Centro di Ateneo di Studi e Attività Spaziali
Università di Padova

Proposal of Research Activity

DAMAGE DETECTION IN AEROSPACE STRUCTURES

PhD Course in Space Sciences, Technologies and Measurements (STMS)

Curriculum: Sciences and Technologies for Aeronautics and Satellite Applications (STASA)
XXXIV Cycle

PhD Student: Greta Ongaro

Matricola: 1196644

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1. INTRODUCTION AND RESEARCH BACKGROUND

MAIN PROBLEM

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Understanding of **fracture phenomenon** and **damage** initiation and evolution **mechanism** to **improve aircraft maintenance**

CURRENT SOLUTION

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Scheduled maintenance programs that must take place at **regular intervals**

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SAFETY and **ECONOMIC LOSSES**

INNOVATIVE PROPOSED SOLUTION

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Creation of a reliable **structural health monitoring** (SHM) system

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Evaluation of damages and implementation of **continuous online monitoring** of aircraft **structures**

Example of a crack in an aircraft structure

2. PROJECT OBJECTIVES

I. Development of **reliable simulations** of **wave propagation** in the **presence of cracks**

II. Analysis of the **influence** of **damage growth** on wave propagation

III. Identification of **suitable systems of sensors** for **damage detection** in various structural configurations by means of **simulation tools**

IV. Validation of numerical simulations through experimental activities

V. Optimization of sensor positioning for **passive sensing**

3. WORK METHODOLOGIES AND TOOLS

3.1 Wave propagation modelling and crack evaluation

Analysis of **perturbations** induced by damages **on wave propagation** → **detection** of **structural crack** presence

As **experimental testing** is very **expensive** and **time-consuming**

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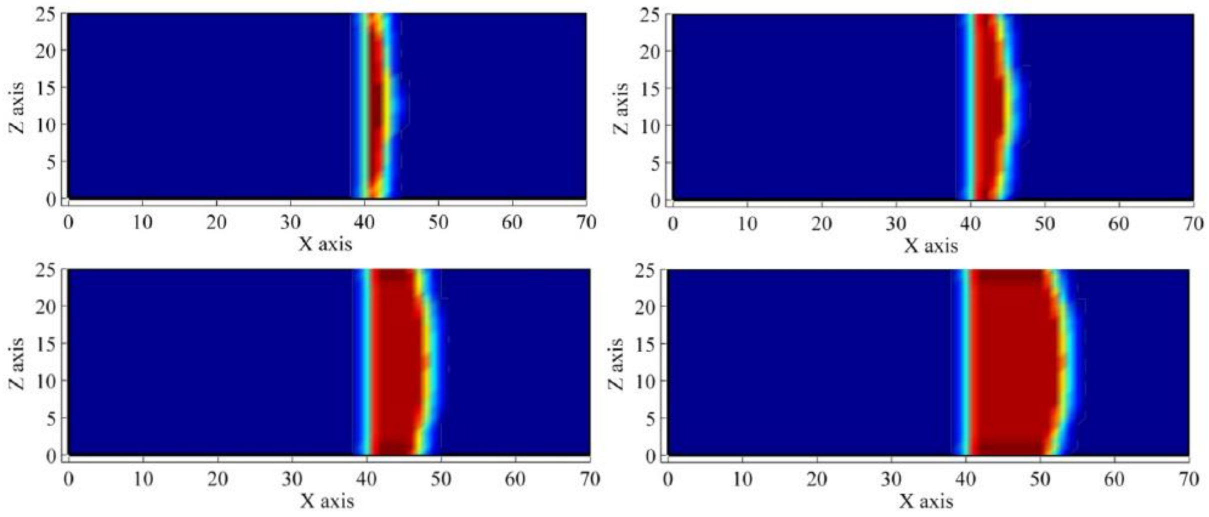
It is **essential** to develop **novel computational methods** for:

DAMAGE EVALUATION

CRACK PROPAGATION SIMULATION



Damage maps of a 3D crack propagation example

3.2 LINEAR/NONLINEAR ULTRASONIC RESPONSE AND ANALYSIS TECHNIQUES

Basis of damage detection

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Wave propagation **features** are **different** in **damaged** and **pristine** materials

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Defects can be detected **analysing** the **interactions** between **materials** and **propagating waves**

Relatively large cracks
(having dimensions greater than the signal wavelength)

Linear ultrasonic analysis

Very small damages
(when signal wavelength is greater than the size of each micro-cracks)

Nonlinear ultrasonic methods

Development of **reliable nonlinear ultrasonic numerical techniques** is essential

3.3 NOVEL COMPUTATIONAL METHODS FOR CRACK PROPAGATION SIMULATION

3.3.1 Peridynamic Theory

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Continuum theory based on a **non-local approach** and formulated with **integral equations**

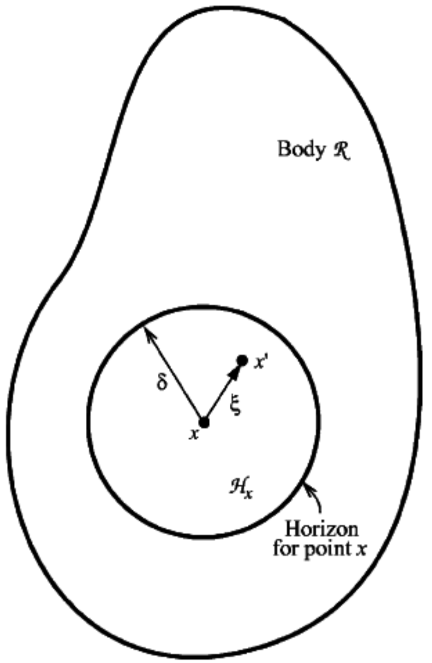
Fundamental equation of motion for any material point of the structure:

$$\rho \ddot{\mathbf{u}}_i = \int_{H_i} \mathbf{f}\left[\mathbf{u}(\mathbf{x}_j,t) - \mathbf{u}(\mathbf{x}_i,t), \mathbf{x}_j - \mathbf{x}_i\right] dV_j + \mathbf{b}(\mathbf{x}_i,t)$$

$$\forall \mathbf{x}_j \in \mathrm{H}_i$$

where:

- $\mathbf{x_i}$ is a material point of the structure
- $\mathbf{H_i}$ is the spherical neighbourhood of radius $\boldsymbol{\delta}$ centred at point $\mathbf{x_i}$
- **u** is the displacement vector field
- **b** is a body density force vector
- **f** is a pairwise force function (a force per unit square volume)



Each point x in the body interacts directly with points in the sphere H_x through bonds

3.3.1 Peridynamic Theory

Main advantages

1. **Integral formulation**

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No spatial differentiability of displacement fields is assumed

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Incompatibility of **cracks** with **PDEs** used in the **classical theory** of solid mechanics is overcame

2. Introduction of the concept of **structural damage** for a **material point**

3. **No a-priori knowledge** about crack initiation and propagation required

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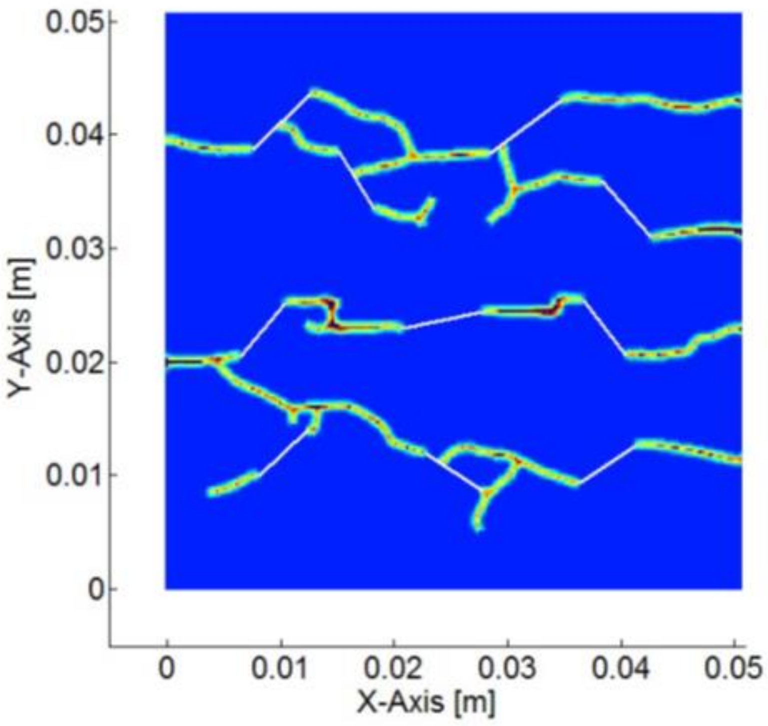
Cracks are **free** to **arise** and **grow** in every part of the structure

Disadvantages

1. PD methods are **computationally very expensive**
2. **Bandwidth** of the stiffness matrix in PD software is **bigger** than that in CCM software
3. Defining **boundary conditions** in a non-local theory introduces some difficulties



Coexisting cracks in a plate simulated with Peridynamics

3.3.2 FEM/PD coupling

Coupling of **FEM** meshes with **Peridynamic** grids is very **convenient**

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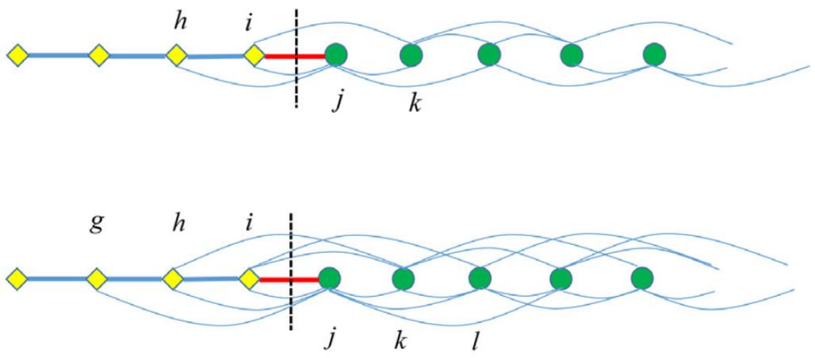
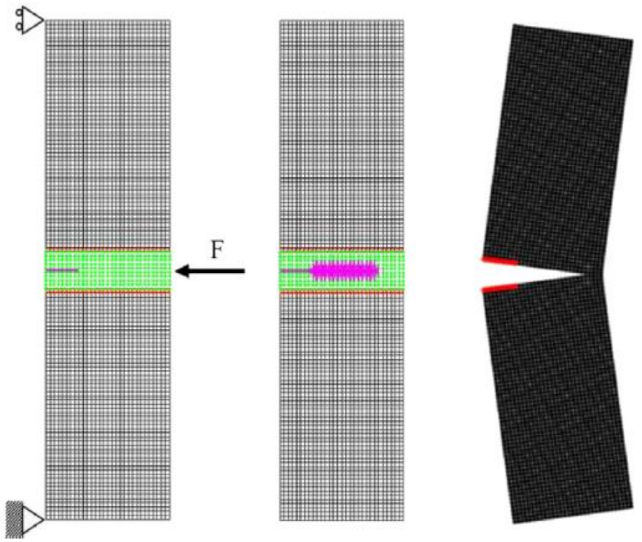
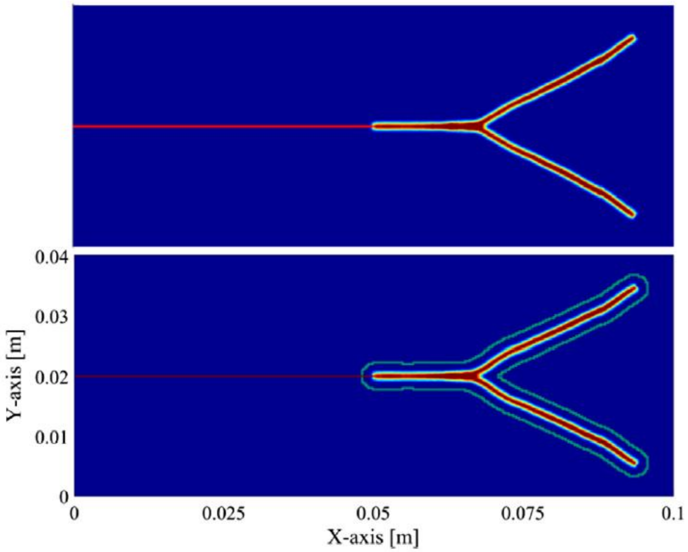
Implementation of **efficient numerical tools**



1D coupled models of a bar



2D coupled model of a three-point bending test



Damage maps of crack branching: fully PD and coupled FEM-PD models

3.3.2 FEM/PD coupling

Main advantages

1. **Simple coupling method** that can be **easily introduced** in **commercial FE codes**
2. **PD grids** applied to **portions** of the model where **cracks** are **likely to develop**

   ↓

   Remaining parts modelled through the **FEM meshes**
3. **No** need to **interpolate displacements** or **forces** between PD and FEM portions
4. **All PD nodes** have a **fully internal family** → **solution** to the PD "**surface problem**"
5. **No arbitrary** choice or **blending functions** required

3.4 WAVE PROPAGATION SIGNAL ANALYSIS FOR PREDEFINED SCENARIOS

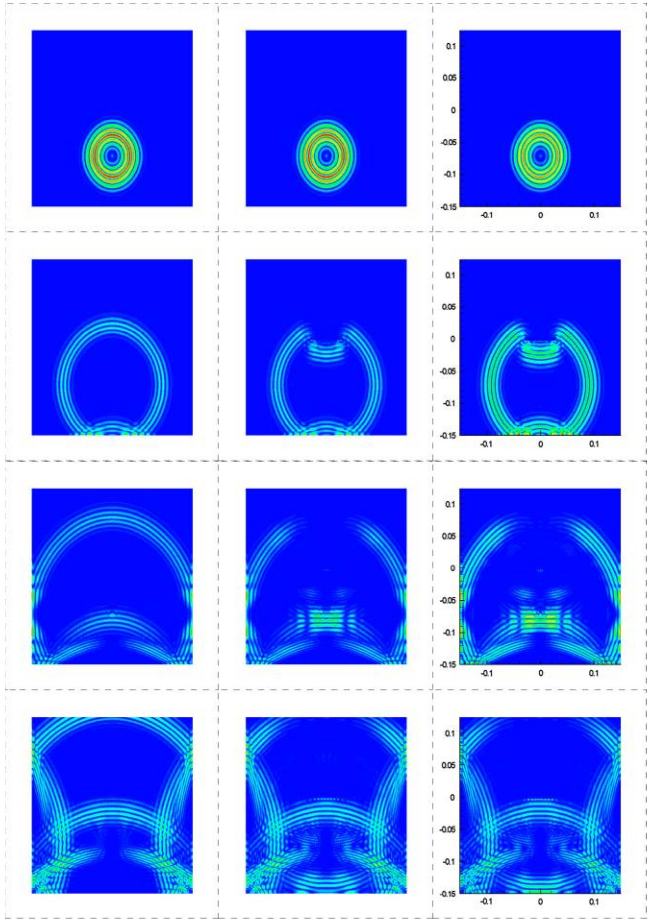
Implementation of **crack numerical models** for **various known scenarios**

Identification of **suitable** systems of **sensors** for **wave** propagation **analysis**

Determination of the **optimal** sensor **positioning** and **number** for **passive sensing**

Examination of the **influence** of the following **parameters** on **wave propagation**

- *Crack loading mode*
- *Loading dynamics*
- *Crack propagation increment length*
- *Numerical model parameters*
- *Crack modelling*



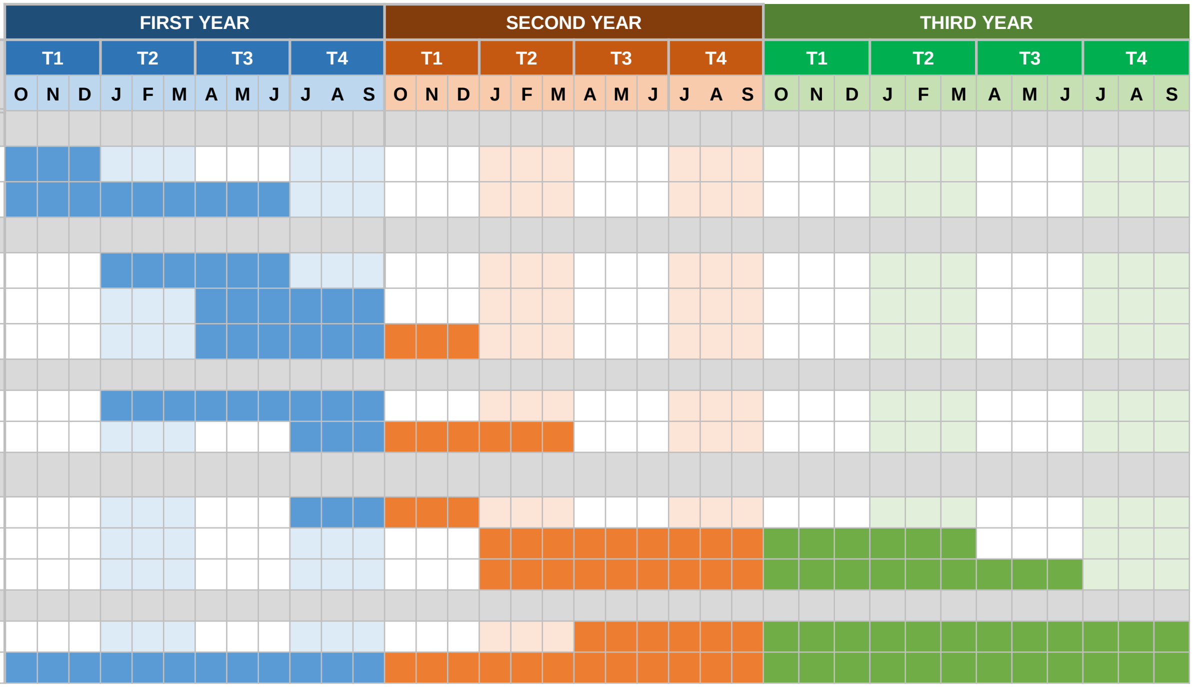
Wave motions in a square structure at different times in its pristine and damaged configurations

4. RESEARCH METHODOLOGY AND SCHEDULE

4.1 GANTT CHART

PHD STUDENT	GRETA ONGARO	DATE	26/10/2018
PHD THESIS	DAMAGE DETECTION IN AEROSPACE STRUCTURES	ADMISSION TO	FIRST YEAR

WBS NUMBER	TASK TITLE	% OF TASK COMPLETE
1	**Bibliographic research on Peridynamics State of Art**	
1.1	Bibliographic research on bond-based and state-based Peridynamics	20%
1.2	Bibliographic research on coupling FEM meshes and PD grids. Study of Multiphysics problems	10%
2	**Extension of bond-based FEM/PD coupling software developed at the UniPD for 3D static and dynamic analyses**	
2.1	Study of the mathematical formulation of bond-based Peridynamics	0%
2.2	Study of the mathematical formulation of state-based Peridynamics and FEM/PD coupling methods	0%
2.3	Study of the implemented models and software tools extension to 3D systems	0%
3	**Implementation of structural elements and of the adaptive refinement/coarsening in an integrated code**	
3.1	Implementation of the adaptive refinement/coarsening approach	0%
3.2	Implementation of different structural elements	0%
4	**Further development of the coupling method. Study of Multiphysics phenomena and implementation in FEM commercial codes**	
4.1	Further development of the coupling method	0%
4.2	Study of Multiphysics phenomena and implementation in FEM codes	0%
4.3	Comparison between obtained numerical results and results found in literature	0%
5	**Writing of PhD thesis and reports throughout the 3-year course**	
5.1	Writing PhD thesis	0%
5.2	Writing reports about research progress	0%



5. FINAL REMARKS

Main proposed research activities:

- **Extension** of bond-based **FEM/PD coupling software** for **3D static** and **dynamic** analyses
- **Implementation** of different **structural elements** and of the **adaptive refinement approach** in an integrated code for **multidimensional** analyses
- Study of tools for FEM analysis (**ABAQUS**, **Patran/Nastran**) and writing of subroutines to insert **Peridynamics code** into **commercial software**
- **Simulations** on **Multiphysics** problems and **comparison** between results available in literature and benchmark problems

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THANK YOU FOR YOUR ATTENTION

Greta Ongaro 1196644