Introduction
The ultrasonic inspection of composites is usually performed by moving a transducer along the inspected area and by steering the ultrasonic beam below and nearby the transducer, when this is a multi-element probe. On the other hand, ultrasonic guided waves, e.g. Lamb waves, could be used to perform, from a single remote location, a rapid inspection of large plate-like composite structures [1-3]. The objective of this work is to consider such approach with a removable multi-element probe, not permanently attached to the tested structure.

Experimental set-up and method
The proposed method is to perform long-range Lamb waves inspection with a new dedicated low-frequency multi-element ultrasonic probe. The 11x11 elements of the probe are driven by using the phased array principle for generating/detecting pure Lamb modes in/from various successive directions [4-6]. In order to detect remote defects, the received signals are processed (in the frequency domain for compensating the dispersive effects of the guided wave modes) to produce an accurate image of the inspected area [7]. However, in orthotropic materials, the inspected directions are limited to principal axis of symmetry because the algorithm is only valid for collinear phase and group velocities.

Two experimental set-ups are used to illustrate the efficiency of the method: i) composite plate (1.6-mm thick carbon epoxy, stratified plate, [0/90]3s) with a metallic insert (diameter of 20 mm) (Fig. 1); ii) a stiffened curved composite structure (4-mm thick) with an impact damage on the surface (Fig. 2).

Experimental results
For the composite plate, the image (Fig. 3) is obtained by using the S0 Lamb mode at 0.35 MHz and with the probe located at 210 mm from the simulated delamination. The plate edges and the insert are localized with a precision of 10 mm.

For the curved composite structure, the image (Fig. 4) is obtained by using the S0 Lamb mode at 0.5 MHz, with the probe located at 210 mm from the damage. The plate edges, the impact damage, the holes with diameter of 5 mm close to one edge and two stiffeners are detected and localized with a precision of 10 mm.

Conclusions
The proposed NDT process demonstrated high-quality and promising performance for the accurate detection and localization of delamination-like defect and impact damage in composite materials. The presented method is limited to principal axis of symmetry but, considering the usual arrangements of plies in composite materials, principal directions are often quite numerous, and this should not be limiting for many applications. Whatever, the method is currently under development for further applications to any direction in orthotropic materials.
References


Fig. 1 Photograph of the experimental set-up of the composite plate with a metallic insert.

Fig. 2. Photograph of the stiffened curved composite structure with an impact damage.

Fig. 3 The image of the composite plate is obtained by ultrasonic inspection with the probe.

Fig. 4. The image of the curved composite structure is obtained by ultrasonic inspection with the probe.