Span Super-Sonic Transport wind-tunnel model (S4T)



Probabilistic

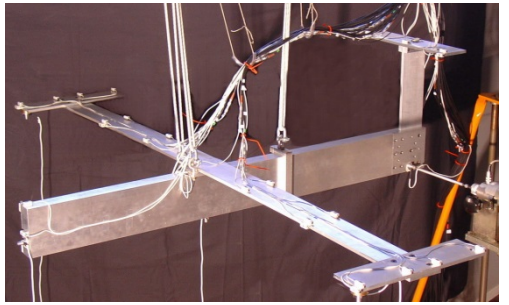


Non-probabilistic-Fuzzy

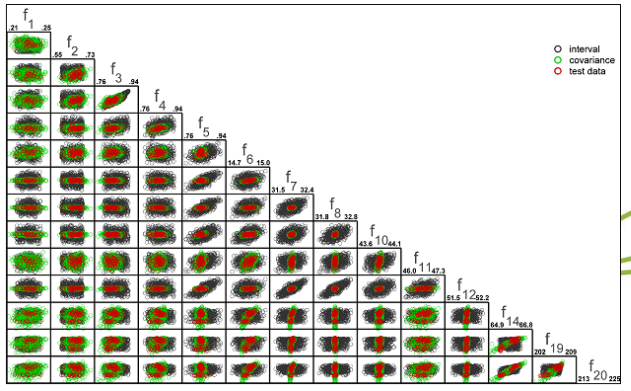


Development of non-probabilistic Stochastic Model Updating techniques

Simplified AIRcraft MODel- AIRMOD (DLR-Germany)



Comparison of non-probabilistic and probabilistic stochastic model updating using the DLR AIRMOD test structure



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Sondipon Adhikari: Structural dynamics across different length scales

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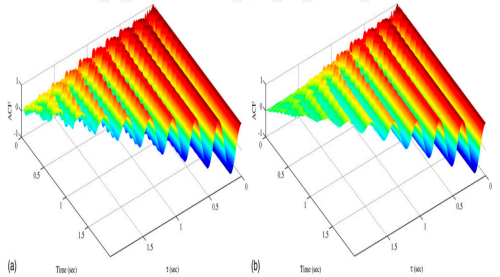
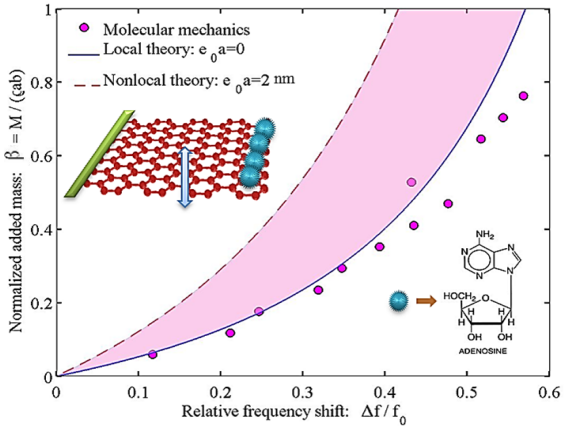
Uncertainty quantification and model validation

Stochastic Structural Dynamics



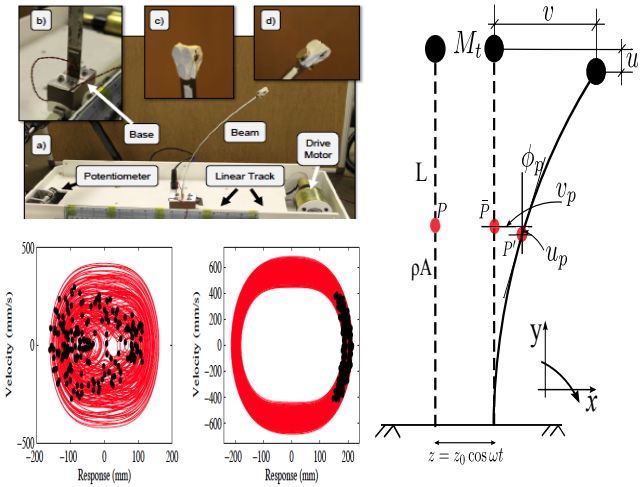
Novel computational methods for transient dynamic response of dynamical systems with uncertainty

Dynamics of Nanoscale Structures

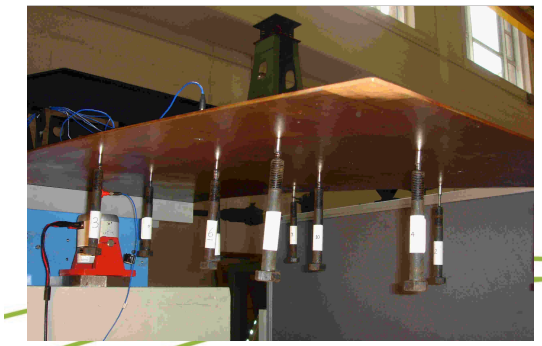


Nonlocal continuum method of vibration based nanosensors

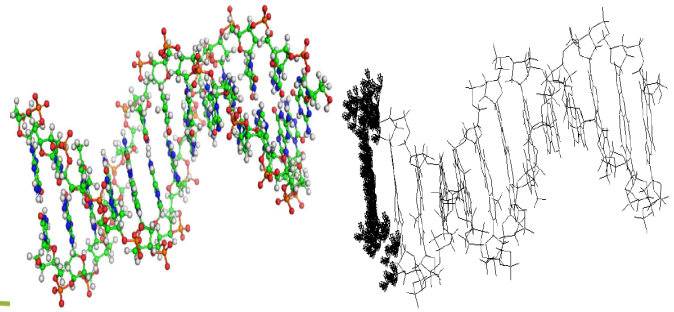
Vibration Energy Harvesting



Nonlinear vibration energy harvesting under random ambient excitations



Experimental methods for uncertainty quantification in structural dynamics

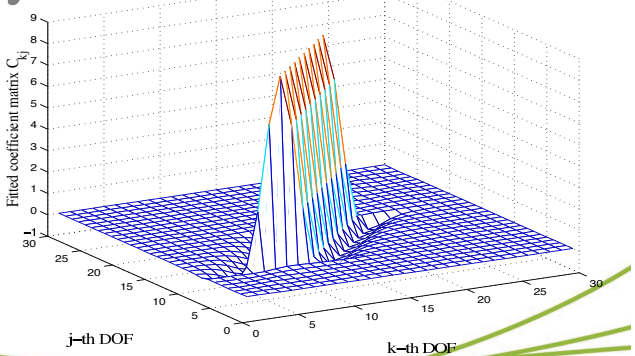


(a) The DNA molecule from the pdb file

(b) Finite element model with fixed boundary conditions

Atomistic finite element method for dynamics of general nano scale structures like DNA, Graphene sheets, Boron Nitride

System Identification



Damping identification from experimental measurements

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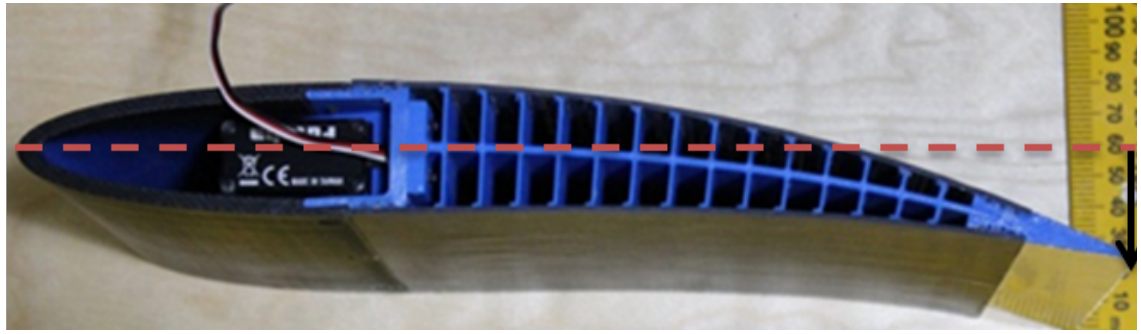
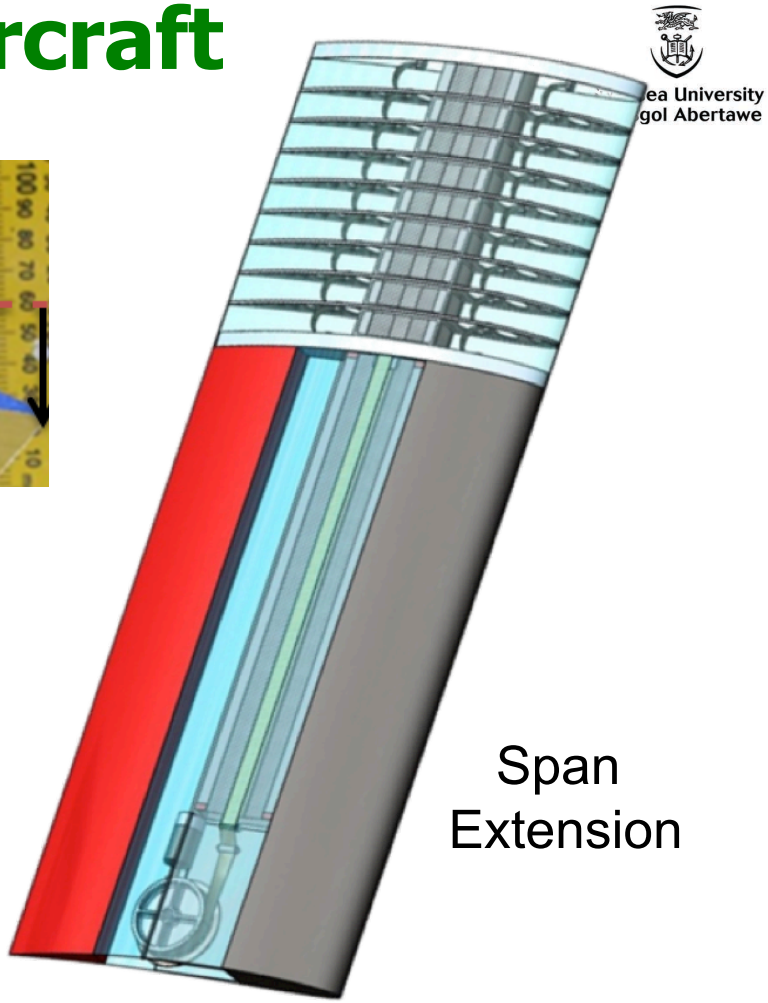
Morphing Aircraft and Nonlinear dynamics

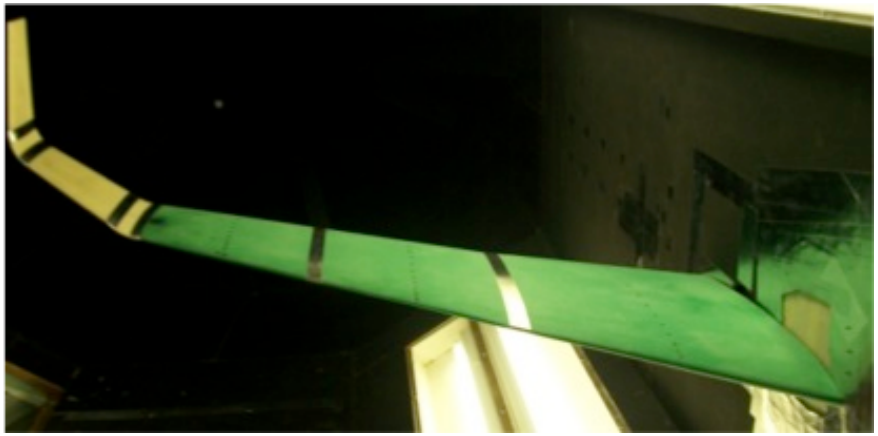
Morphing Aircraft



Camber morphing - FishBAC



Span Extension



Morphing Winglet - MORPHLET

Corrugated Skins

Nonlinear Structural and Rotor Dynamics

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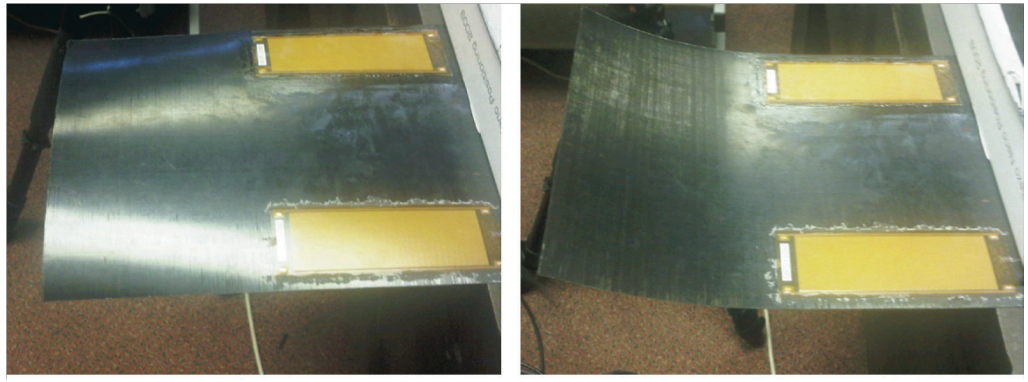
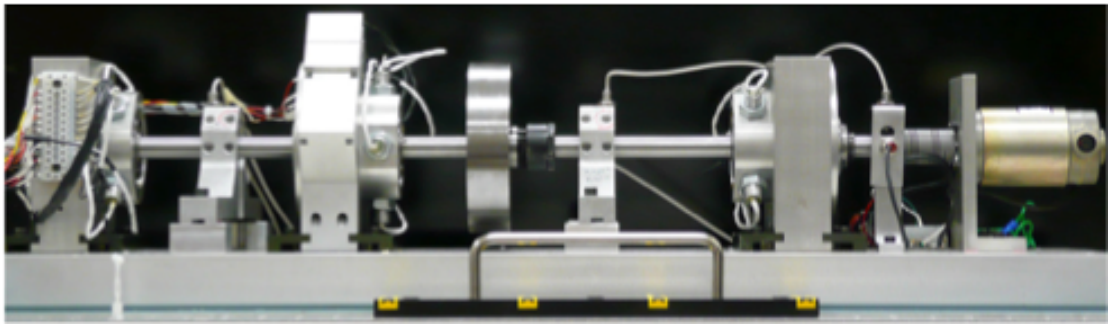
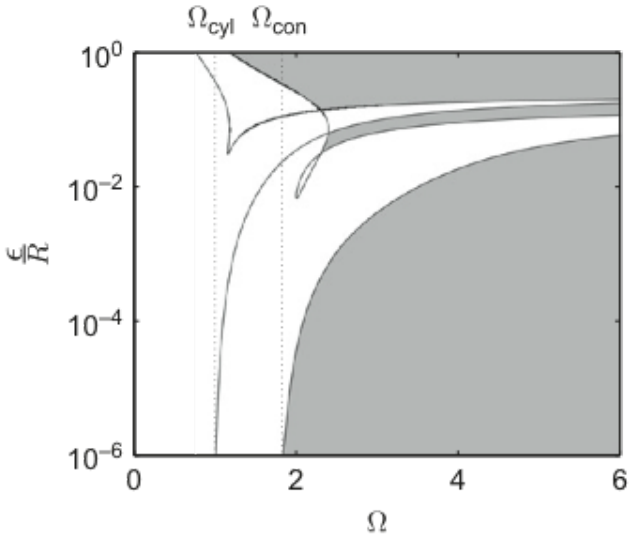


Bistable plates – applications, design, analysis, control



Rotating machine analysis & diagnostics – breathing cracks, unbalance, rotor-stator contact, etc



Automatic ball balancers, bifurcation analysis

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Vibration energy harvesting

Vibration energy harvesting

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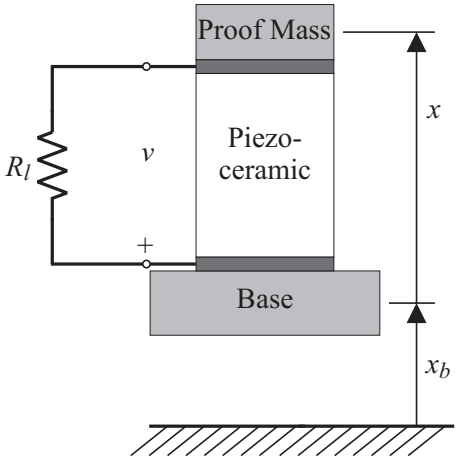
- Wireless sensor network for structural health monitoring
- Self-powered sustainable sensors – vibration energy harvesting

Energy harvesting with broadband noice



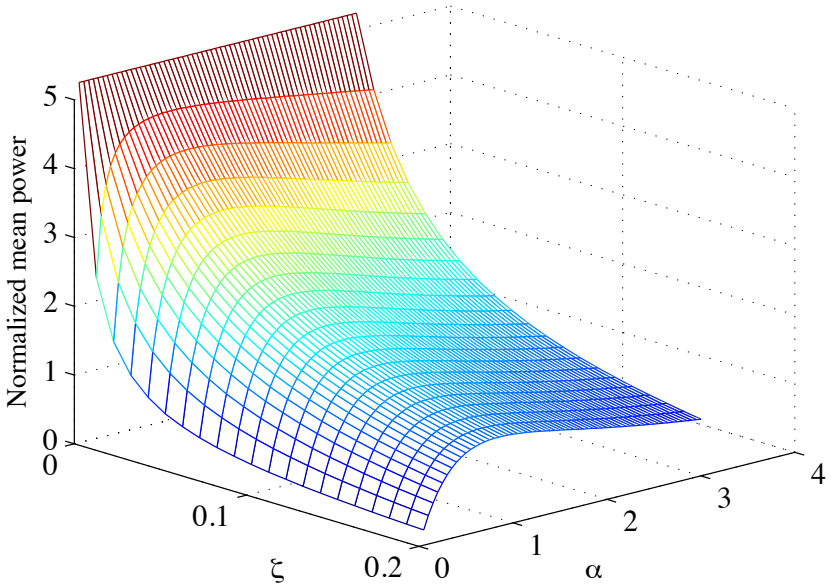
$$m\ddot{x}(t) + c\dot{x}(t) + kx(t) - \theta v(t) = -m\ddot{x}_b(t)$$

$$\theta\dot{x}(t) + C_p\dot{v}(t) + \frac{1}{R_l}v(t) = 0$$

The average harvested power due to white-noise base acceleration with a circuit without an inductor can be obtained as

$$\mathrm{E}\left[\widetilde{P}\right] = \mathrm{E}\left[\frac{|V|^2}{(R_l\omega^4\Phi_{x_b x_b})}\right]$$

$$= \frac{\pi\, m\,\alpha\,\kappa^2}{(2\,\zeta\,\alpha^2 + \alpha)\,\kappa^2 + 4\,\zeta^2\alpha + (2\,\alpha^2 + 2)\,\zeta}$$



The optimal condition is

$$R_l^2 C_p \left(kC_p + \theta^2\right) = m.$$

Vibration energy harvesting

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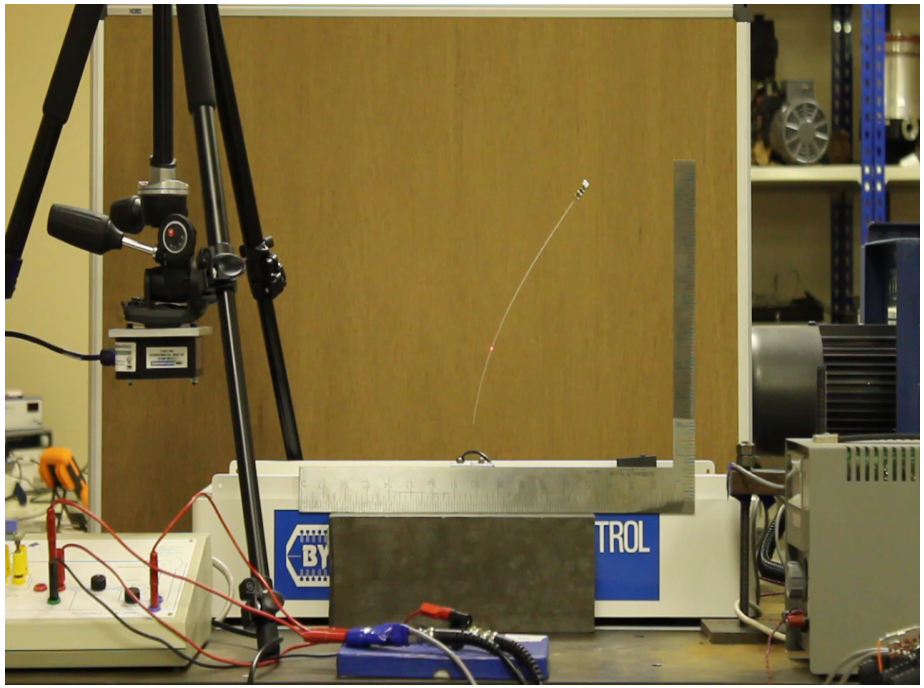

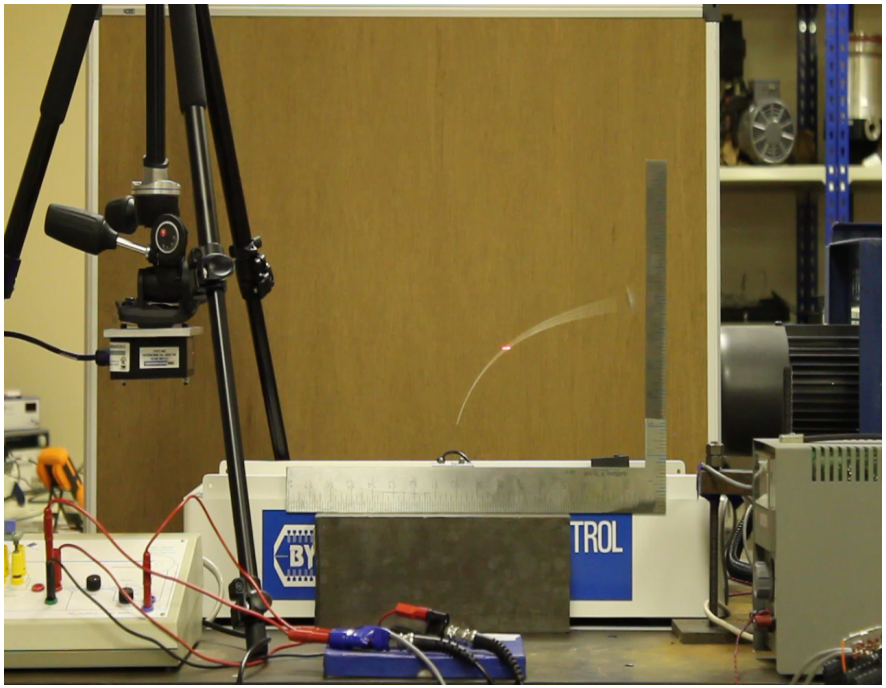

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Uncertainty quantification

Uncertainty in Structural Dynamics

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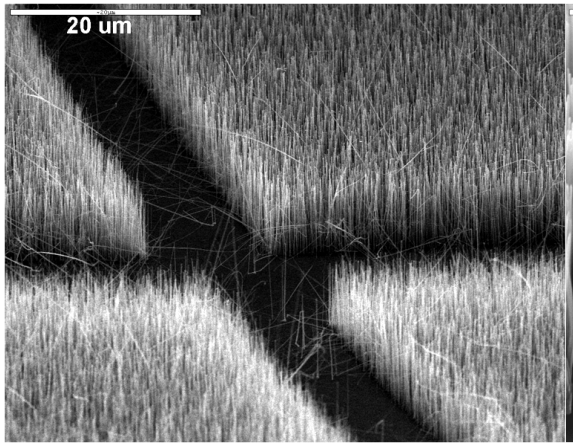
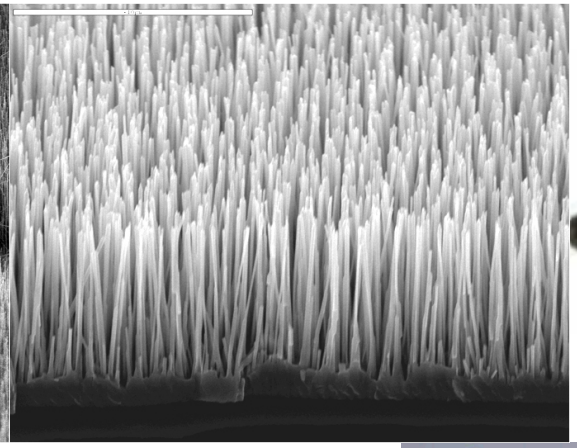
Stochastic dynamical systems across the length-scale





Uncertainty modeling in structural dynamics

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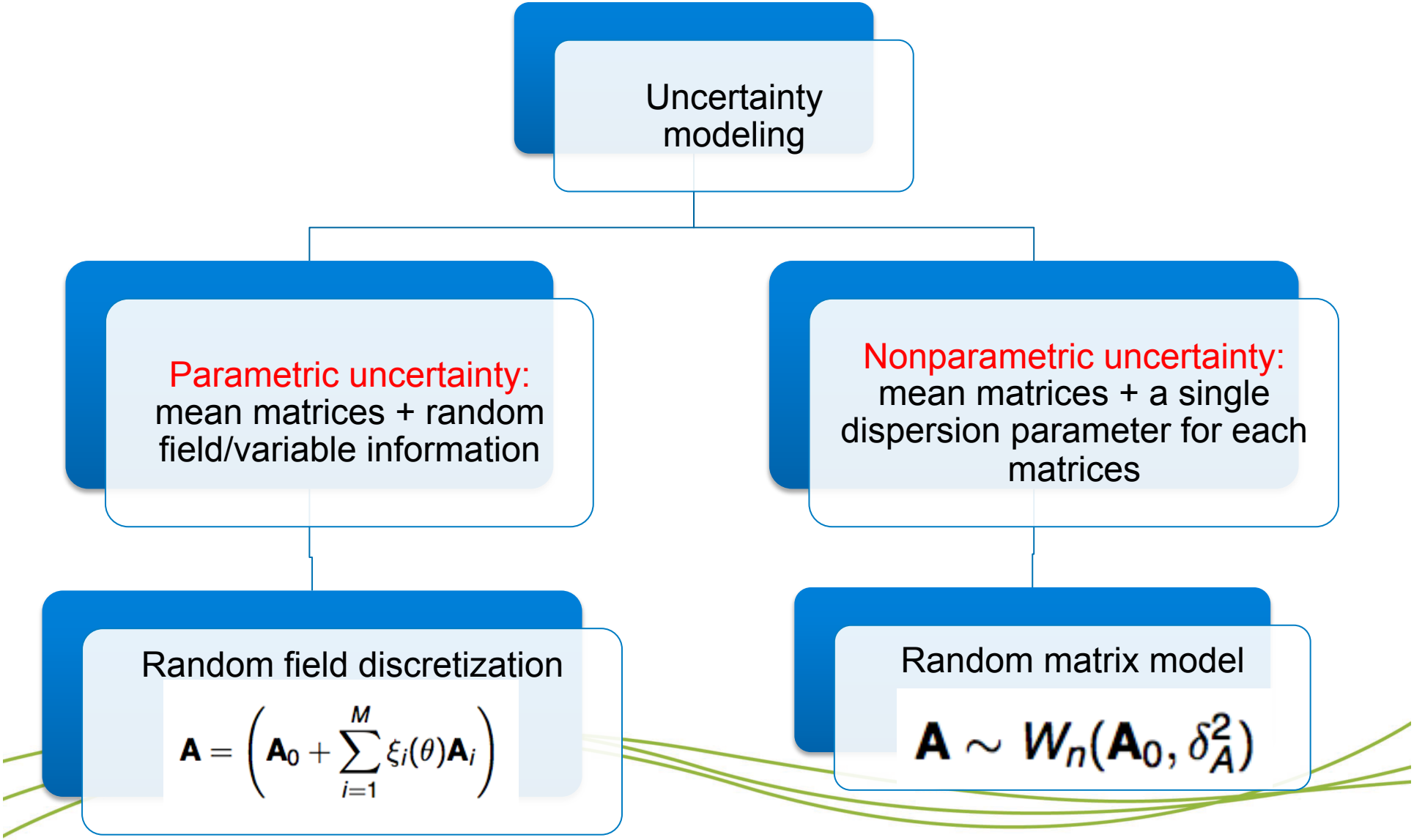

Dynamic Response

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- For parametric uncertainty propagation:

$$\mathbf{u}(\omega,\theta)=\sum_{k=1}^{n_r}\frac{\phi_k^T\mathbf{f}(\omega)}{-\omega^2+2i\omega\zeta_k\omega_0^2+\omega_{0_k}^2+\sum_{i=1}^{M}\xi_i(\theta)\Lambda_{i_k}(\omega)}\phi_k$$

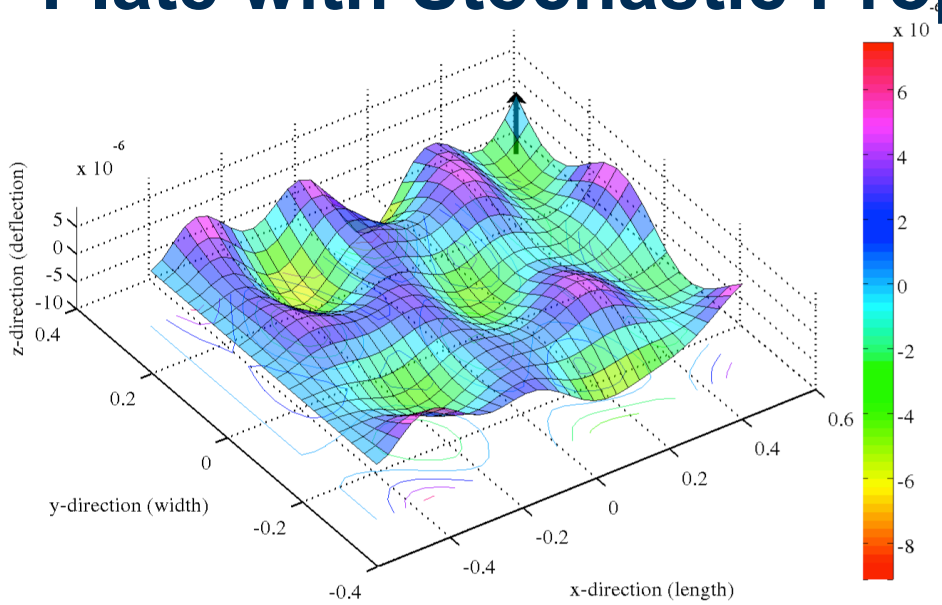
- For nonparametric uncertainty propagation

$$\mathbf{u}(\omega,\theta)=\sum_{k=1}^{n_r}\frac{\mathbf{x}_{r_k}(\theta)^T\mathbf{f}(s)}{-\omega^2+2i\omega\zeta_k\omega_{r_k}(\theta)+\omega_{r_k}^2(\theta)}\mathbf{x}_{r_k}(\theta)$$

$$\mathbf{X}_r(\theta)=\mathbf{\Phi}\mathbf{\Psi}_r,\quad \mathbf{\Psi}_r^T\mathbf{W}\mathbf{\Psi}_r=\mathbf{\Omega}_r^2$$

- Unified mathematical representation
- Can be useful for hybrid experimental-simulation approach for uncertainty quantification

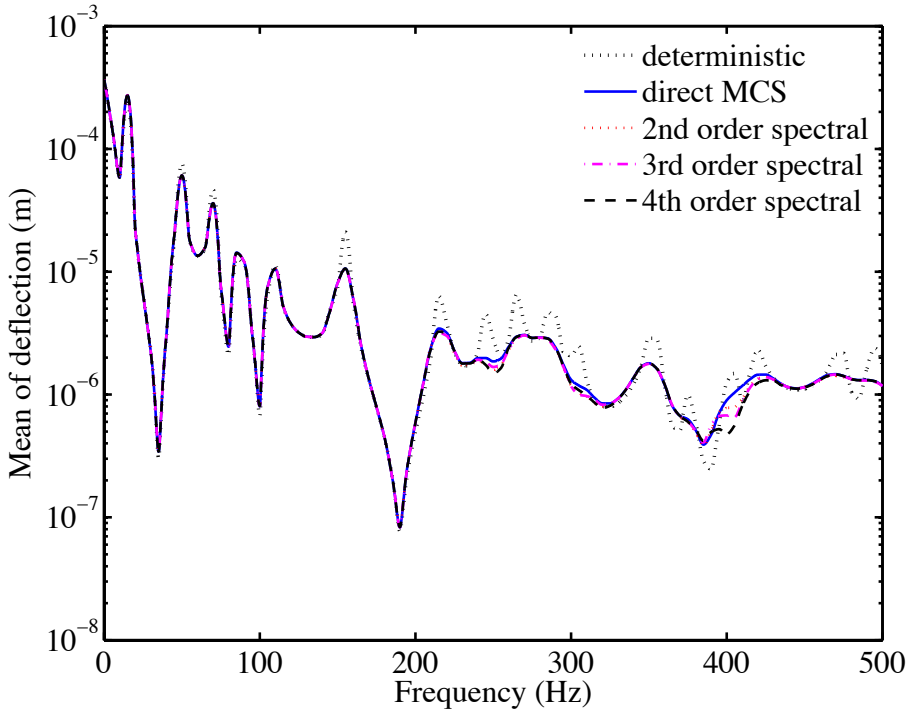
Plate with Stochastic Properties



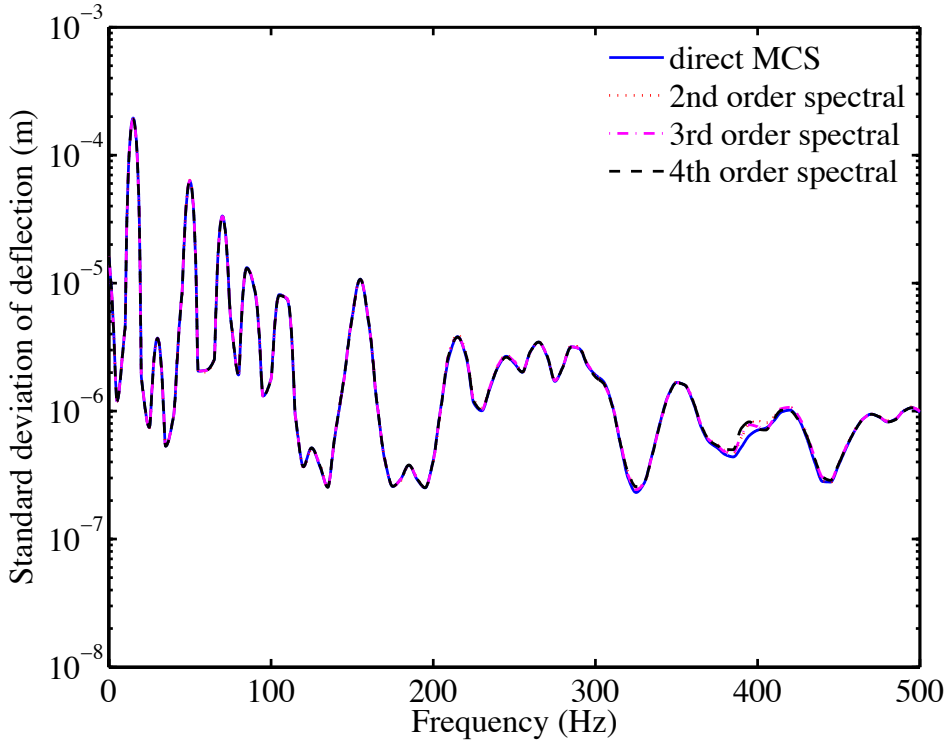
- Thin plate with stochastic bending modulus (nominal properties 1m x 0.6m, t=03mm, E=2 x 10^{11} Pa)
- 16 random variables approximating the random field

- We study the deflection of the plate under the action of a point The bending modulus is taken to be a homogeneous stationary Gaussian random field with exponential autocorrelation function (correlation lengths L/5)
- Constant modal damping is taken with 1% damping factor for all modes.

Response Statistics



Mean with $\sigma_a = 0.1$

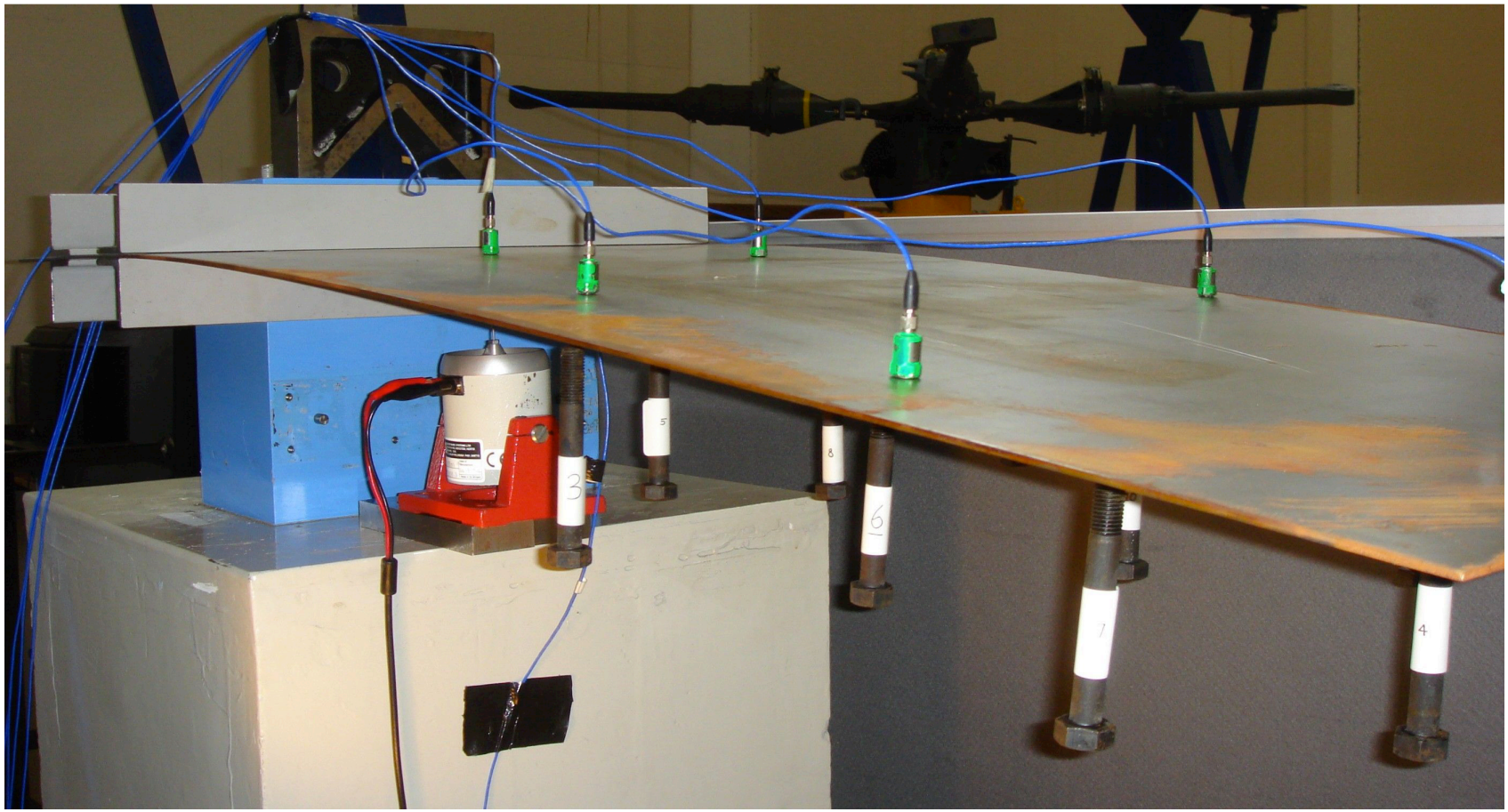


Standard deviation with $\sigma_a = 0.1$

Proposed approach: 150 x 150 equations

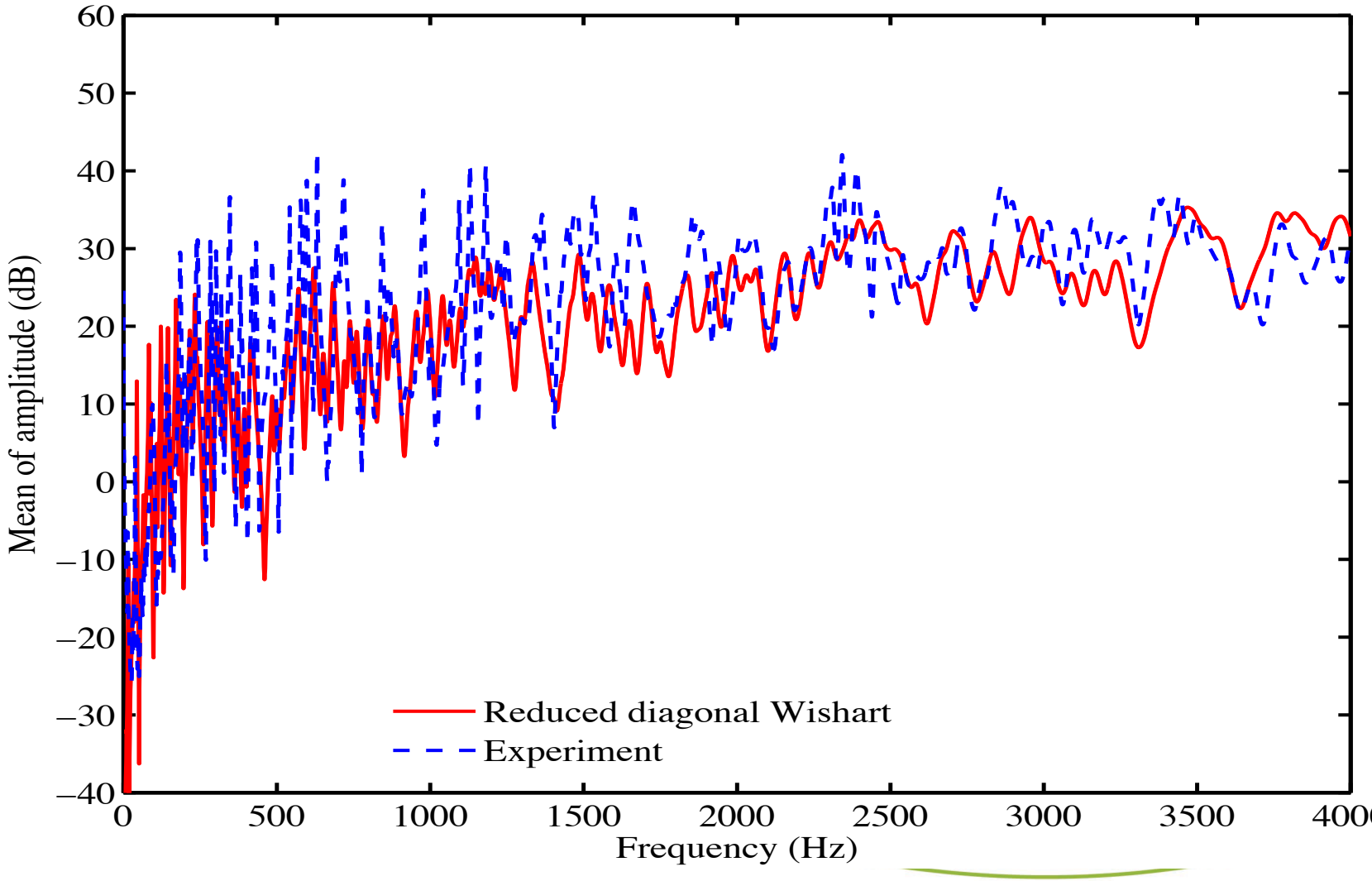
4th order Polynomial Chaos: 9113445 x 9113445 equations

Plate with randomly placed oscillators

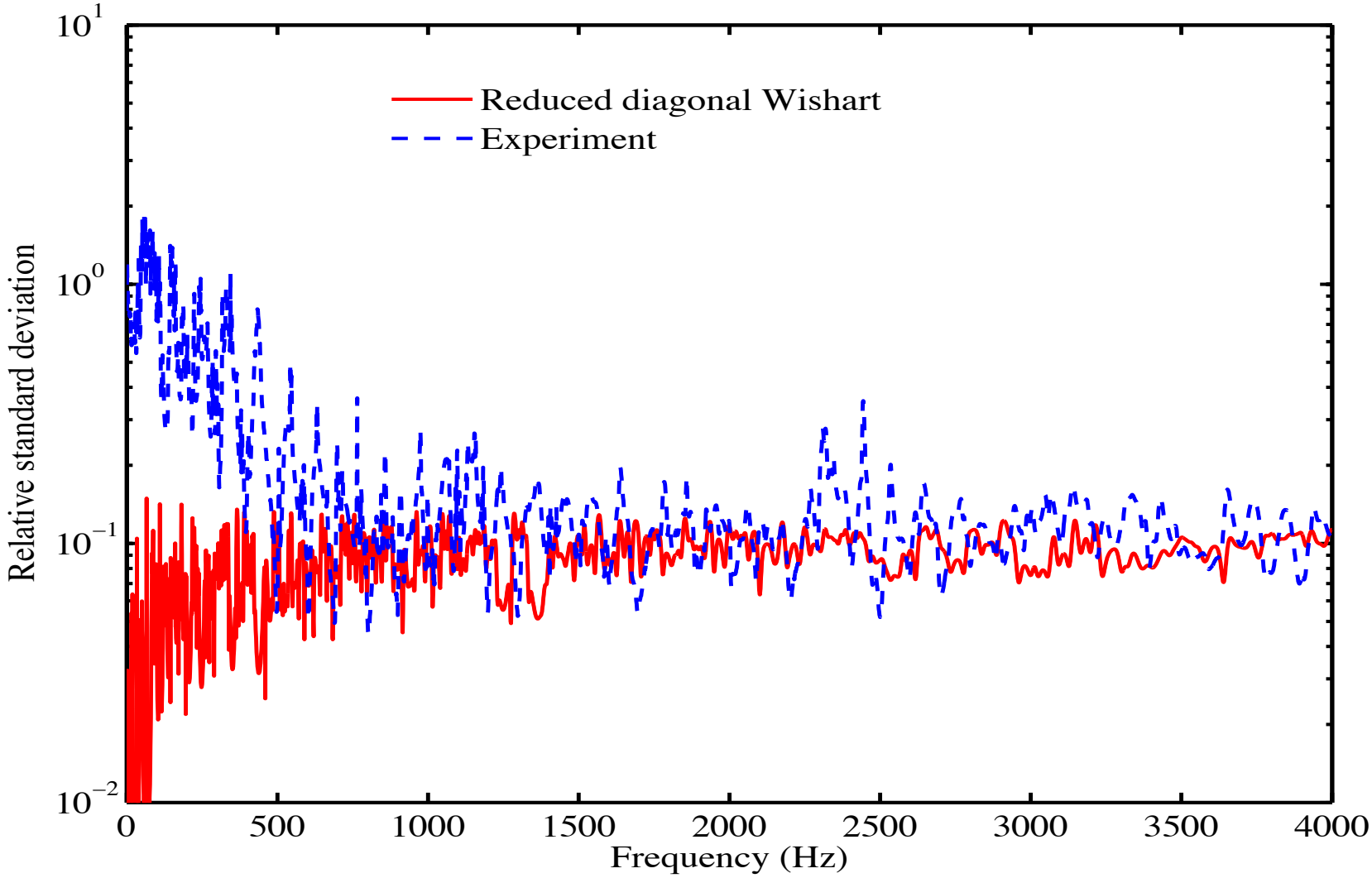


10 oscillators with random stiffness values are attached at random locations in the plate by magnet

Mean of a cross-FRF



Standard deviation of a cross-FRF



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Model updating and inverse problems

Model Updating

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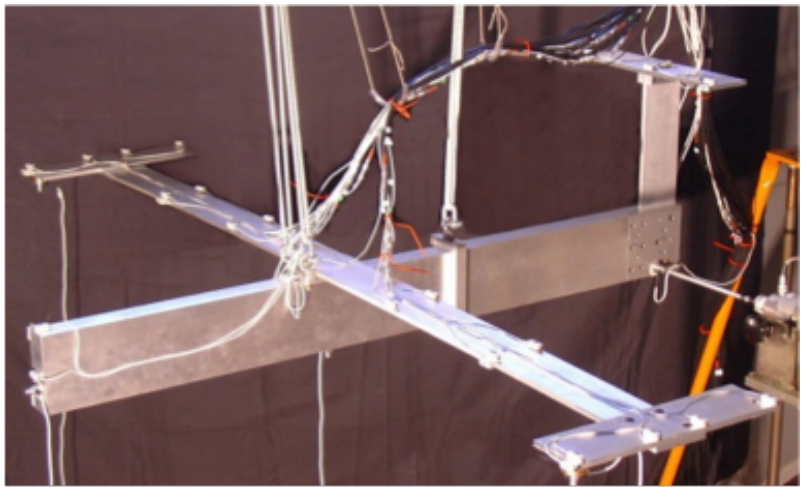
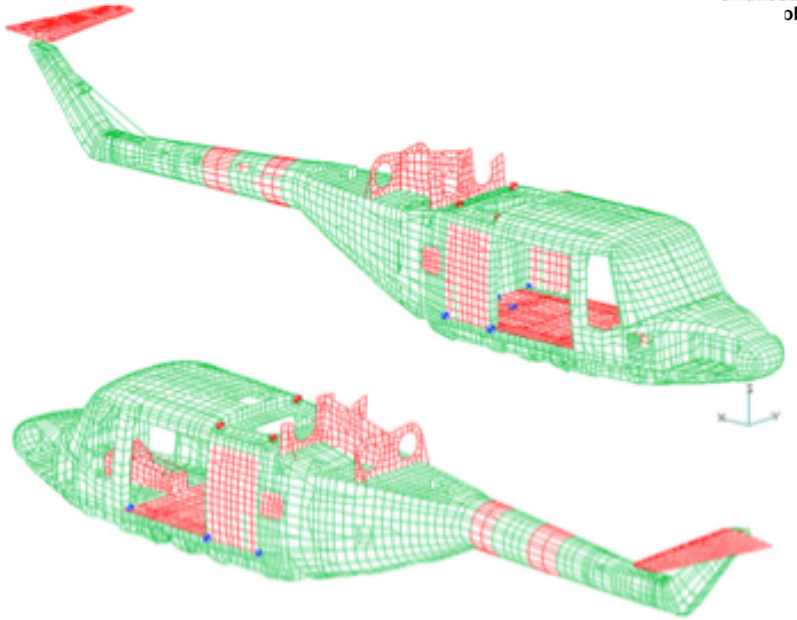
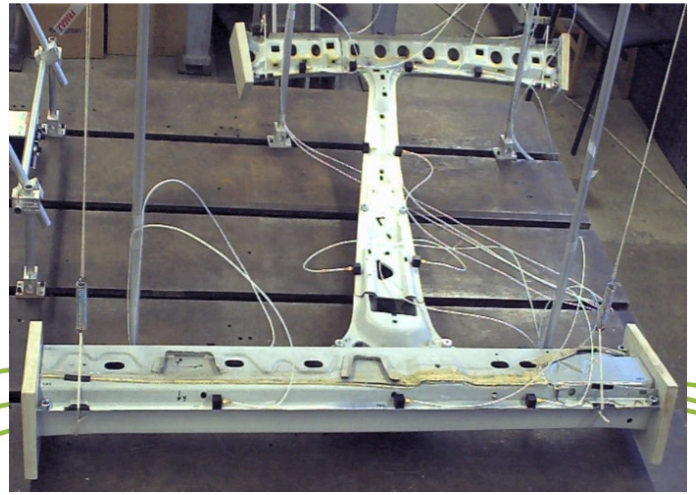


Vibration measurement, modal analysis



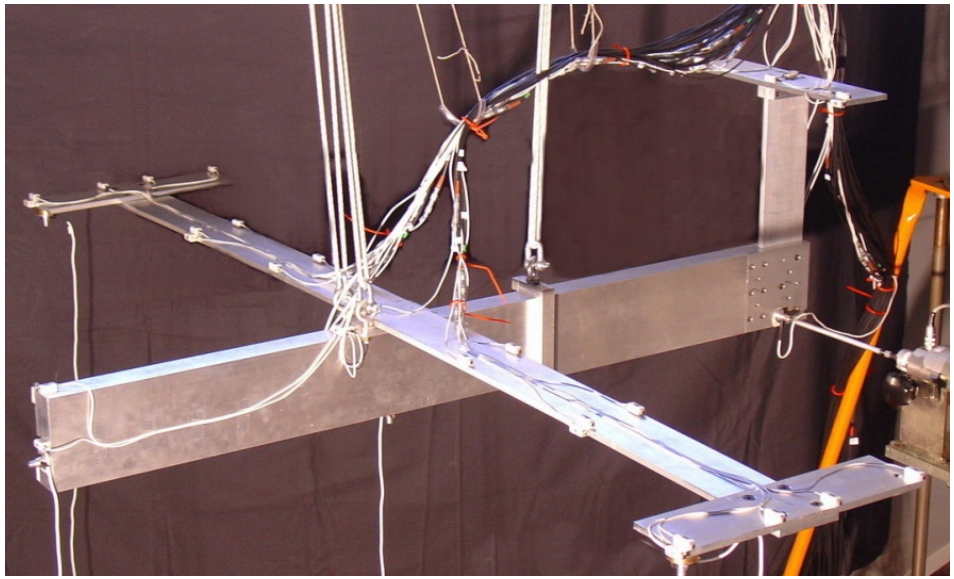
Improve FE models using measured data,regularisation



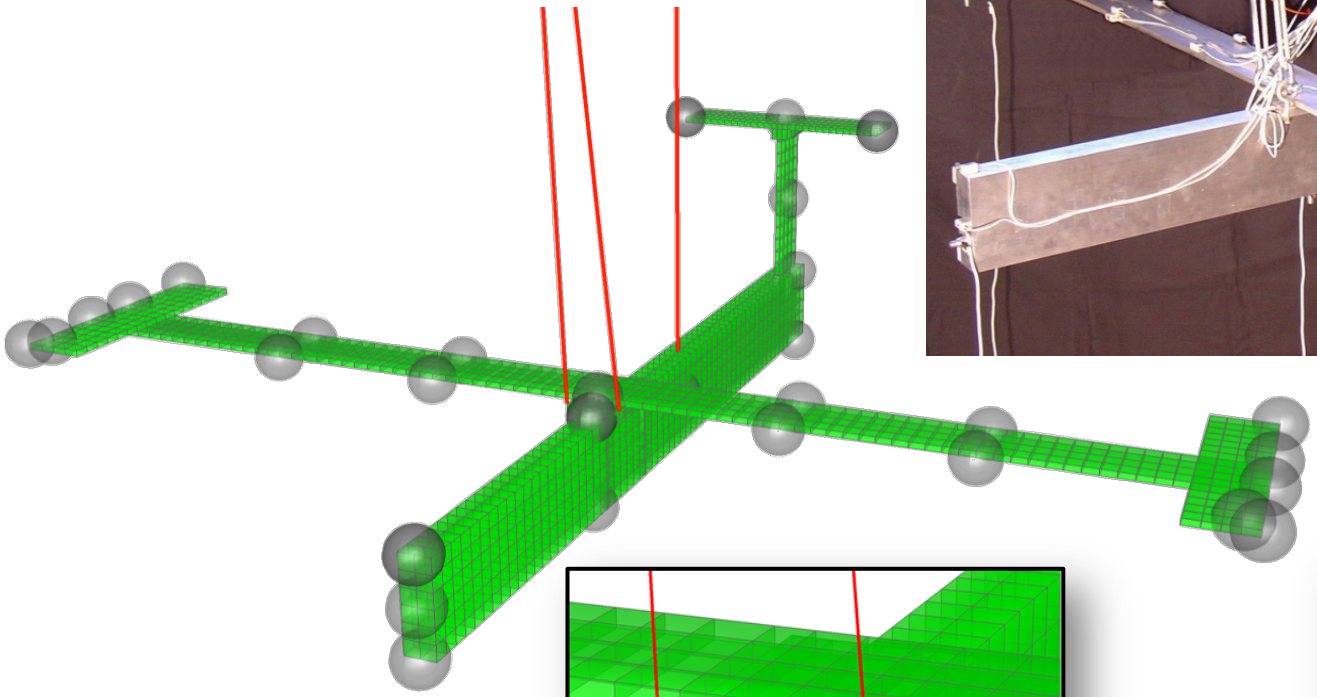
Choose parameters: car body, Lynx tail

Stochastic model updating: DLR AIRMOD Structure

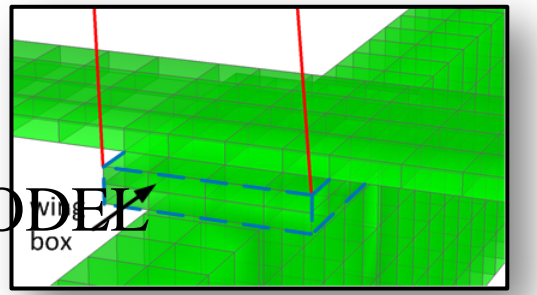
Identifying joint stiffness variability due to assembling and reassembling process.

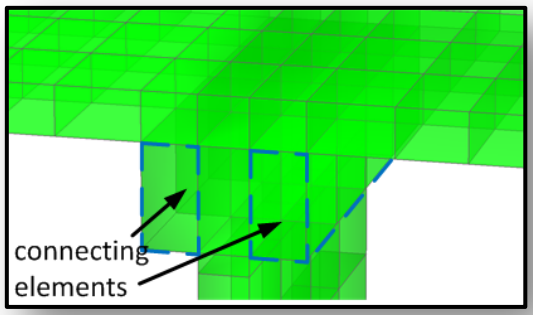


Physical structure



FE NASTRAN MODEL





Experimental mode shapes

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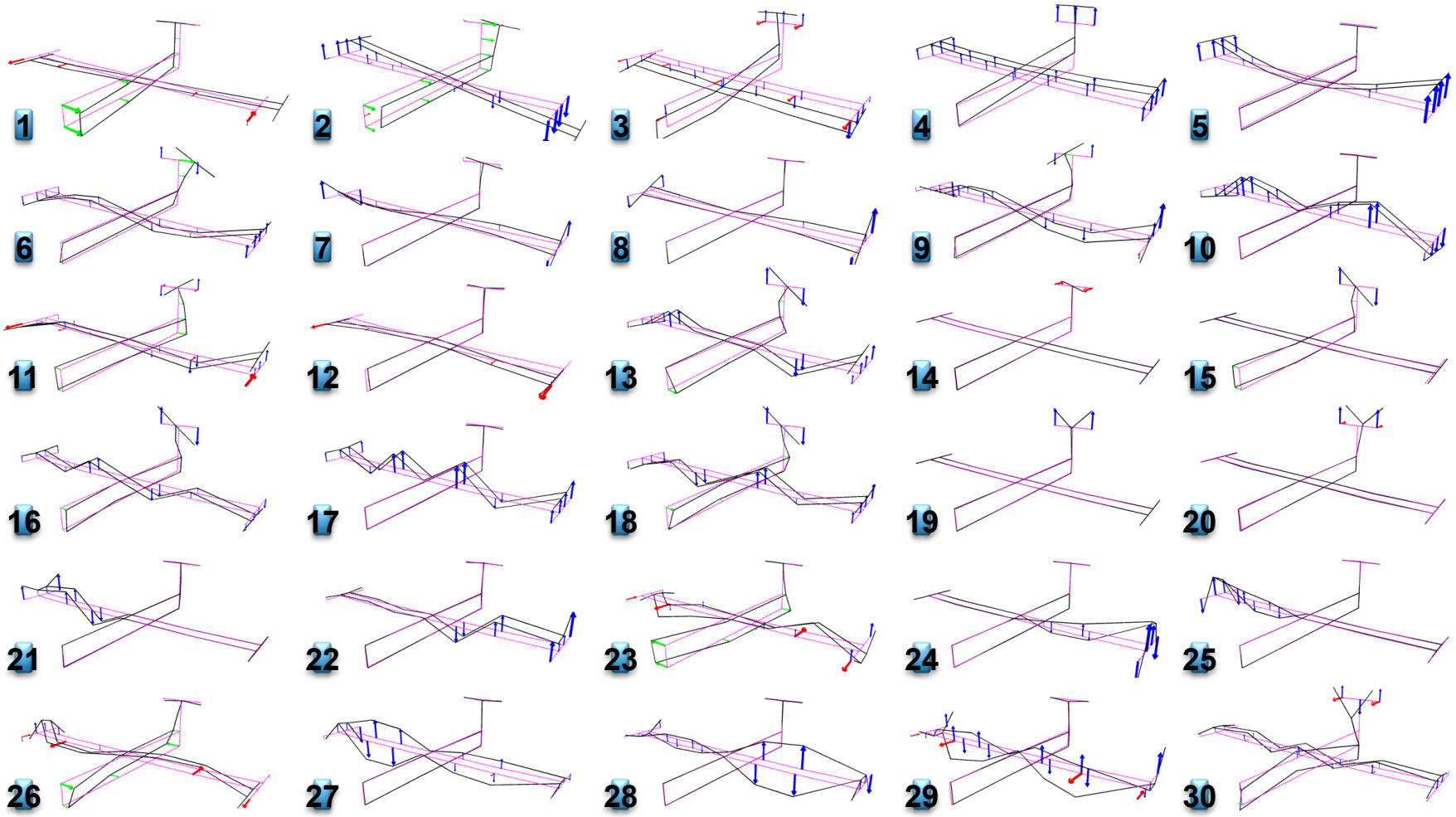

AIRMOD – Observed Variability

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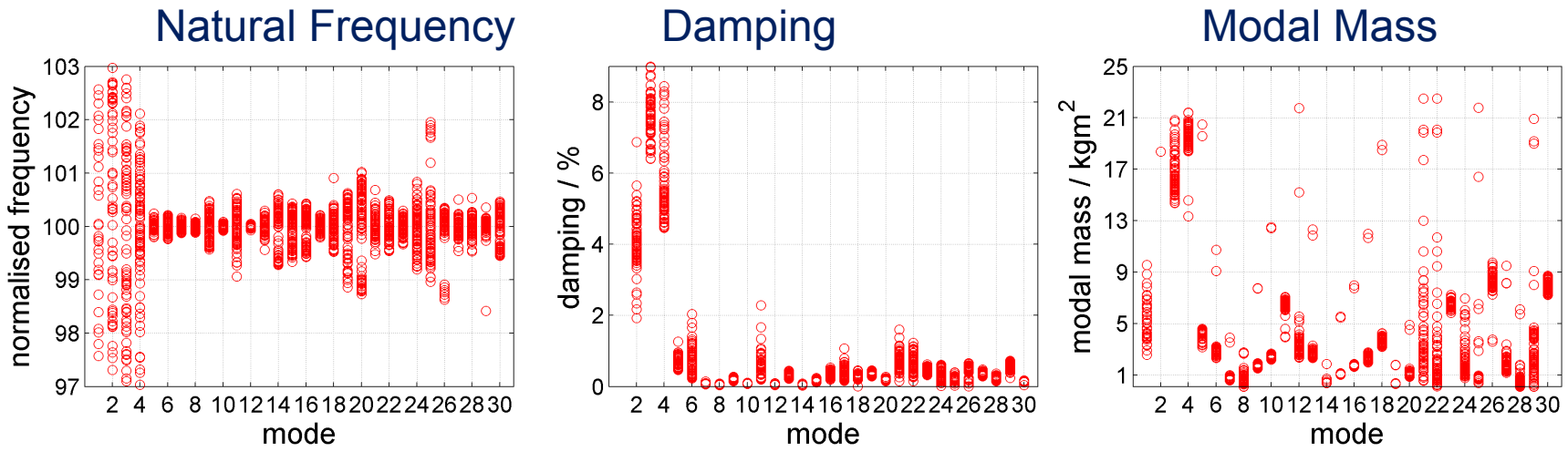
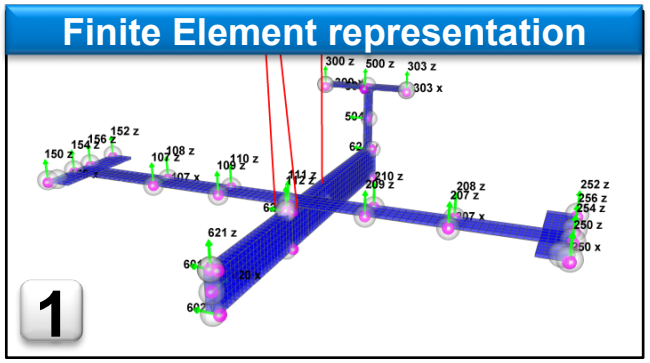
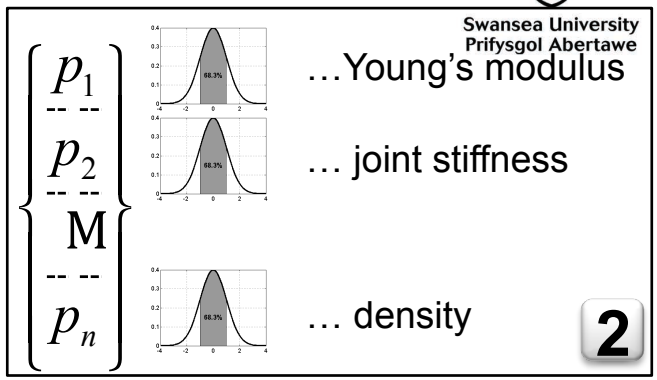


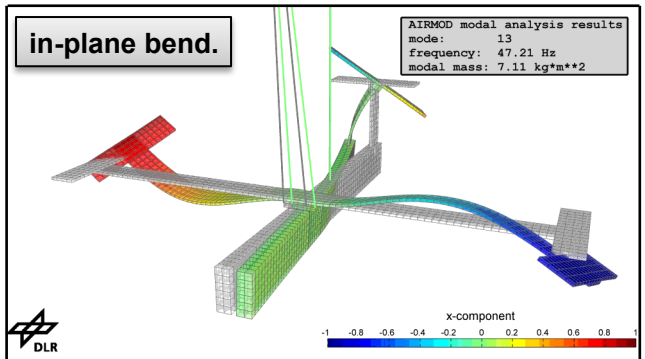
Stochastic model updating procedure



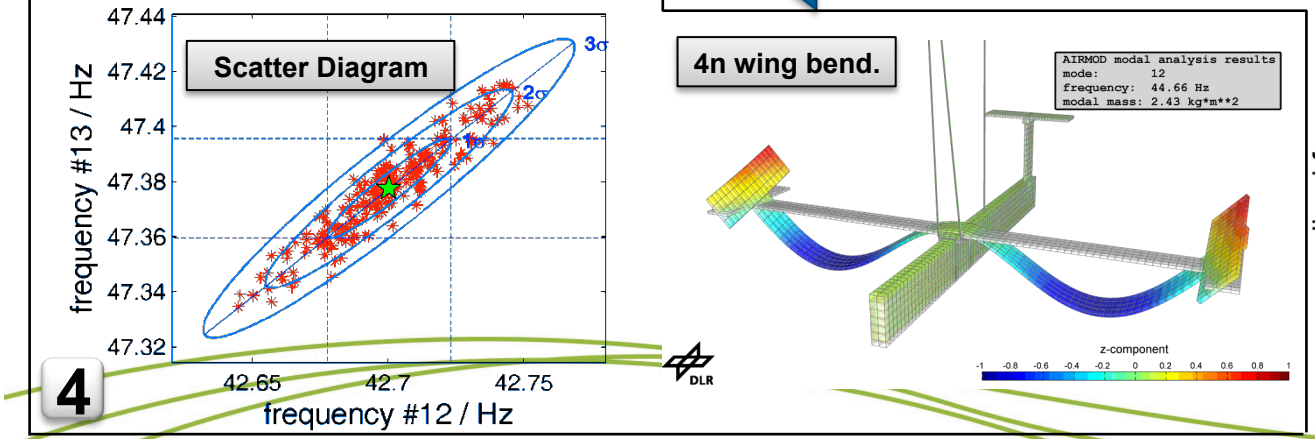
Randomise Parameters (Latin Hypercube Sampling)



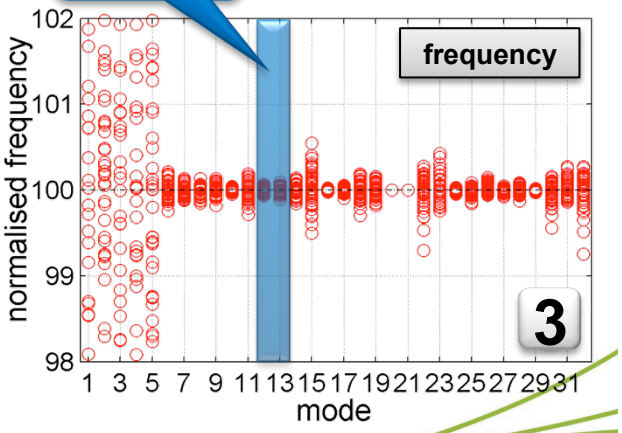
Monte Carlo Simulation (MCS)



Correlation of visible in scatter diagram

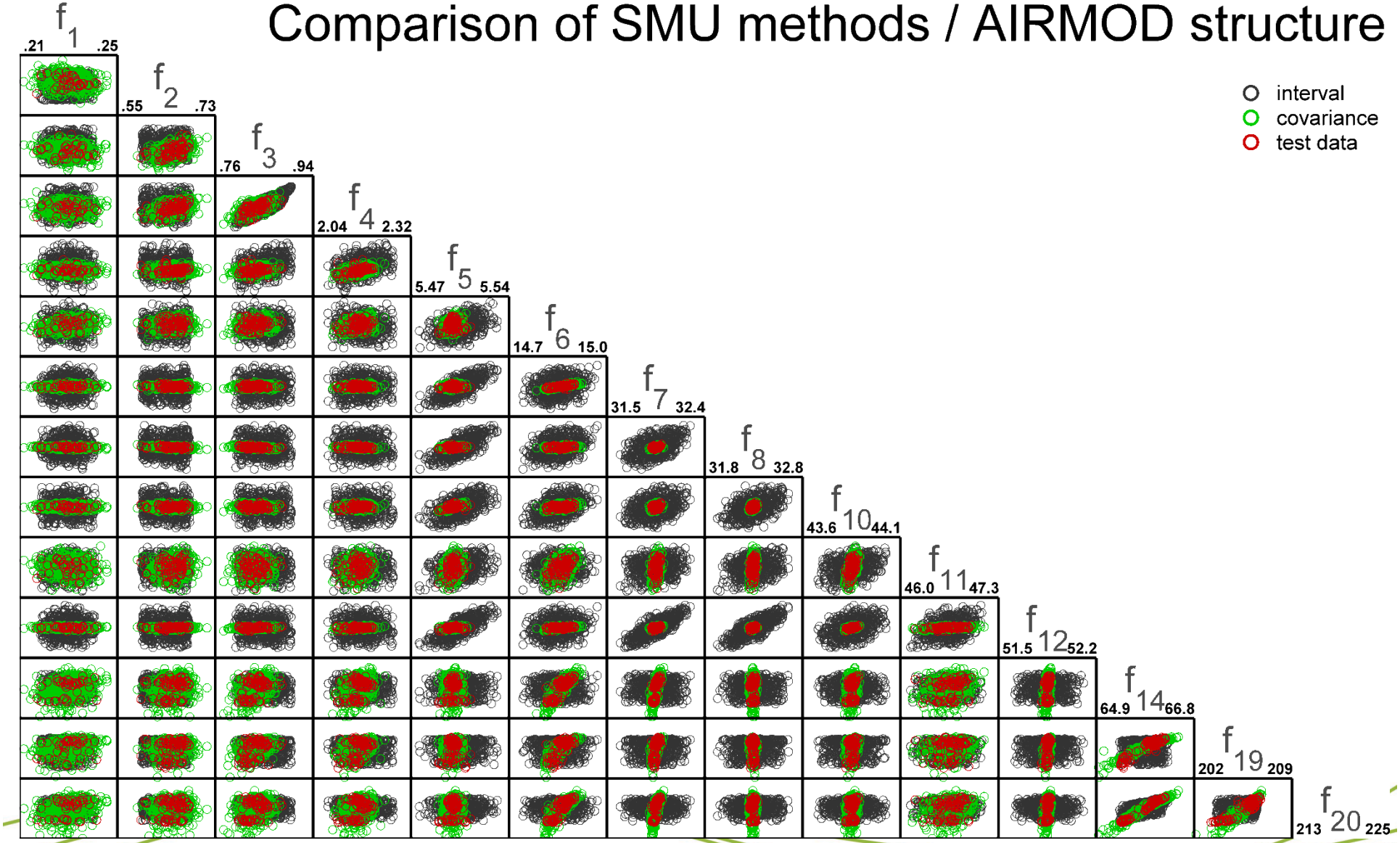


Mode 12
Mode 13



Interval updating vs. perturbation method

Comparison of SMU methods / AIRMOD structure



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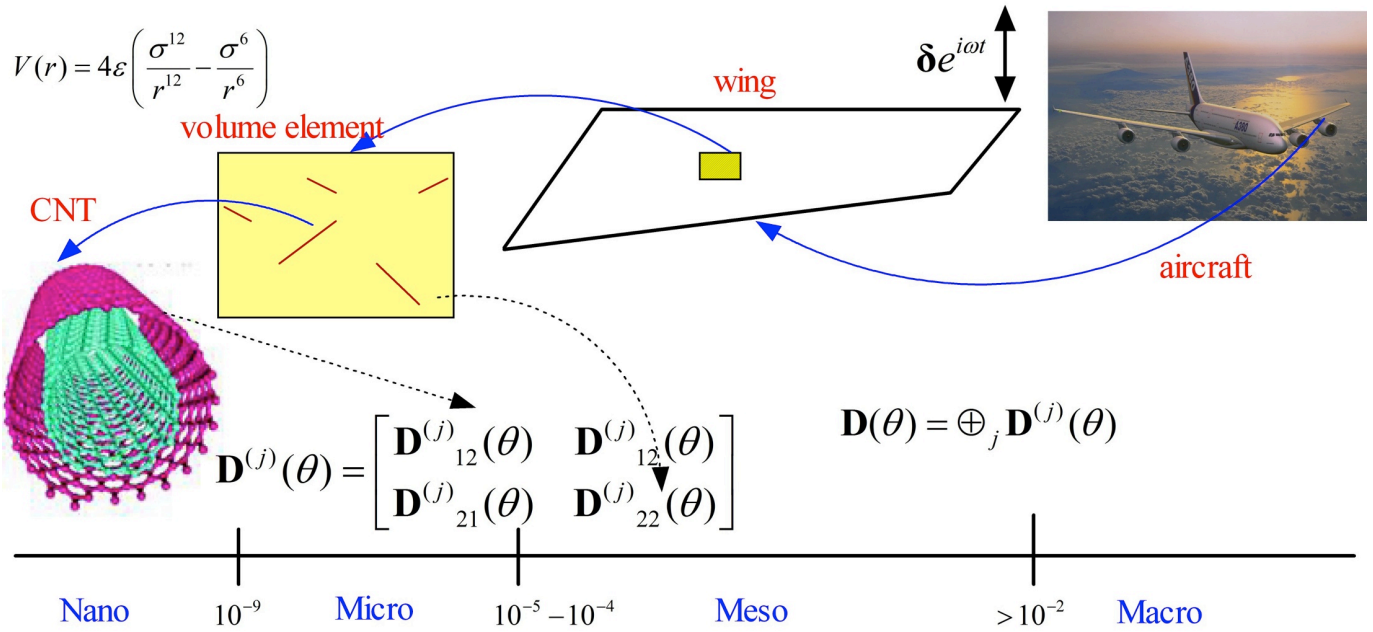
Other research interests

Stochastic multiscale mechanics



- New generation of structural materials
- Nano-composites, bio-composites
- Self-sensing, multifunctional, self-healing and sustainable materials – high strength to weight ratio
- We need to embrace new materials and develop next generation of analysis and design tools
- Requires multiscale and multiphysics approach

Nano-scale stochastic mechanics

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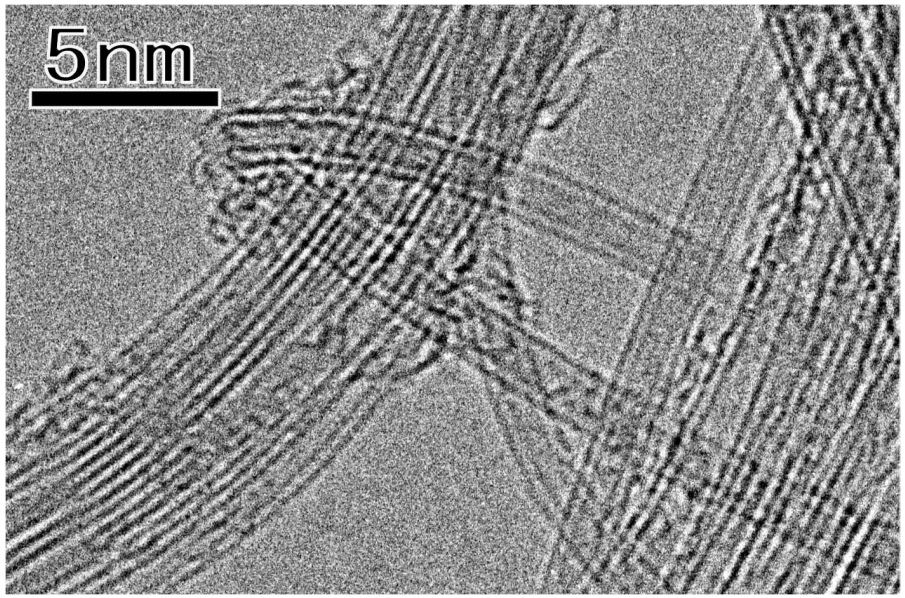

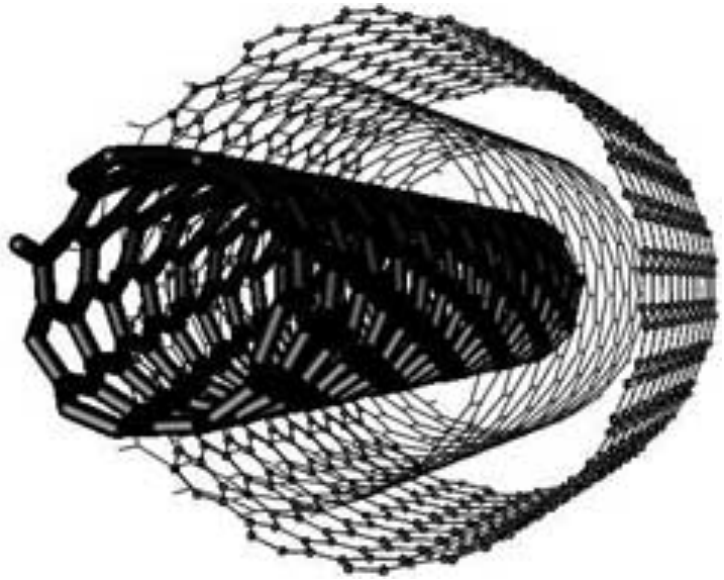

- Uncertainty in modeling (geometry, boundary condition, system parameters)
- There are defects which may not be known a-priori
- Analysis using the principles of structural mechanics, dynamics, stochastic finite element method
- Propagation of uncertainty across the length and time-scale