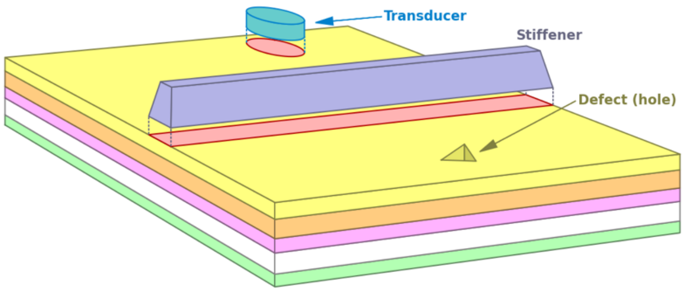
Development of hybrid numerical methods for the diffraction of ultrasonic waves by obstacles on the surface of laminated structures, and application to non-destructive testing.

Context - Various mechanisms can lead to the deterioration of materials or structures. For example, due to various stresses (mechanical, thermal, chemical), micro-cracking occurs over time and can have dramatic consequences. An impact, during the take-off and landing of an aircraft for example, is likewise likely to cause both an internal defect and microcracking. The various possible flaws are not necessarily visible to the eye, making testing techniques necessary for inspecting the core of the material. In this context, defect detection (NDT) and ultrasonic wave imaging are particularly important issues in many areas. The development and improvement of such methods, as well as the identification of defects using testing results, are based on the simulation of wave propagation in the inspected medium (or structure) and of the scattering of waves by defects. Thus, the availability of high-performance simulation tools are essential in this context, particularly for 3D analyses that require potentially prohibitive computational effort.



Objectives of the thesis - In this context, the aim of this thesis is to develop and implement the simulation of the scattering of incident ultrasonic waves by various types of obstacles, in three-dimensional conditions. These obstacles are located on the surface of a laminated solid structure with a canonical geometry, such as the plate depicted in the figure, and may represent either local structural reinforcements or defects in the form of indentations or protrusions. Moreover, we also aim at including refined models of the sensor(s) on the surface, both in transmission and in reception, in the computational model.

Methods - Numerical simulation of the interaction between elastic waves and defects under three-dimensional conditions can be very costly, in terms of computation time but also of model preparation due to the complexities entailed by the correct geometrical representation of small defects and other details. For this reason, we focus this work on the formulation and development of faster and simpler implementation tools where local features, including sensors, are to be represented using either a domain decomposition approach or asymptotic expansions with respect to their size. The fields in a structure with a canonical geometry, such as a laminated plate or tube will be expressed in terms of the Green's tensor associated with the healthy reference structure (implemented in semi-analytical form in the existing TraFiC code developed at I2M), which avoids any meshing of the complete structure. Two types of approaches are then envisaged for the modelling of diffraction by defects, obstacles or sensors:

1/ Defects of small characteristic size. These will be modelled asymptotically with respect to their size, their physical characteristics (nature, shape, etc.) being integrated via tensor-valued coefficients to be defined and determined. This leads to an approximate formulation of the defect response using the Green's tensor of the flaw-free structure, which requires no meshing. In particular, we will seek to improve the accuracy of this approach by formulating high-order expansions, and to assess it mathematically and numerically. We will mainly consider defects emerging at the structure surface.

2/ Sensors, reinforcements and protruding defects. These features, and their effect on the elastodynamic fields, will be represented by means of local 3D Finite Element models. In order to determine the fields in the structure and the external elements by independent computational methods (FE and TraFiC), an iterative domain decomposition algorithm will be designed and developed, driven by the satisfaction of the kinematic and dynamic continuity conditions at the EF / TraFiC interfaces (indicated in orange-pink on the figure). We will focus in particular on proving the convergence of the iterations and optimising their convergence speed.

Validation and transfer - 1/ Experimental measurements will be carried out at I2M on different types of diffracting objects, against which models will be compared. 2/ A digital demonstrator will be produced. The computational modules developed are to be eventually made available in the CIVA platform as plug-ins, in collaboration with a CEA LIST engineer.

Partners - CEA List (Saclay), POEMS laboratory (ENSTA Paris), I2M laboratory (University of Bordeaux).

Contacts - Eric Ducasse (I2M, eric.ducasse@u-bordeaux.fr) and Marc Bonnet (POEMS, marc.bonnet@ensta-paristech.fr)