Research directions in computational mechanics

Instituto Tecnológico de Aeronáutica (ITA)
November 2014

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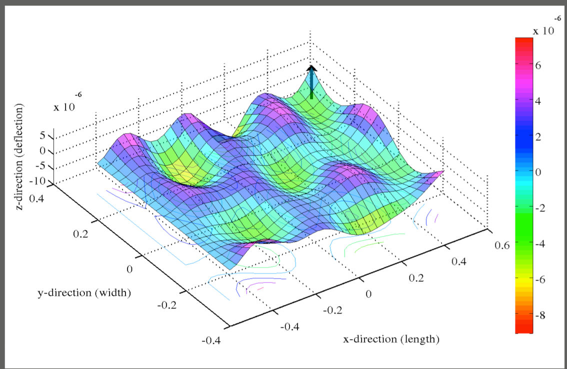
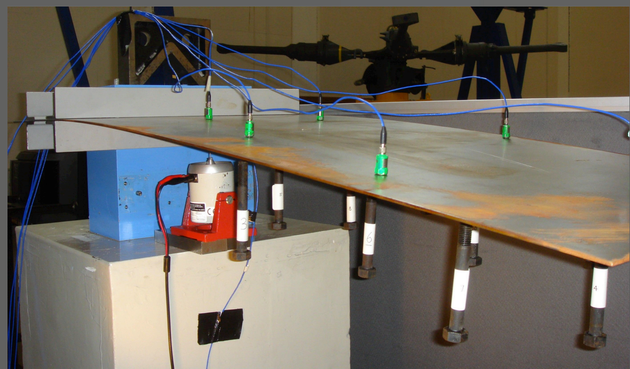
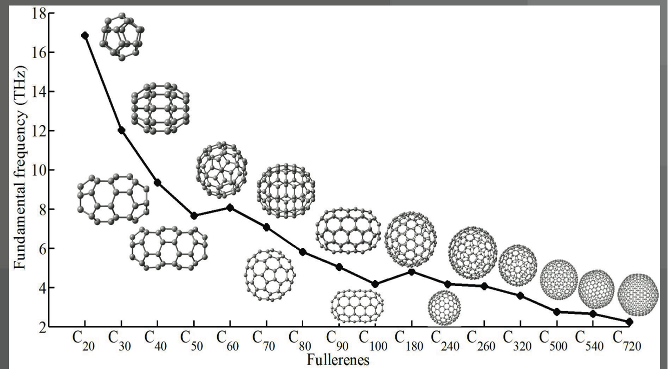






Overview

- Introduction – Swansea University
- College of Engineering – Aerospace program
- My research overview
- Nanotubes, Graphene, Fullerenes: static and dynamic analysis, buckling, composites
- Nanobio sensors: vibrating nanotube and graphene based mass sensor
- DNA mechanics
- Conclusions

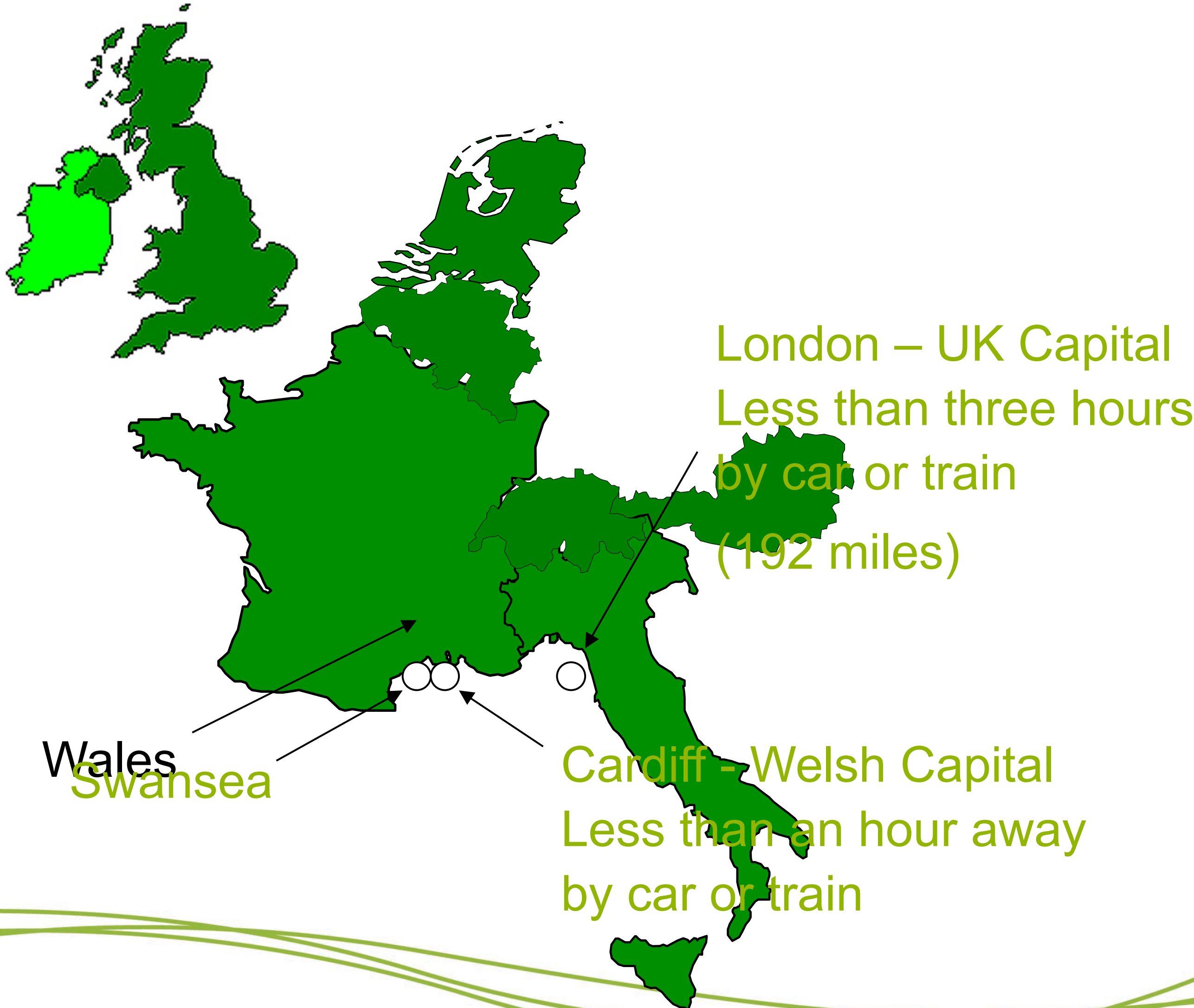
Overview

Swansea University
Prifysgol Abertawe

- Introduction – Swansea University
- College of Engineering – Aerospace program
- My research interests
- Stochastic dynamic analysis
- Vibration energy harvesting
- Nanotubes, Graphene, Fullerenes, DNA: static and dynamic analysis, buckling, composites
- Conclusions

Where is Swansea?

Swansea University
Prifysgol Abertawe








Swansea University

Swansea University
Prifysgol Abertawe

- 29^{th} UK university to be established
- King George V laid the foundation stone of the University in July 1920
- Now over 12,500 students - 1,800 international

The College of Engineering

- Engineering established at the Universities Inception in 1920
- Formed into Multidisciplinary College in 2001
- Offering 11 undergraduate disciplines
- Wide portfolio of postgraduate options, including MSc, MRes, PhD and EngD
- Professionally accredited degrees
- Extensive Industry links, including TATA Steel, Rolls Royce, Airbus, European Space Agency, BAe systems, Siemens, IBM, Motorola, BT, Ericsson, Esso, BP Chemicals
- Friendly and supportive study environment within the College and the Campus

The College of Engineering

Swansea University
Prifysgol Abertawe

~ 100 academic staff

~ 45 support staff

~ 500 research staff and postgraduate students

(~150 International)

~ 1600 undergraduates

(~300 International)

Undergraduate Degrees

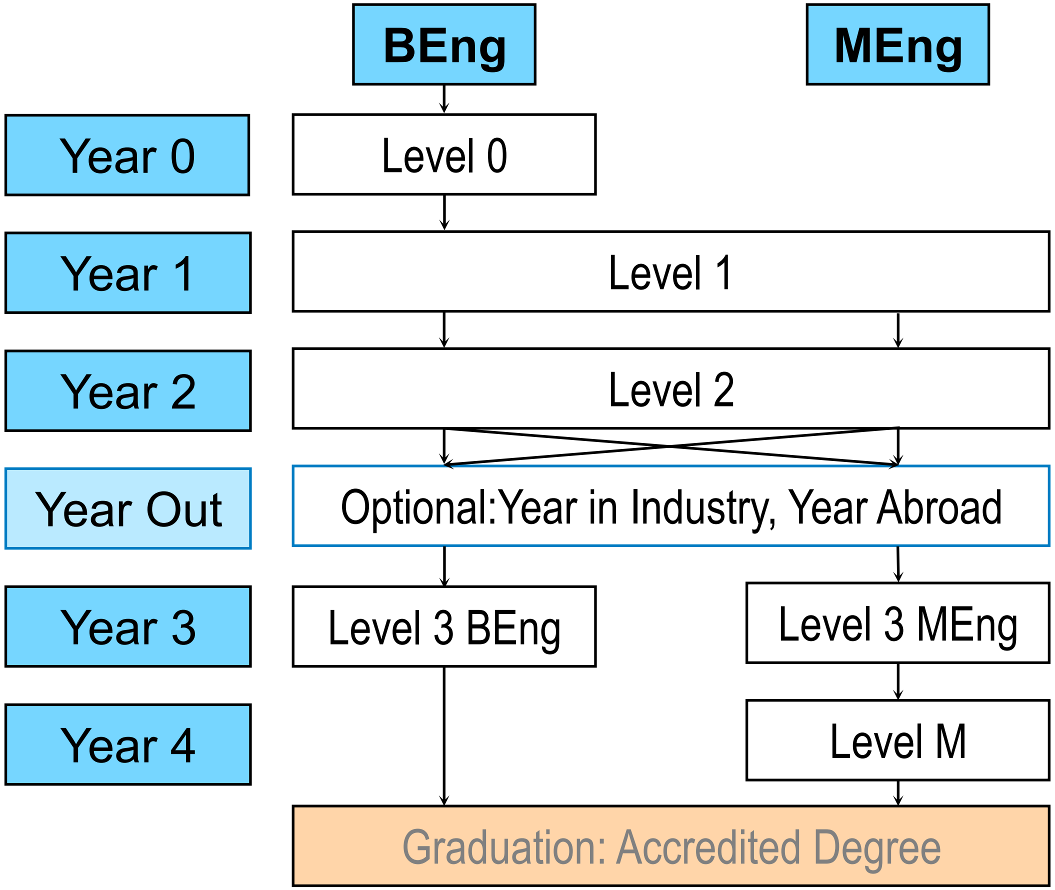
Aerospace
Chemical and Biological Process
Civil
Electrical and Electronic
Materials
Mechanical
Product Design

Environmental
Medical

Sports Science & Engineering
Sports Materials

Undergraduate Degrees

Swansea University
Prifysgol Abertawe



Accreditation

Swansea University
Prifysgol Abertawe

Accreditation to the appropriate professional bodies:

Institute of Materials, Minerals and Mining (IOM3)

Royal Aeronautical Society (RAeS)

Institution of Chemical Engineers (IChemE)

Institution of Mechanical Engineers (IMechE)

Institute of Civil Engineers (ICE)

Institution of Electrical Engineers (IEEE)

A graduate can achieve “Chartered” (CEng) Status with additional work experience.

Postgraduate Degrees

Swansea University
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Masters Degree Schemes:

Master of Science (MSc)

Master of Science by Research (MScR)

Master of Philosophy (MPhil)

Master of Research (MRes)

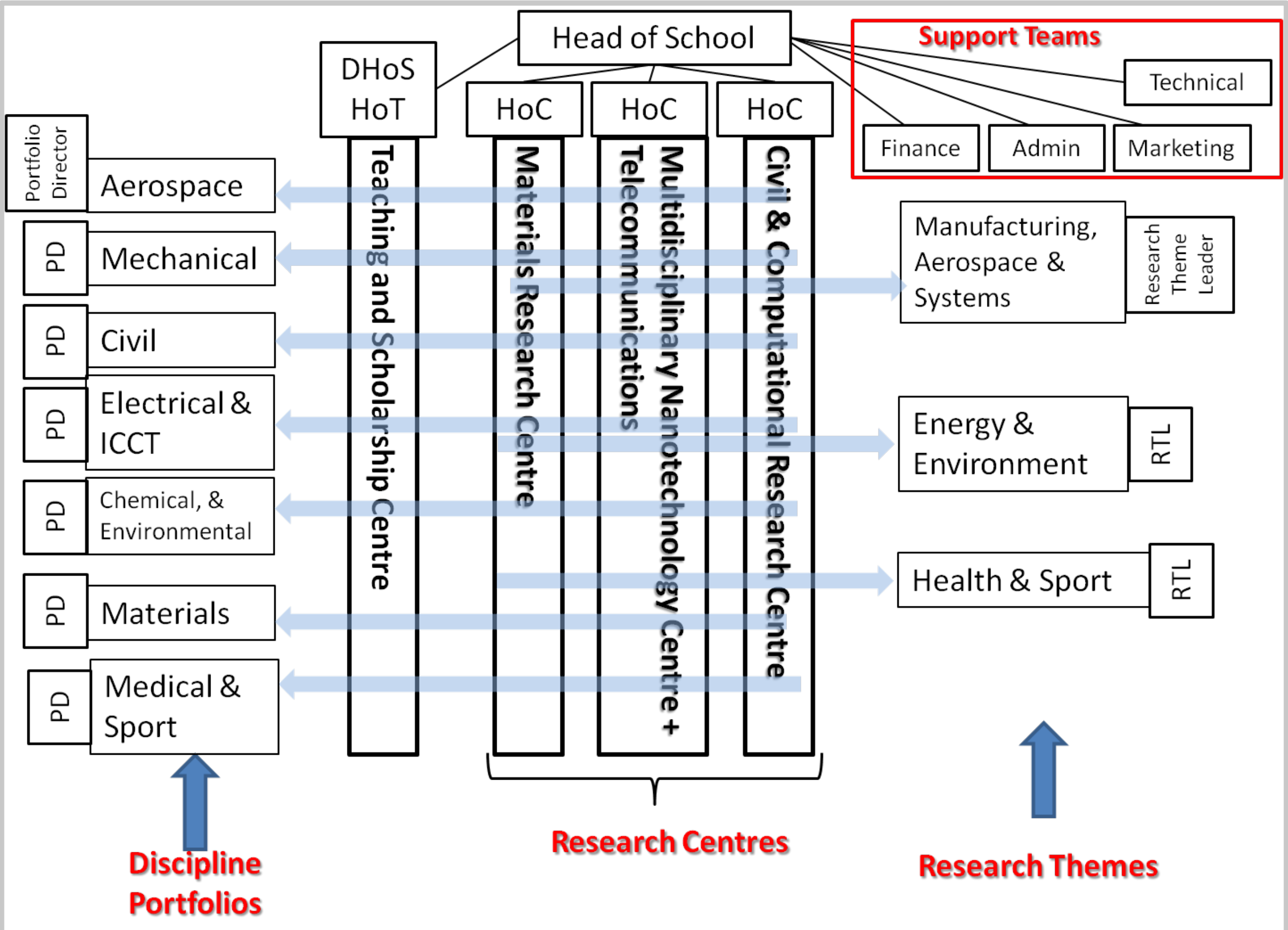
Doctorate Degree Schemes:

Doctor of Philosophy (PhD)

Engineering Doctorate (EngD)

World Class Research

Swansea University
Prifysgol Abertawe



RAE Ranking

Source: Research Assessment Exercise 2008, overall summary of results using weighted averages* www.rae.ac.uk *)

Swansea University
Prifysgol Abertawe

Institution name	Staff FTE's	Overall GPA	Position in UK
University of Cambridge	210	3.321	1
University of Oxford	122.7	3.07	2
Imperial College London	293.1	3.036	3
University of Manchester	180.22	2.963	4
University of Nottingham	114.51	2.948	5
University of Surrey	110.25	2.93	6
University of Leeds	132.7	2.911	7
Swansea University	**63.5**	**2.902**	**8**
University of Bristol	88.1	2.88	9
University of Warwick	69.45	2.85	10

League Tables

The Guardian

Institution Name	Position in UK
University of Cambridge	1
University of Oxford	2
Durham University	3
Nottingham Trent	4
University of Warwick	5
Cardiff University	6
University of Exeter	7
University of Bristol	8
Leicester University	9
Swansea University	10

The Times

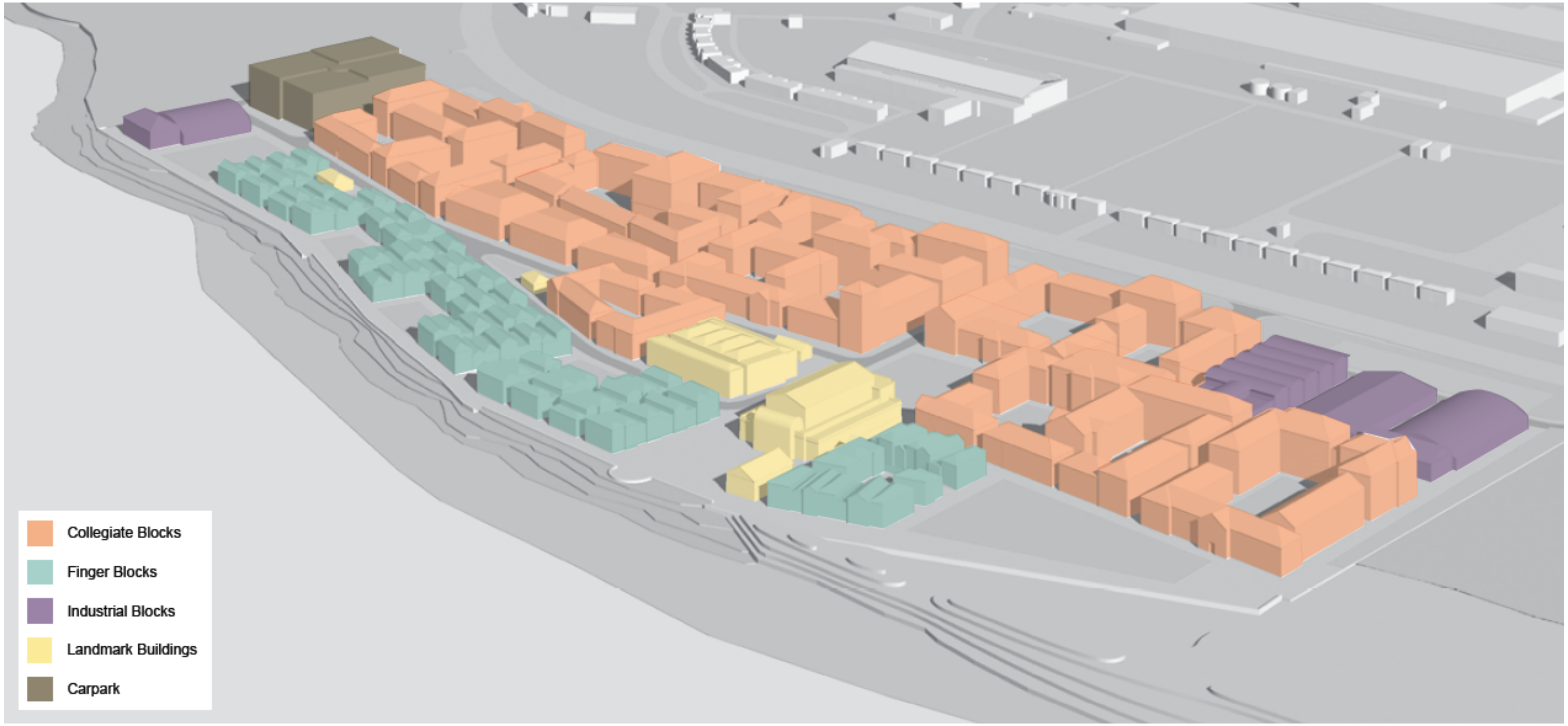
Institution Name	Position in UK
University of Oxford	1
Imperial College London	2
University of Camrbidge	3
Warwick University	4
Brunel University	5
Bournemouth University	6
Leicester University	7
Durham University	8
University of Exeter	9
Hull University	10
Swansea University	11

Science and Innovation Campus Site

Swansea University
Prifysgol Abertawe

Science and Innovation Campus

Swansea University
Prifysgol Abertawe



Science & Innovation Campus

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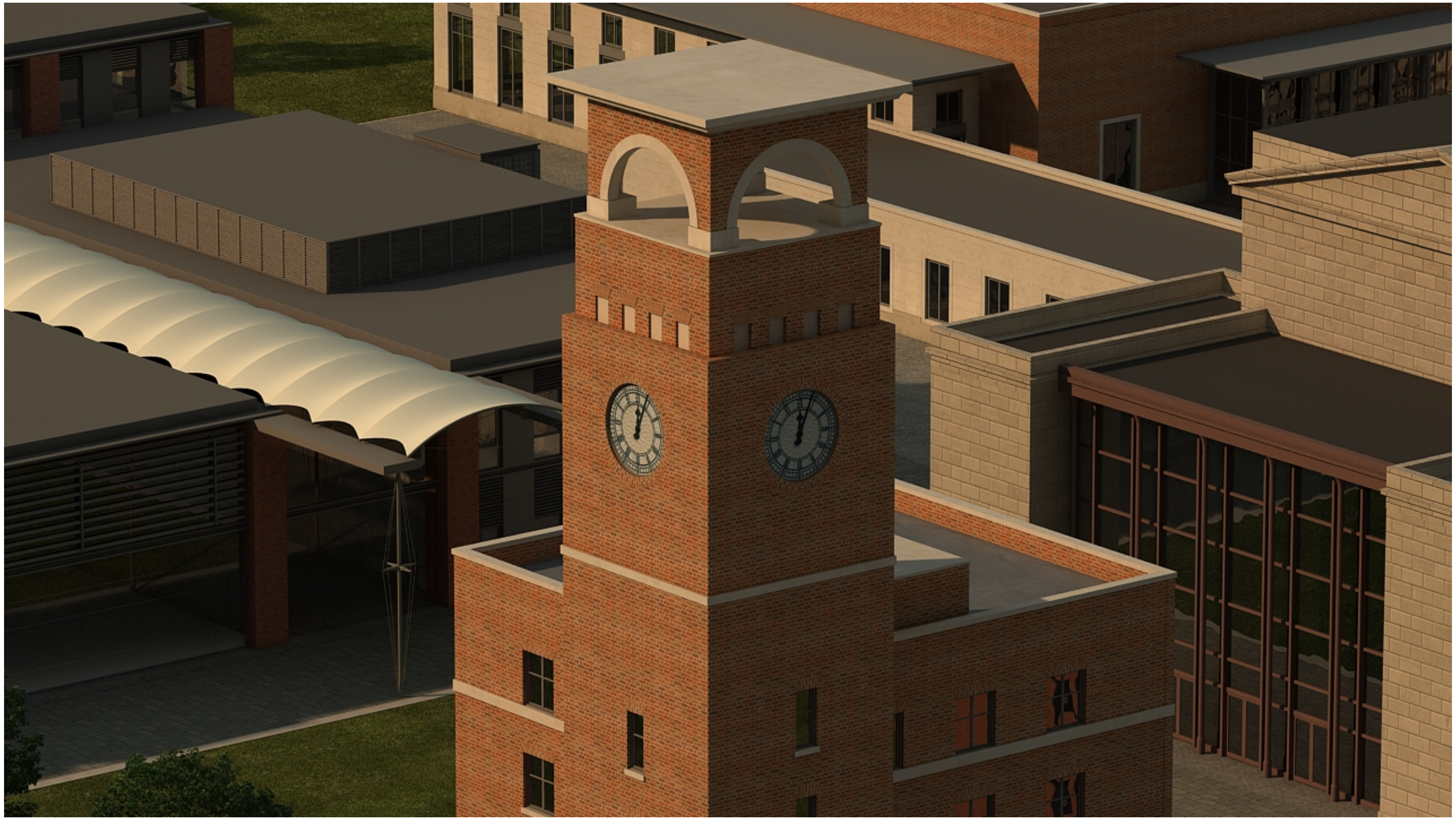

Science & Innovation Campus

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Swansea University
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bp

ST.MODWEN
ARBENIGWYR ADFYWIO MWYAF BLAENLLAW'R DU

Campws Gwyddoniaeth ac Arloesedd Arfaethedig Newydd

Swansea University

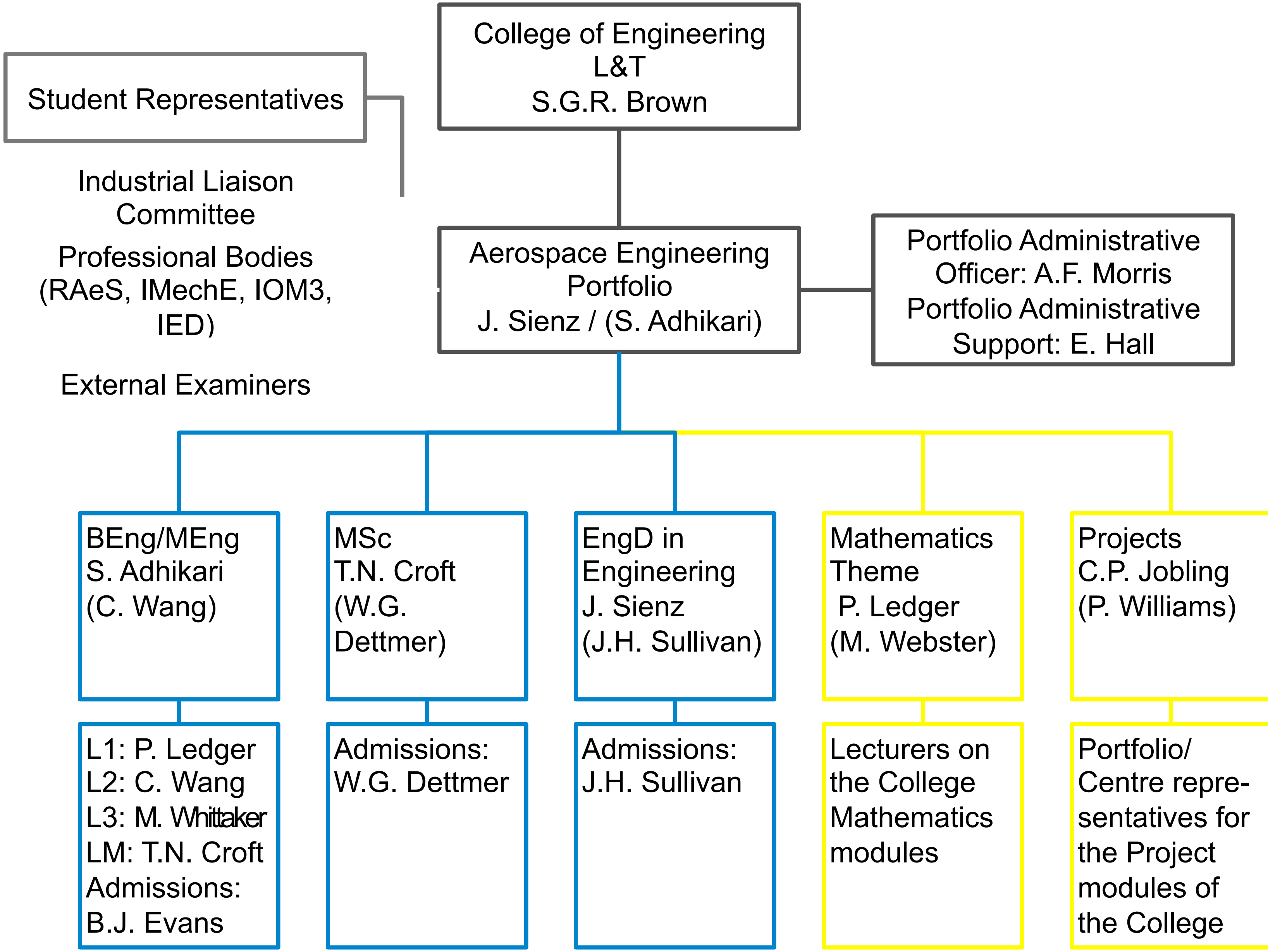
BEng/MEng Aerospace Engineering

Swansea University
Prifysgol Abertawe

College of Engineering

www.swansea.ac.uk/engineering

Aerospace Engineering Structure



Aerospace Summary

Swansea University
Prifysgol Abertawe

Accreditation: BEng/MEng/MSc/EngD with minor changes

BEng/MEng:

- 60% increase in L1 students from 10/11 to 11/12
- 192 FTEs overall (4 L0, 89 L1, 65 L2, 26 L3, 8 LM)
- Second highest UCAS entry (just behind Welsh)
- Highest conversion rate in Engineering

Current Student numbers

• Level 1	91
• Level 2	85
• Level 3	71
• Level M	6

Level 1

Semester 1 Modules	Semester 2 Modules
EG-106 Engineering Skills and Experiments I Masters (Co-ordinator) 20 credits	EG-120 Strength of Materials J Bonet 10 credits CORE
	EG-144 Dynamic Systems R Daniels 10 credits
EG-166 Engineering Mechanics Y Feng 10 credits CORE	EG-160 Fluid Mechanics I M. Webster 10 credits CORE
EG-180 Introduction to Materials Engineering G Fourlaris 10 credits	EG-161 Thermodynamics I J Sienz 10 credits CORE
EG-189 Engineering Analysis 1 PD Ledger 10 credits CORE	EG-165 Engineering Design 1 MJ Clee 10 credits
EG-194 Introduction to Aerospace Engineering TN Croft 10 credits CORE	EG-190 Engineering Analysis 2 P Rees 10 credits CORE
Total 60 credits	Total 60 credits

Level 2

Semester 1 Modules	Semester 2 Modules
EGA220 Aerospace Systems TBD 10 credits	EG-243 Control Systems JSD Mason 10 credits
EG-264 Computer Aided Engineering C Wang 10 credits	EG-260 Dynamics I S Adhikari 10 credits CORE
EG-261 Thermodynamics 2 RS Ransing 10 credits CORE	EG-263 Engineering Design 2 MJ Clee / BJ Evans 10 credits
EG-221 Structural Mechanics 2 (a) C Li 10 credits	EG-268 Experimental Studies AW Lees (co-ordinator) 10 credits
EG-293 Aerodynamics R van Loon 10 credits CORE	EG-294 Airframe Structures W Dettmer 10 credits CORE
EG-296 Flight Mechanics W Dettmer 10 credits CORE	Module 1 10 credits CORE
Total 60 credits	Total 60 credits

Module 1	Structural/Computational Stream	EGA206: Aerospace Structural Mechanics and Materials; KM Perkins/A Gil (required for EG-323 and EG-396)
	Materials/Propulsion Stream	EG-213: Mechanical Properties of Materials 1; K.M. Perkins (required for EG-381 and EGA-301)
	Space Stream	EGA215: Rocket and Space Technology; MR Brown (required for EGA-321 and EGA-301)

Level 3

Semester 1 Modules	Semester 2 Modules
Module 1 10 credits	EG-386 Engineering Management M Evans//D Fulford/I James (External) 10 credits
EG-360 Dynamics 2 M Friswell 10 credits	EGA320 High Performance Materials and Selection TBD 10 credits
EG-399 Engineering Analysis 3 M Webster 10 credits	Module 2 10 credits
EG-335 Gas Dynamics I Sazonov 10 credits	EG-397 Propulsion MT Whittaker 10 credits
EGA302 Aerospace Engineering Design 3 MJ Clee/BJ Evans 10 credits	
EG-353 Individual Project 30 credits CORE	
Total 60 credits	Total 60 credits

Module 1	Structural/Compu-tational Stream	EG-323: Finite Element Method; D Peric (requires EGA206)
	Materials/Propulsion Stream	EG-381: Fracture and Fatigue; R Johnston (requires EG-213)
	Space Stream	EGA321: Satellite Systems; I Sazonov

Module 2	Structural/Compu-tational Stream	EG-396: Computational Aerodynamics; P Ledger (requires EGA206)
	Materials/Propulsion Stream	EGA301: Composites; CJ Arnold
	Space Stream	EGA301: Composites; CJ Arnold

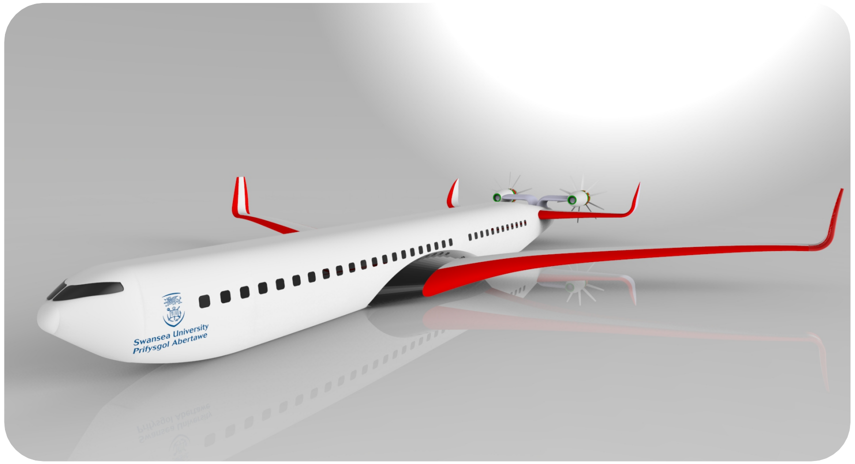
Level M

Semester 1 Modules	Semester 2 Modules
EGIM02 Numerical Methods MG Edwards 10 credits	EGEM07 Fluid Structure Interaction W Dettmer 10 credits
EG-M47 Entrepreneurship for Engineers K Board 10 credits	EGIM06 Computational Fluid Dynamics P. Nithiarasu 10 credits
EG-M81 Flight Dynamics and Control S Adhikari 10 credits	EG-M82 Rotary Wing Aircraft MI Friswell 10 credits
EG-M85 Strategic Project Planning D Oatley 10 credits	
Option (See notes below) 10 credits	
EG-M63 Research Dissertation TN Croft (aerospace co-ordinator) 10 credits	
EG-M62 Group Project J Sienz (aerospace co-ordinator) 30 credits	
Total 120 credits	

Level M Design project

Winner of Merlin Design and Aircraft Handling Competition:

- IT FLIES UK 2011
- IT FLIES US 2012
- Swansea is the first university to hold both titles at the same time



Site visits

Site visits to GE and Airbus, and also to Bloodhound Technical Centre

Flight training

Progression/Award Statistics

	BEng/MEng Aero 2010/2011		BEng/MEng Aero 2011/2012	
	%	Number	%	Number
1st	19.35	6	25.9	7
2:1	41.9	13	37	10
2:2	38.7	12	33.3	9
3rd	0	0	3.7	1
Pass	0	0	0	0
other	0	0	0	0

% Good Honours 10/11 = (6+13)/(6+13+12) x 100 = 19/31 x 100 = 61.3

% Good Honours 11/12 = (7+10)/(7+10+9+1) x 100 = 17/27 x 100 = 62.96

Executive Summary

Swansea University
Prifysgol Abertawe

5% improvement to 87% of students satisfied or very satisfied with the overall quality of their course.

Swansea University climbed 38 positions in UK rankings for student satisfaction to 42nd.

Swansea has climbed 12 places in the Sunday Times League Table to 45th position.

11 subject areas now in upper quartile, with 3 ranked in 1st position.

Student Recommendation

89% of final year and 91% of taught postgraduate students would recommend Swansea to a friend or relative

Research

Swansea University
Prifysgol Abertawe

College of Engineering

www.swansea.ac.uk/engineering

Zienkiewicz Centre for Computational Engineering

- Computational Mechanics
- Optimisation
- Computational Fluid dynamics
- Computational electromagnetics
- Rotordynamics
- Morphing wing aircraft
- Energy harvesting
- Computational Biomechanics
- Uncertainty quantification

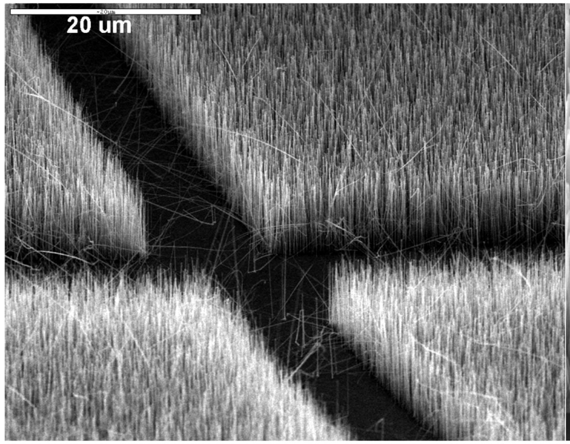
My Research Areas

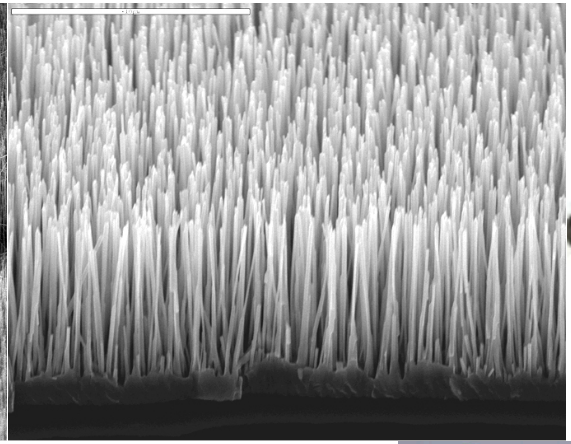
- Uncertainty quantification in modelling and simulation
- Dynamic analysis of complex structures
- Vibration energy harvesting
- Atomistic finite element method
- Dynamics of nanoscale structures
- Nanoscale bio sensors

Uncertainty quantification

Uncertainty in Structural Dynamics

Stochastic dynamical systems across the length-scale





Equation of Motion of Dynamical Systems

- The Equation of motion of all these systems (and many other) about an equilibrium point can be expressed by:

$$\mathbf{M}(\theta)\ddot{\mathbf{u}}(\theta,t) + \mathbf{C}(\theta)\dot{\mathbf{u}}(\theta,t) + \mathbf{K}(\theta)\mathbf{u}(\theta,t) = \mathbf{f}(t)$$

- $\mathbf{M}(\theta) \in \mathbb{R}^{n\times n}$ is the random mass matrix, $\mathbf{K}(\theta) \in \mathbb{R}^{n\times n}$ is the random stiffness matrix, $\mathbf{C}(\theta) \in \mathbb{R}^{n\times n}$ is the random damping matrix and $\mathbf{f}(t)$ is the forcing vector. We use (θ) to denote that the quantity is random.

The uncertainty propagation problem:
Given the stochastic description of the three systems matrices and the input forcing function, obtain the stochastic description of the response

Uncertainty modeling in structural dynamics

Uncertainty modeling

Parametric uncertainty: mean matrices + random field/variable information

Random field discretization

$$\mathbf{A} = \left(\mathbf{A}_0 + \sum_{i=1}^{M} \xi_i(\theta)\mathbf{A}_i\right)$$

Nonparametric uncertainty: mean matrices + a single dispersion parameter for each matrices

Random matrix model

$$\mathbf{A} \sim W_n(\mathbf{A}_0, \delta_A^2)$$

Dynamic Response

- For parametric uncertainty propagation:

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

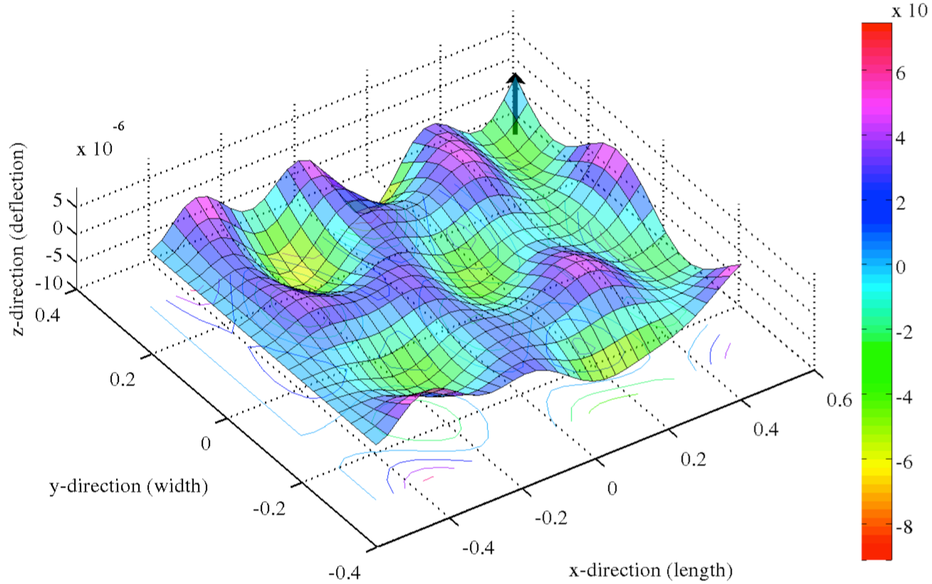
- For nonparametric uncertainty propagation

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

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

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

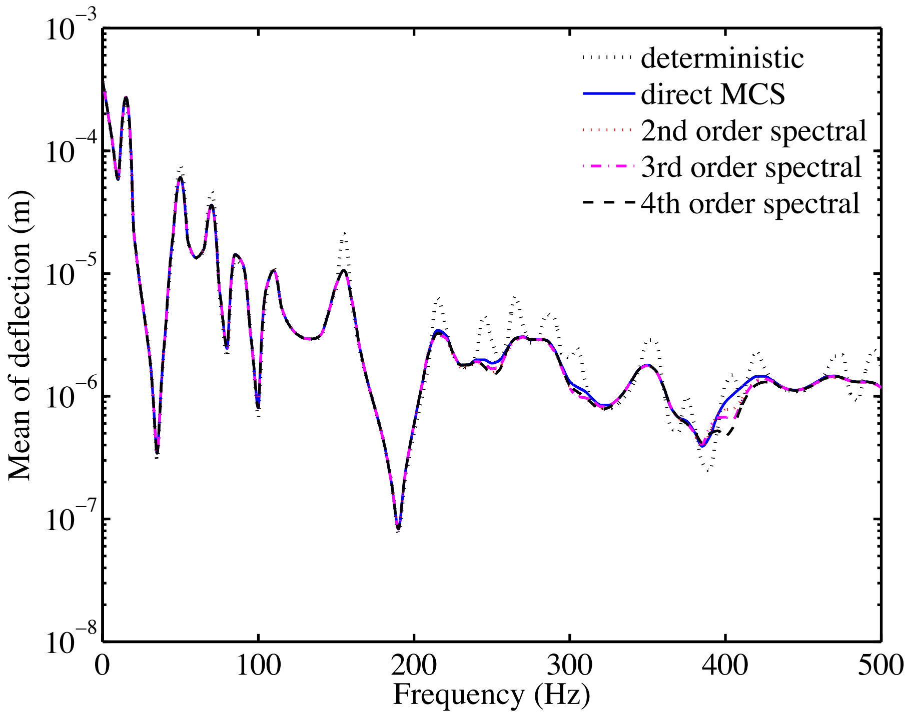
Plate with Stochastic Properties



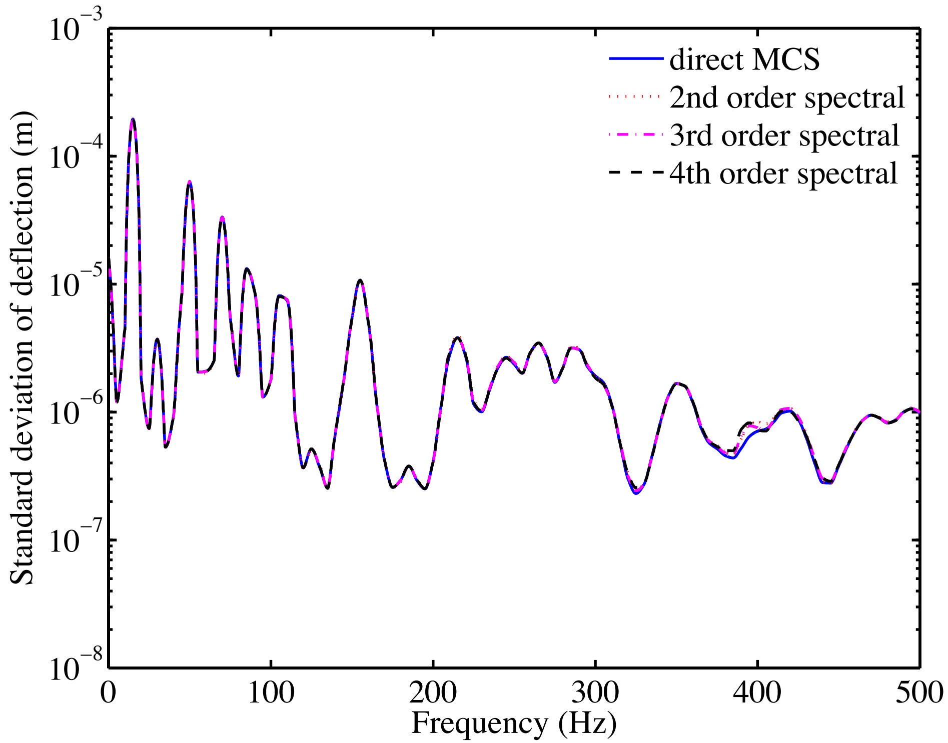
- An Euler-Bernoulli cantilever beam with stochastic bending modulus (nominal properties 1m x 0.6m, t=03mm, E=2 x 10^{11} Pa)
- We use n=1881, M=16

- We study the deflection of the beam under the action of a point load on the free end.
- 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 $\sigma_a = 0.1$

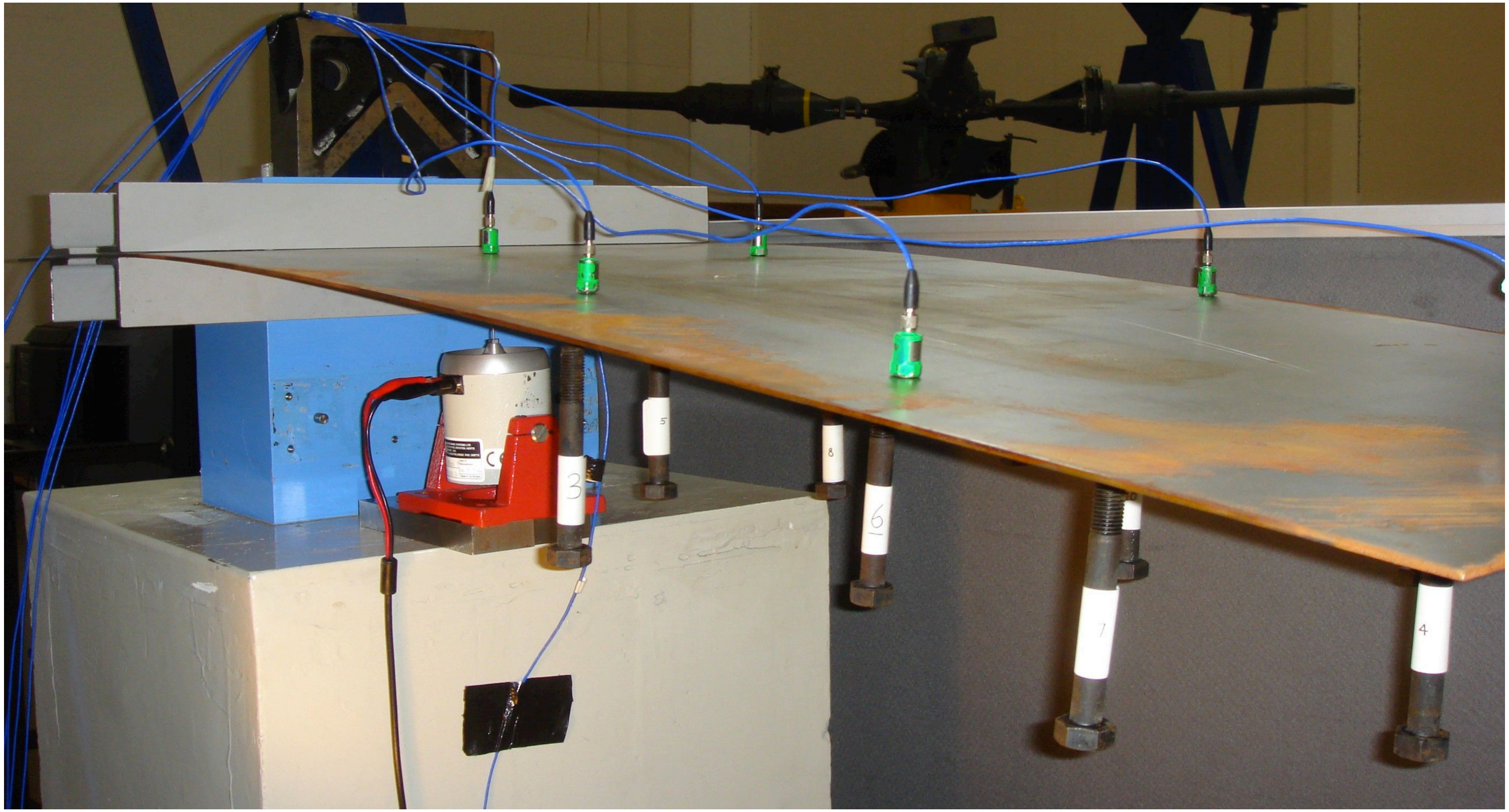


Standard deviation with $\sigma_a = 0.1$

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

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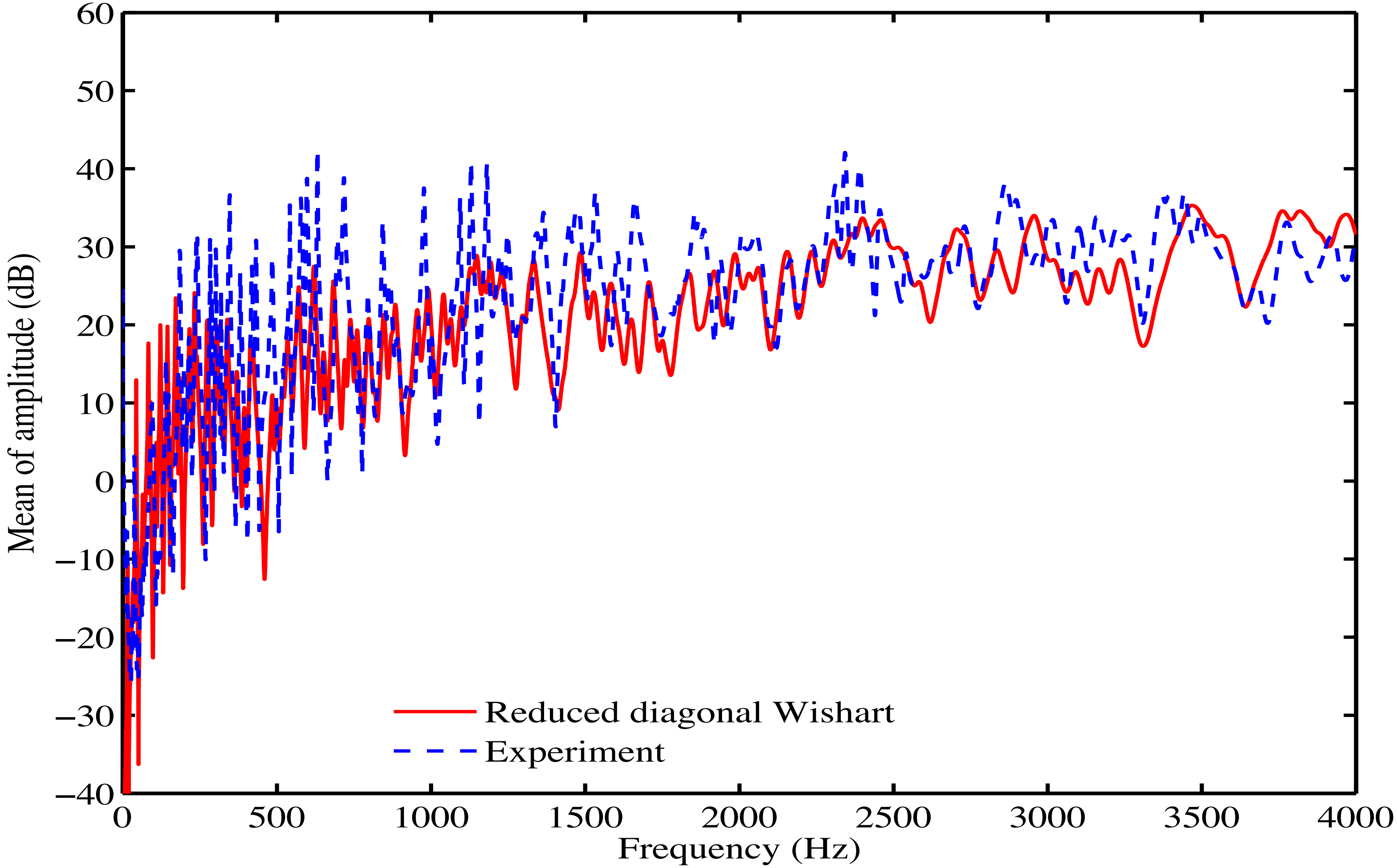

Mean of the driving-point-FRF

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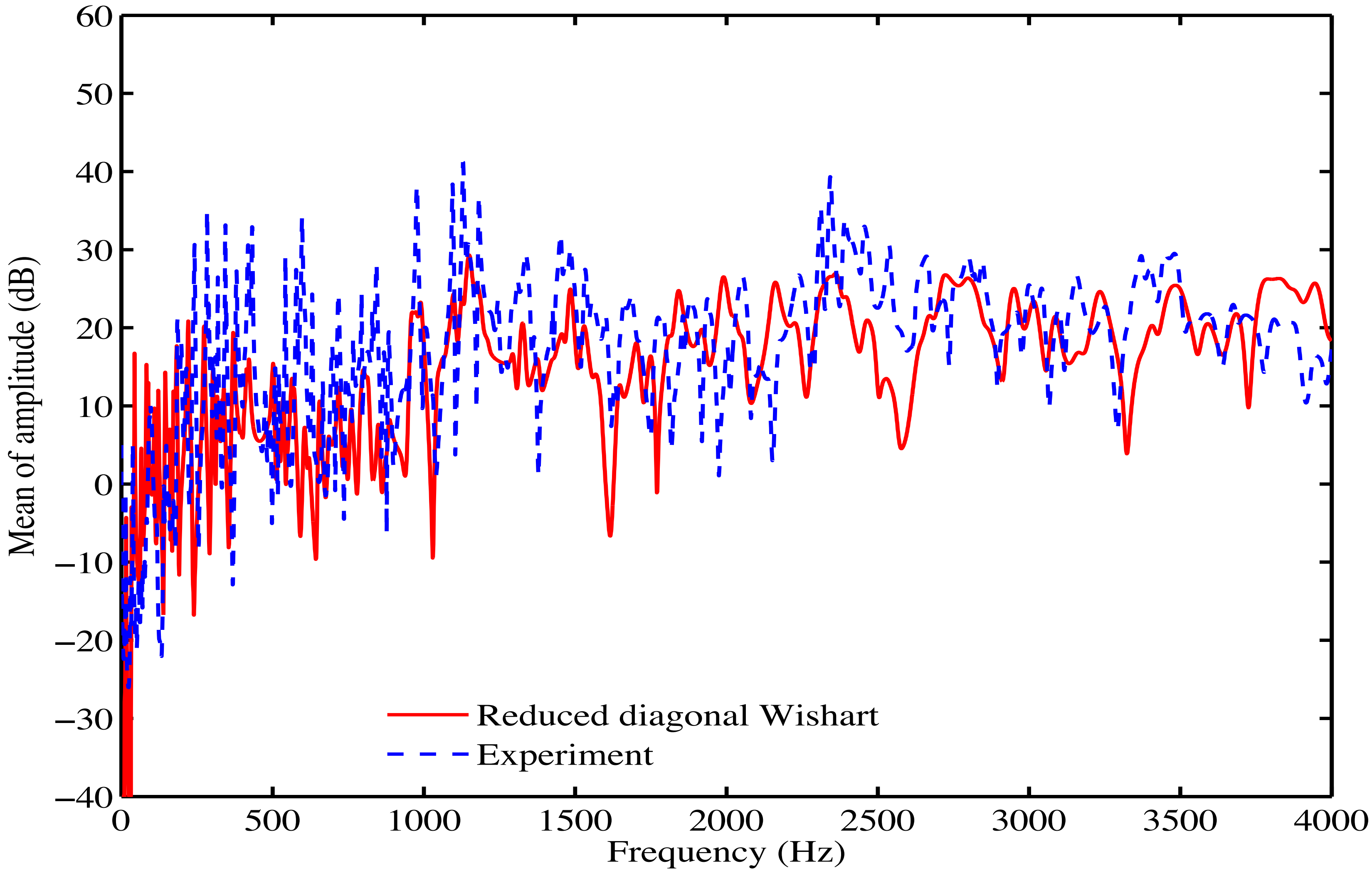

Standard deviation of a cross-FRF

Swansea University
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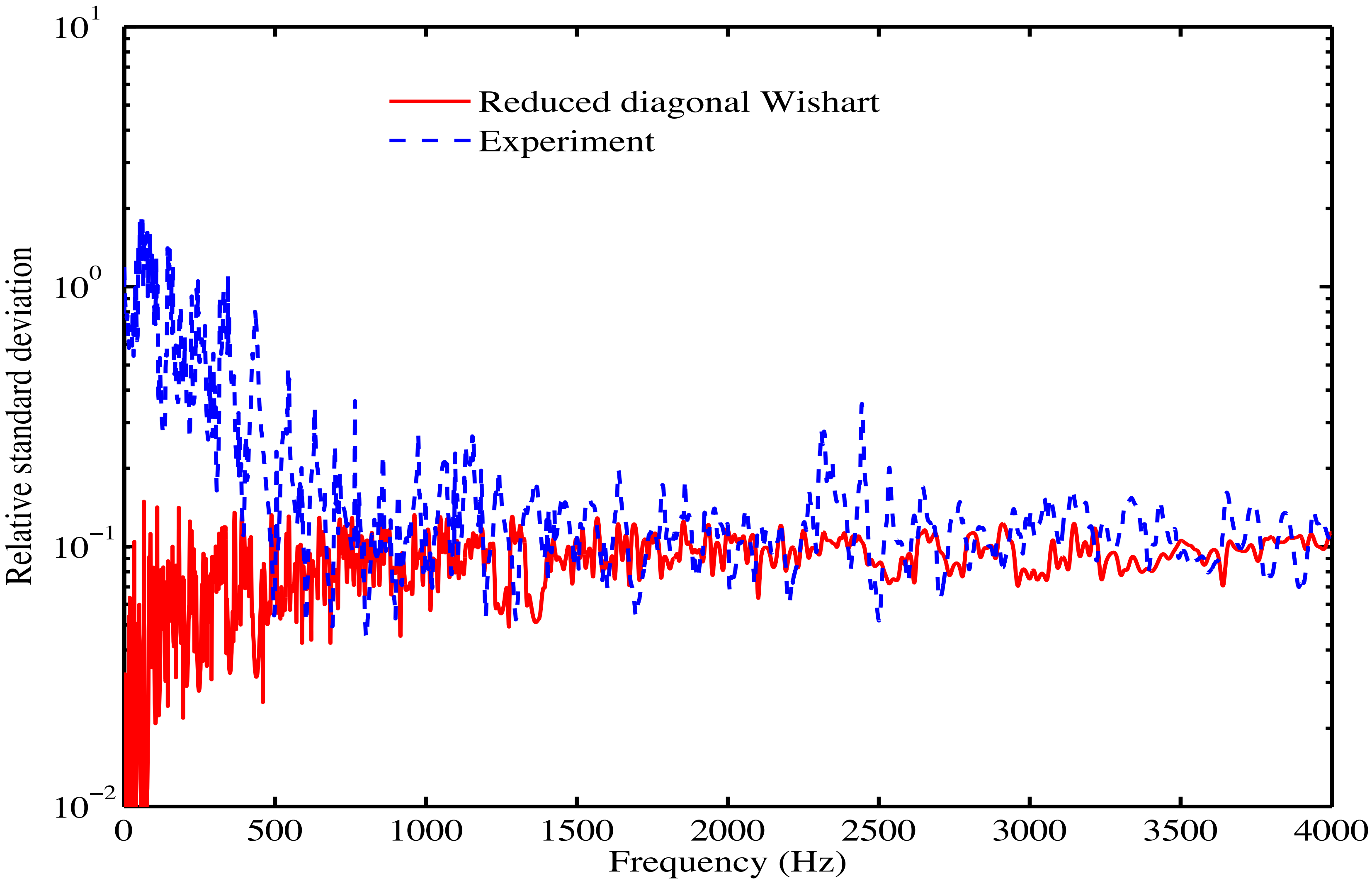
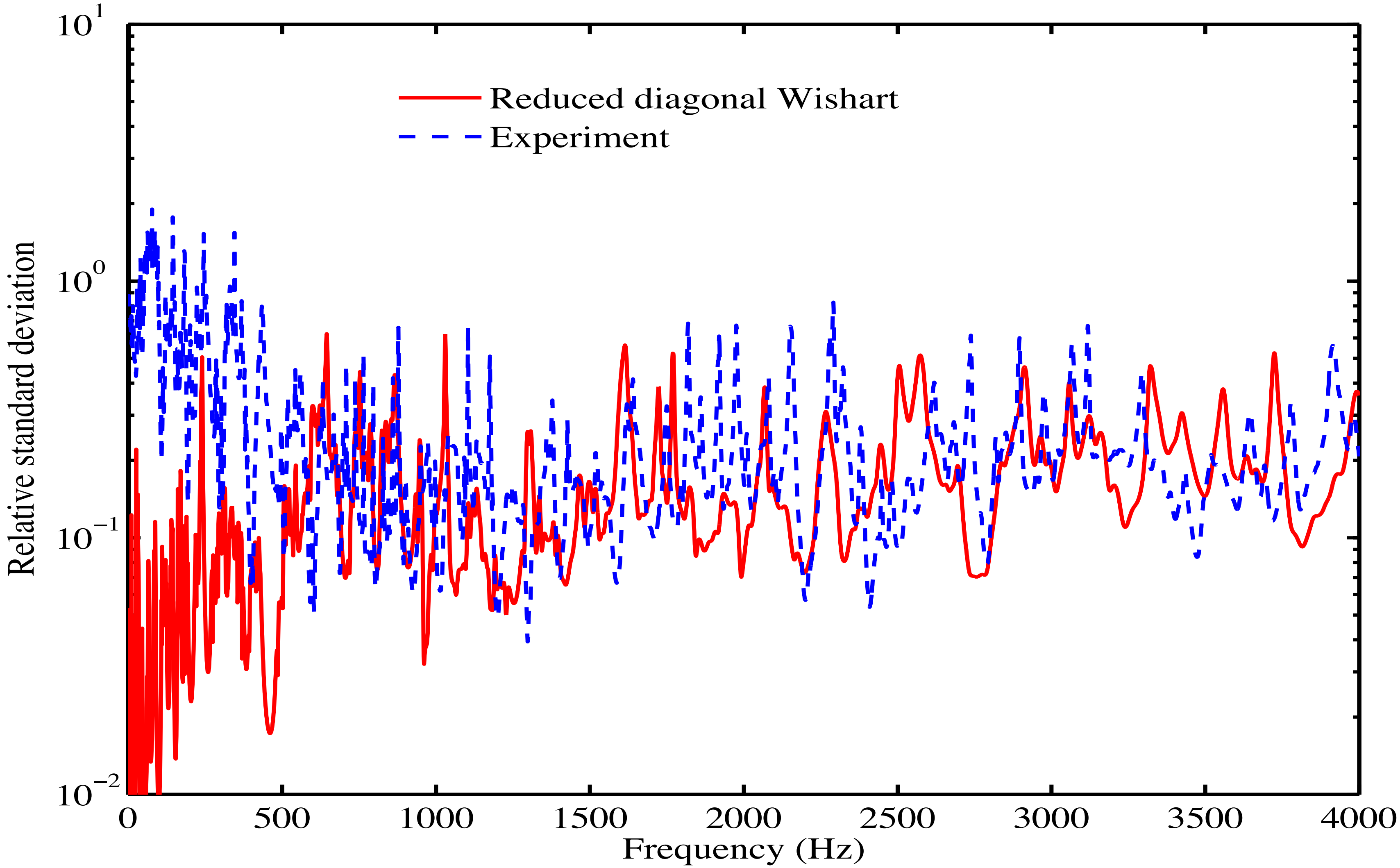


Standard deviation of the driving-point-FRF



Integration with ANSYS

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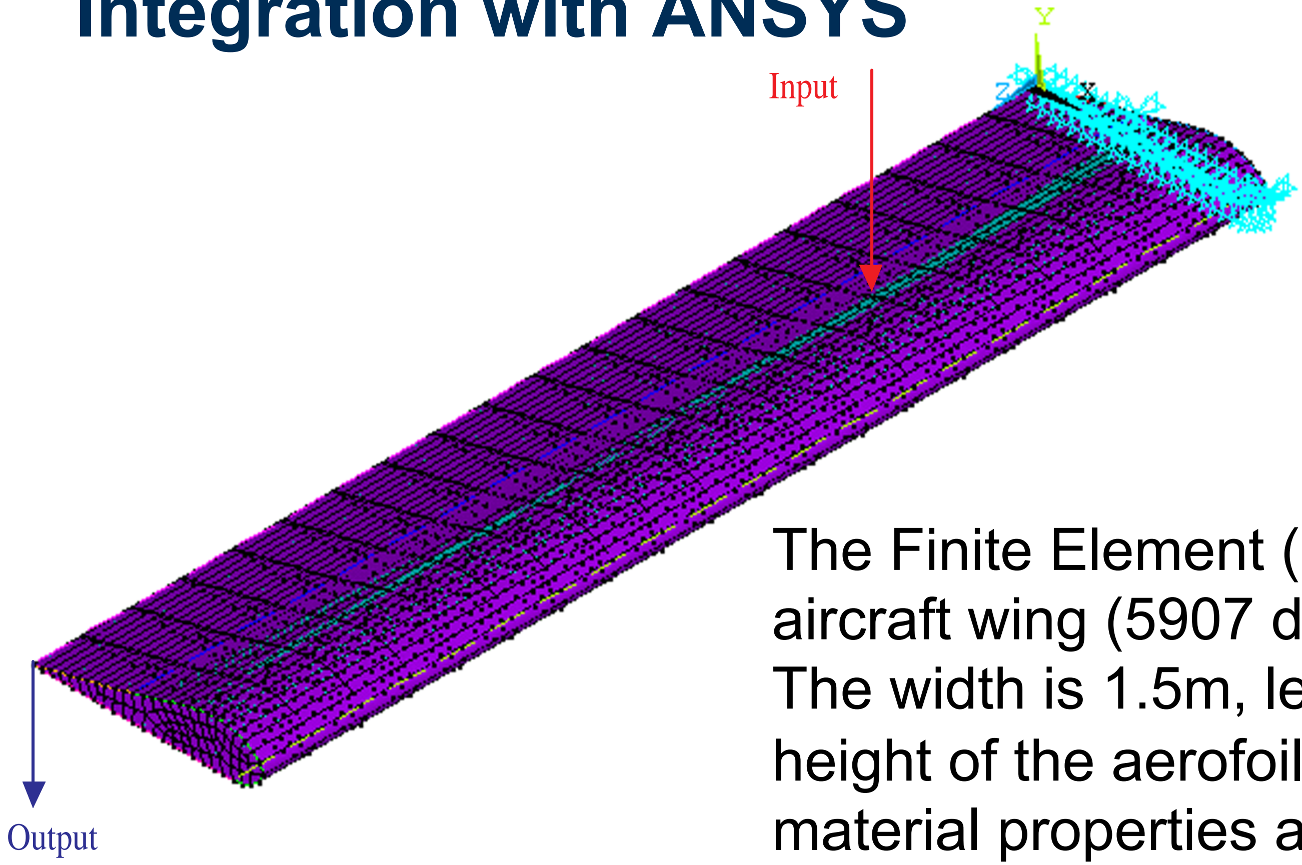
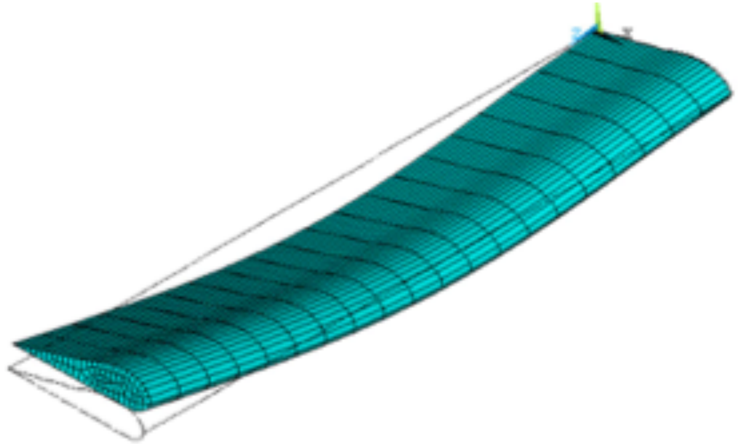
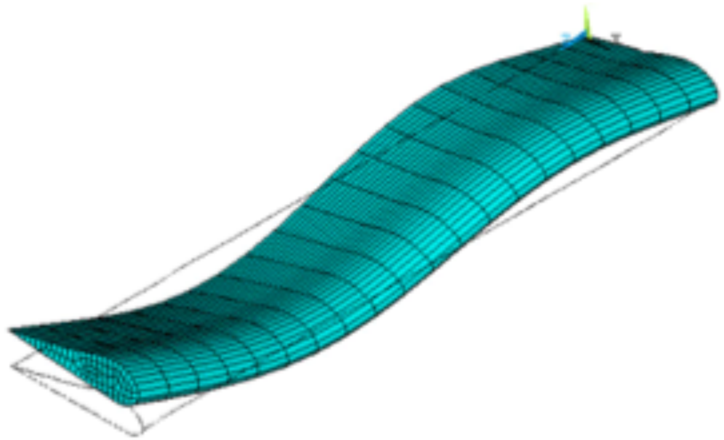


The Finite Element (FE) model of an aircraft wing (5907 degrees-of-freedom). The width is 1.5m, length is 20.0m and the height of the aerofoil section is 0.3m. The material properties are: Young's modulus 262Mpa, Poisson's ratio 0.3 and mass density 888.10kg/m^3. Input node number: 407 and the output node number 96. A 2% modal damping factor is assumed for all modes.

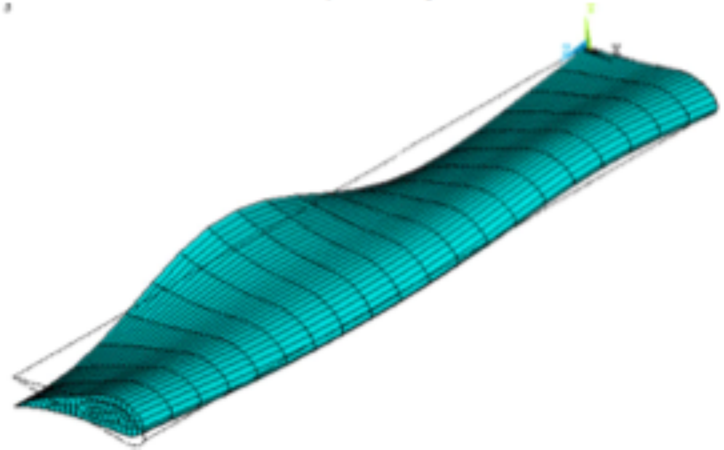
Vibration modes



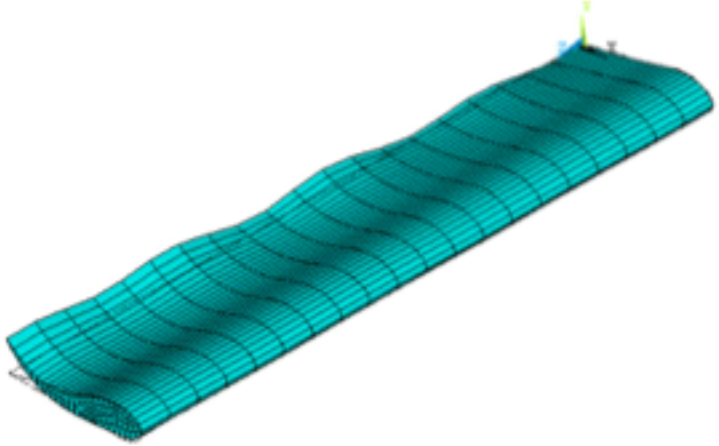
Mode 3, frequency 19.047Hz,



Mode 5, frequency 53.628Hz



Mode 10, frequency 168.249Hz,



Mode 20, frequency 403.711Hz

Mean of a cross-FRF

Swansea University
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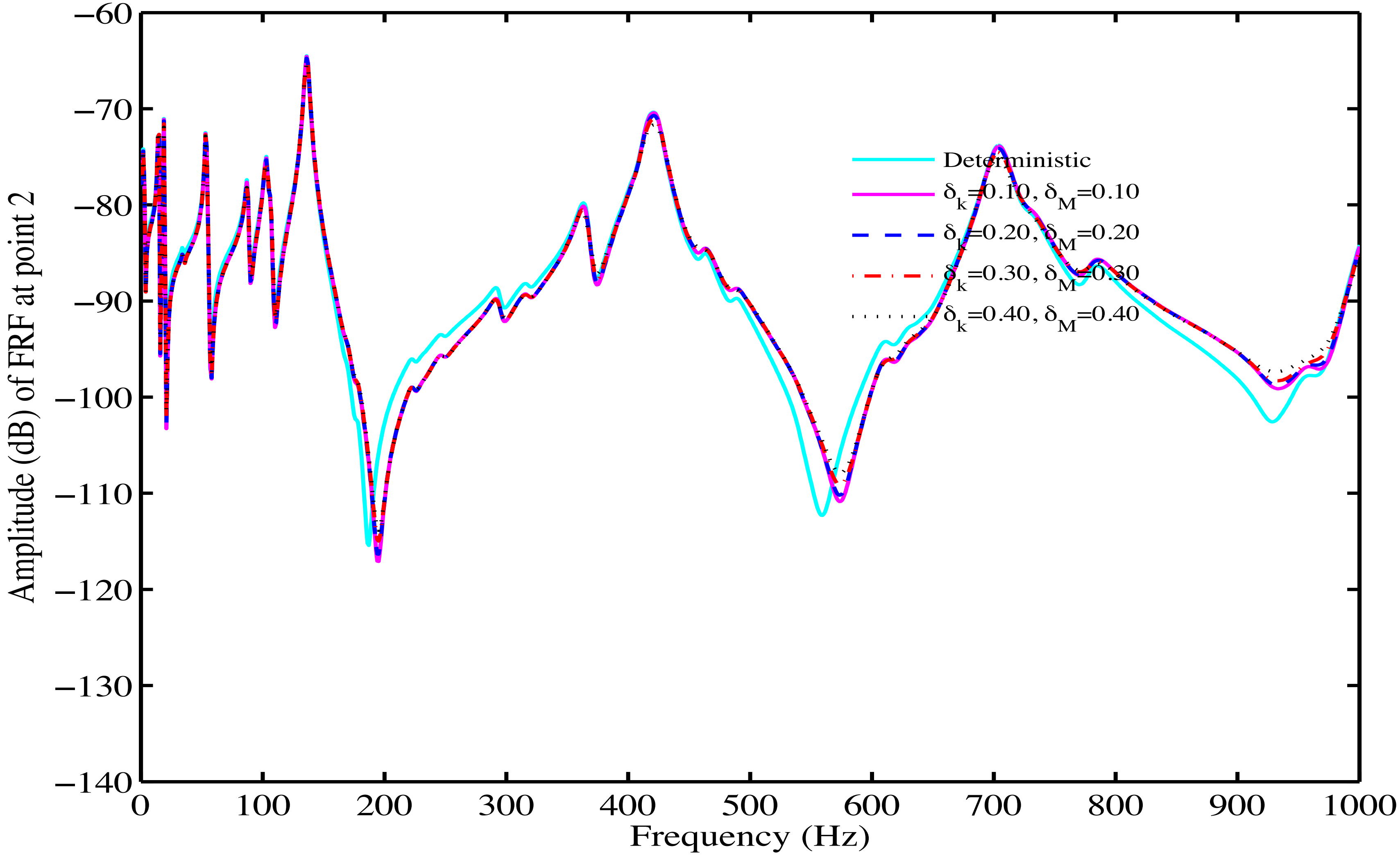
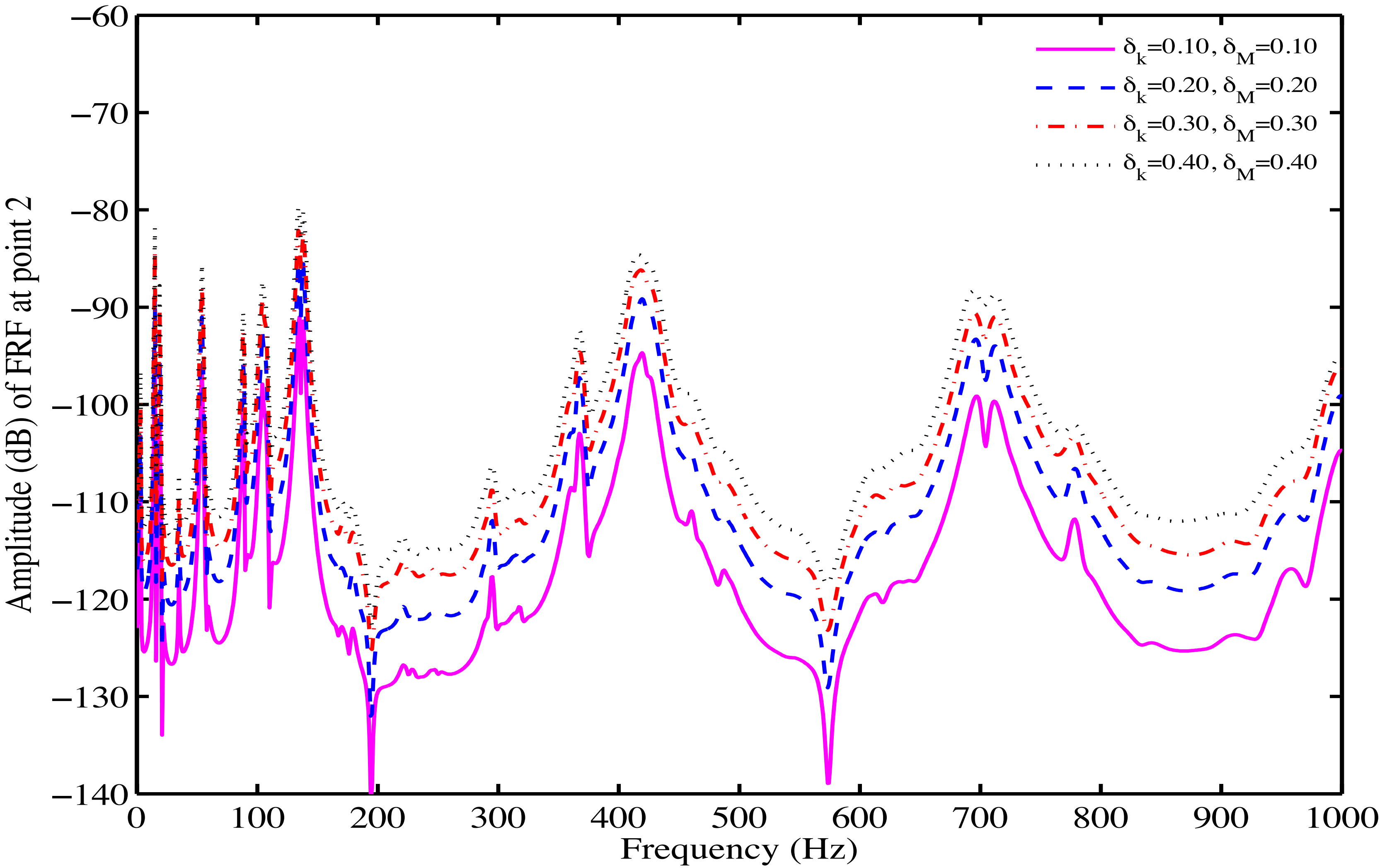


Standard deviation of a cross-FRF



Uncertainty quantification in Dynamics of Composite Plates and Shells

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Energy harvesting under uncertainty

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

Energy harvesting under uncertainty

Swansea University
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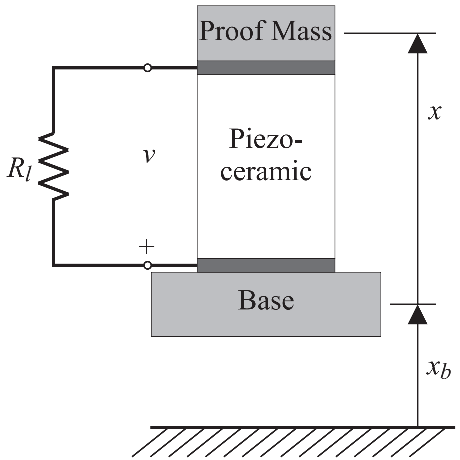


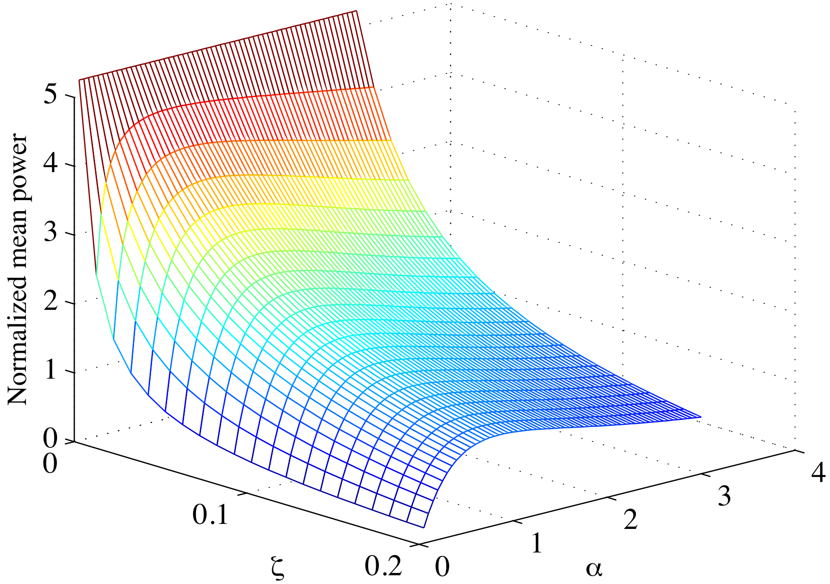
$$m\ddot{x}(t) + c\dot{x}(t) + kx(t) - \theta v(t) = -m\ddot{x}_b(t)$$

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

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

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

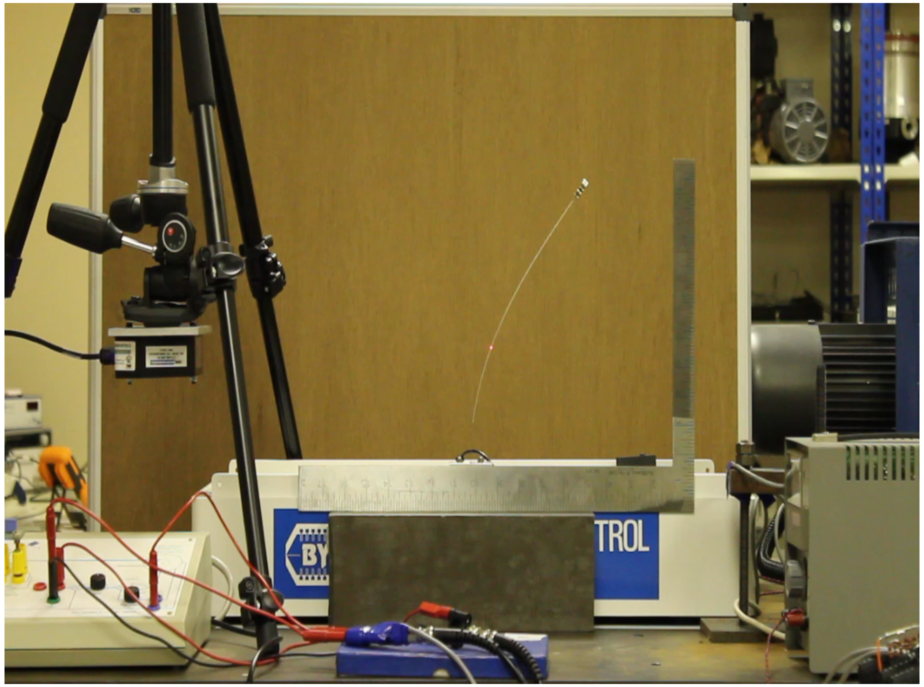
$$= \frac{\pi\, m\, \alpha\, \kappa^2}{(2\,\zeta\,\alpha^2 + \alpha)\,\kappa^2 + 4\,\zeta^2\alpha + (2\,\alpha^2 + 2)\,\zeta}$$

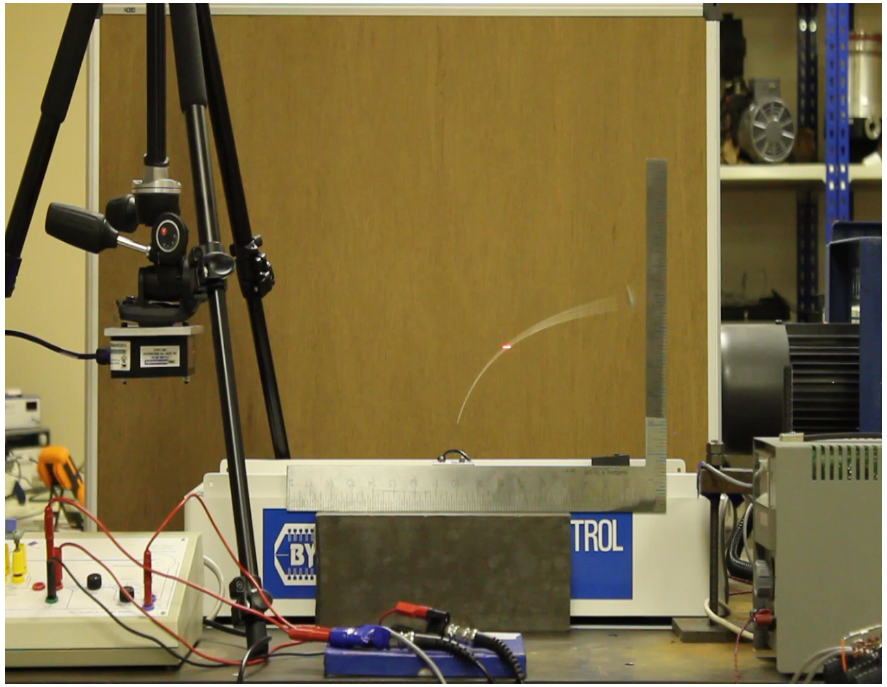


The optimal condition is

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

Vibration energy harvesting





Vibration energy harvesting

1. Borowiec, B., Litak, G., Friswell, M. I., Ali, S. F., Adhikari, S. and Lees, A. W. and Bilgen, O., "Energy harvesting in piezoelastic systems driven by random excitations", International Journal of Structural Stability and Dynamics.
2. Ali, S. F. and Adhikari, S., "Energy harvesting dynamic vibration absorbers", Transactions of ASME, Journal of Applied Mechanics.
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Stochastic multiscale method

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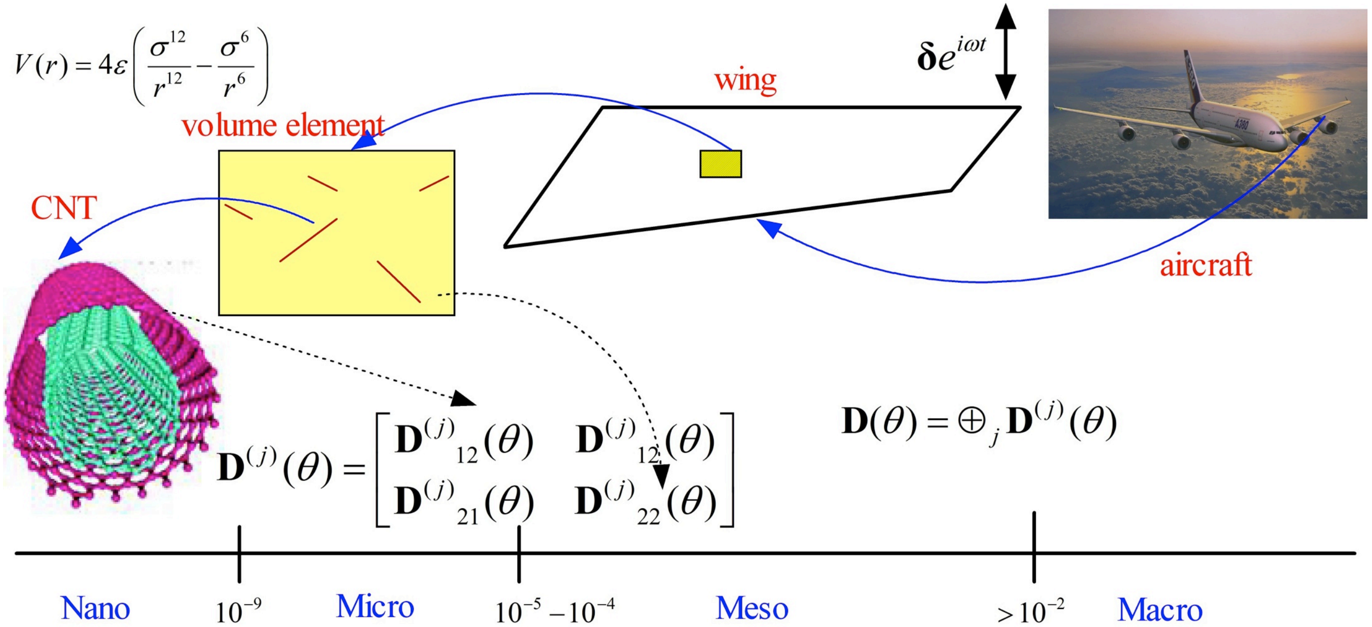

- New generation of structural materials
- Nano-composites, bio-composites
- Self-sensing, multifunctional, self-healing and sustainable materials – high strength to weight ratio
- Structural mechanics community needs to embrace new materials and develop next generation of analysis and design tools
-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

Nano-scale stochastic mechanics

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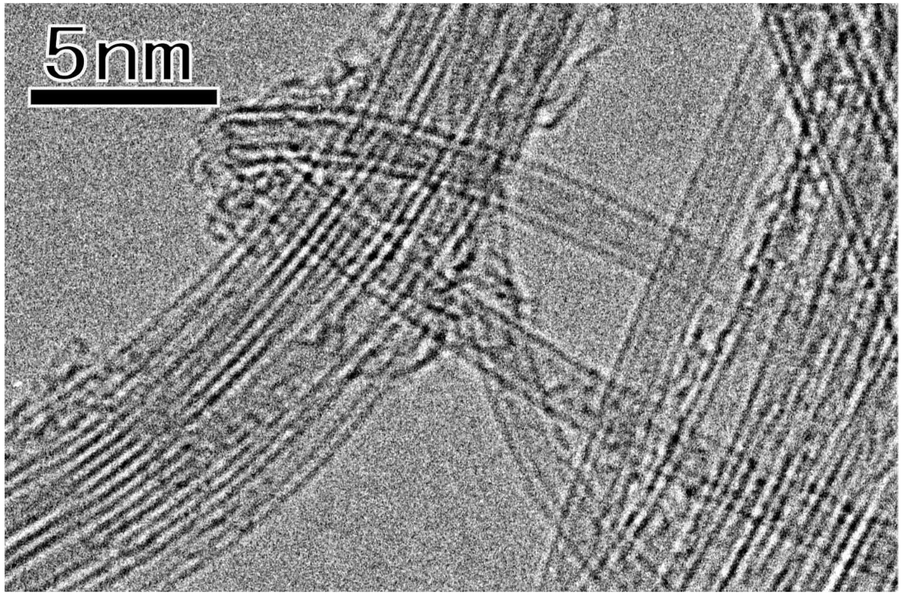

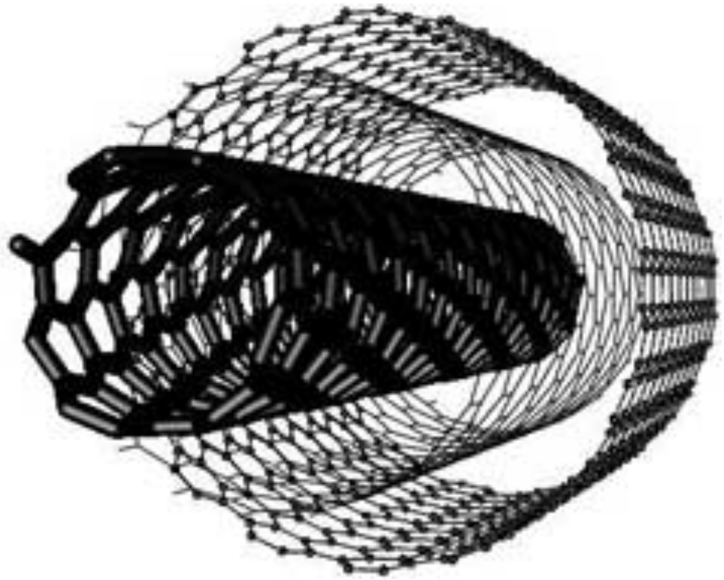

- Uncertainty in modeling (geometry, boundary condition, system parameters)
- There are defects which may not be known a-priori
- Analysis using the principles of structural mechanics, dynamics, stochastic finite element method
- Propagation of uncertainty across the length and time-scale

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