Shape reconstruction of additively manufactured waveguides with smooth thickness variation using laser-induced Lamb modes

Alexandre Yoshitaka Charau, Jérôme Laurent, Tony Valier-Brasier

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Les modes de Lamb: de la théorie à la pratique.
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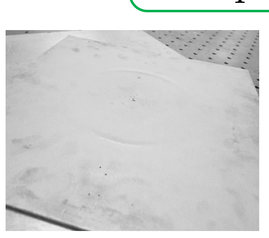
Alexandre Charau[1,2], Jérôme Laurent[1] and Tony Valier-Brasier[2]

Background

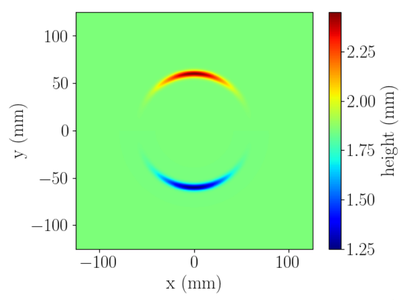
The increasingly widespread use of the metallic additive manufacturing process enables the design of components with intricate geometry, such as structures featuring waveguides, wich may exhibit "complex" dispersion due to their inhomogeneous characteristics. There is a high demand to characterize the geometric defects associate with phenomena occurring during the manufacturing of the sample, such as thickness variations. Through experimental investigations, we explore the propagation of ultrasonic waves in additively manufactured elastic plates, with a specific emphasis on accurately reconstructing its shape using two methods based on propagative Lamb modes induced by laser. Our results demonstrate strong agreement between the calculated profiles and the references.

Local phase method using A_0-mode

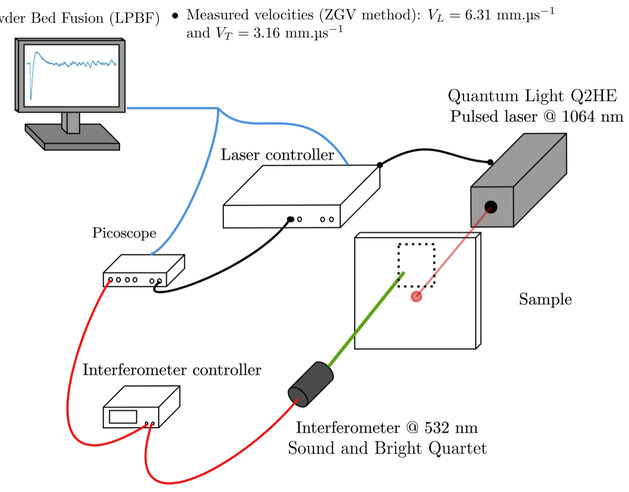
Sample and Laser-Ultrasound setup



- Plate: 250×250 mm²
- Process: Laser Powder Bed Fusion (LPBF)
- Material: Aluminium (AlSi10Mg)
- Measured velocities (ZGV method): $V_L = 6.31$ mm.µs^{-1} and $V_T = 3.16$ mm.µs^{-1}

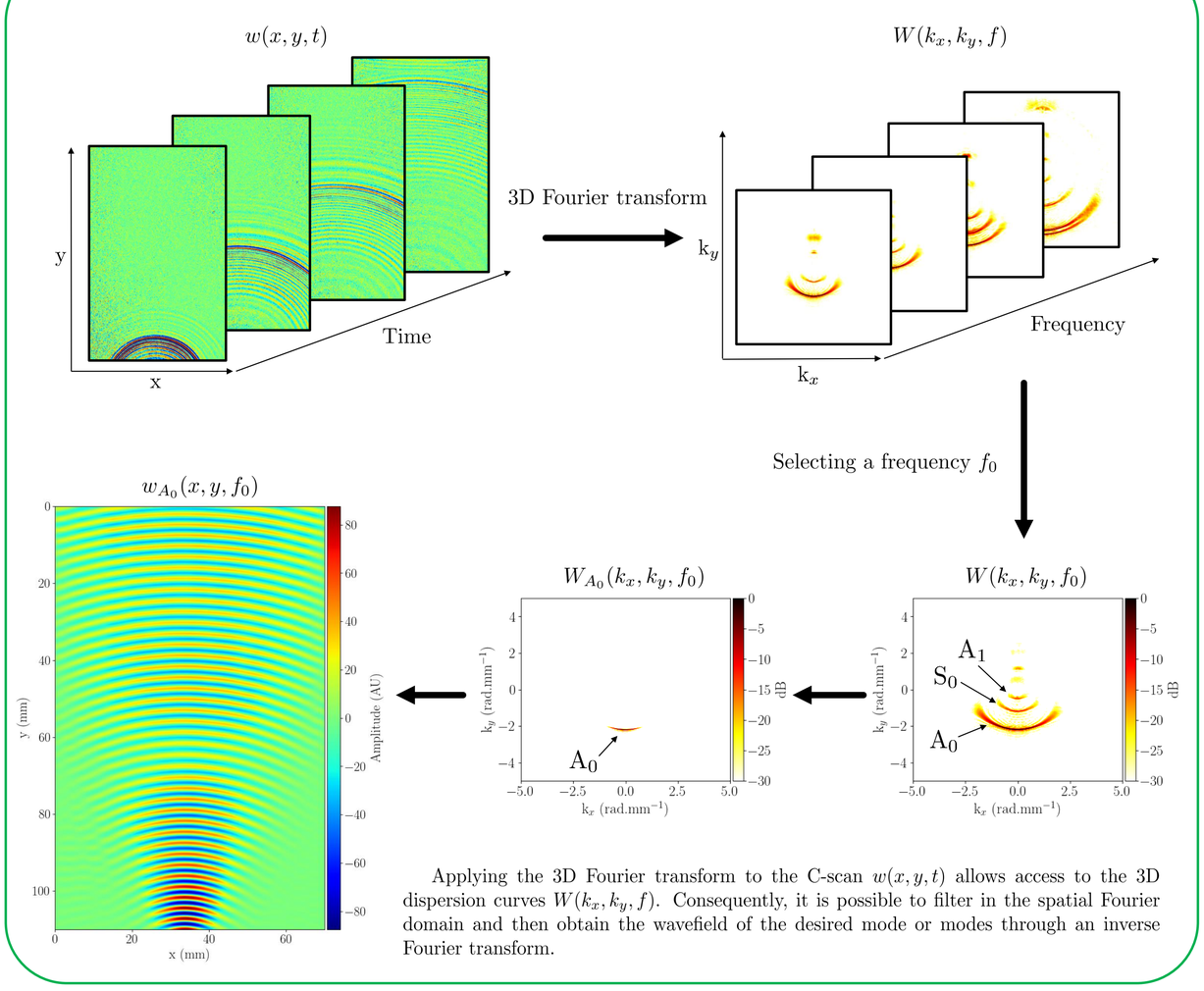


Picture of the sample and its elevation map (CAD file).



Experimental setup

Contribution of the incident A_0-mode



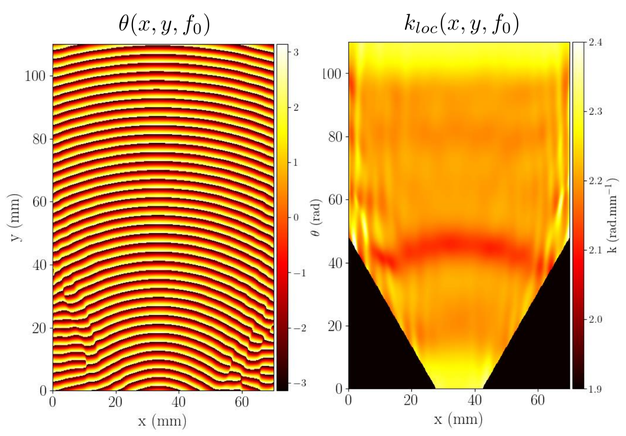
Applying the 3D Fourier transform to the C-scan $w(x,y,t)$ allows access to the 3D dispersion curves $W(k_x,k_y,f)$. Consequently, it is possible to filter in the spatial Fourier domain and then obtain the wavefield of the desired mode or modes through an inverse Fourier transform.

Local wavenumber map to thickness map

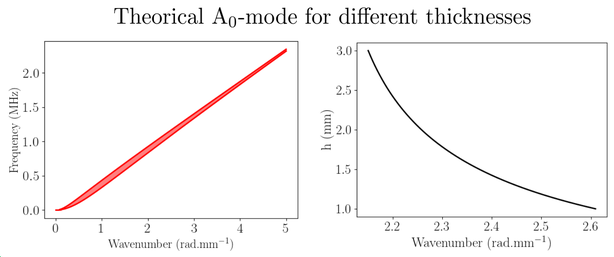
Due to the Fourier transform, w_{A_0} is a complex wavefield wich gives acces to the spatial phase θ for each point of the grid. Therefore by calculating the variation of this local phase, it is possible to estimate the local wavenumber k_{loc} [1-4].

$$\theta(x,y,f_0) = \arg(w_{A_0}(x,y,f_0)) \; ; \; w_{A_0} \in \mathbb{C}$$

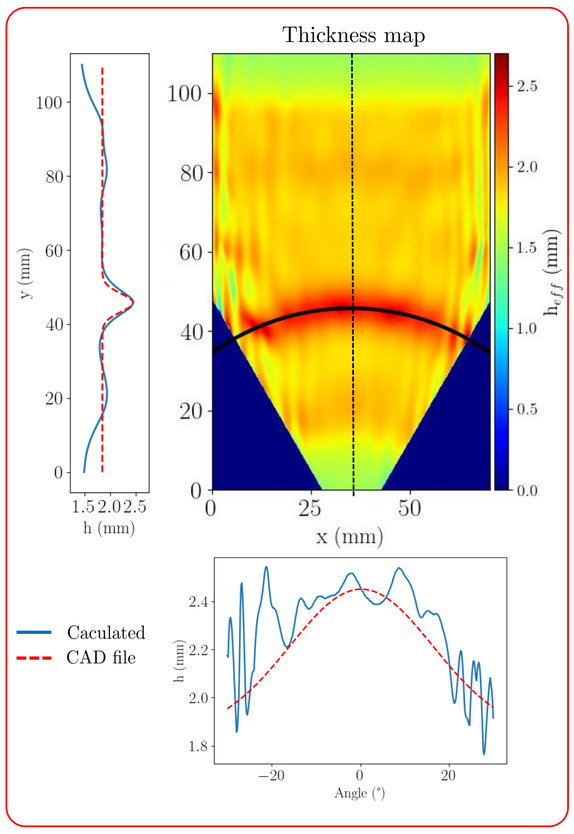
$$k_{loc}(x,y,f_0) = \sqrt{\left(\frac{\partial\theta(x,y,f_0)}{\partial x}\right)^2 + \left(\frac{\partial\theta(x,y,f_0)}{\partial y}\right)^2}$$



Theorical A_0-mode for different thicknesses



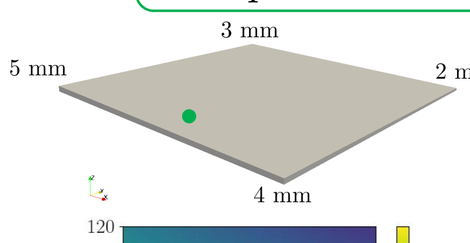
Knowing the dispersion curve of A_0-mode for different thicknesses, it's possible to convert the local wavenumber map to a thickness map.



[1] N.M.Nabighian, SEG, 1972. [2] N.Bournas et al, JAES, 2003.
[3] J. Luis Dean et al, Proc. of SPIE, 2008. [4] O. Mesnil et al, Proc. of SPIE, 2014.

A_1-cutoff frequency based method

Sample and LU setup with reciprocity principle



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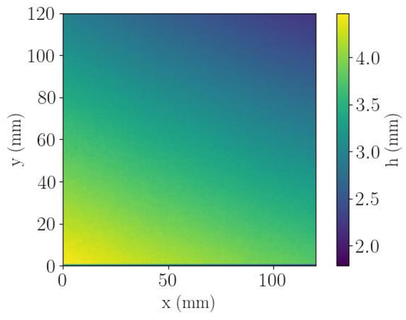
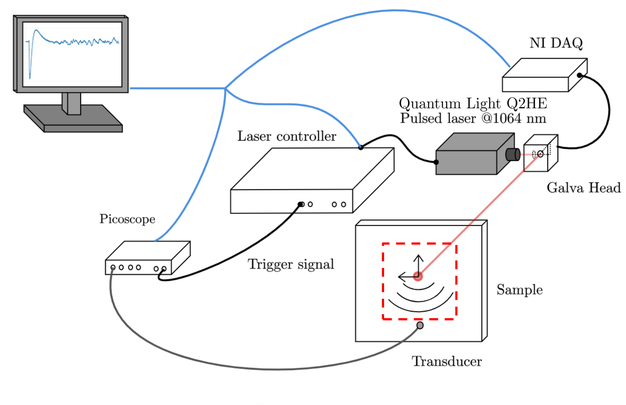
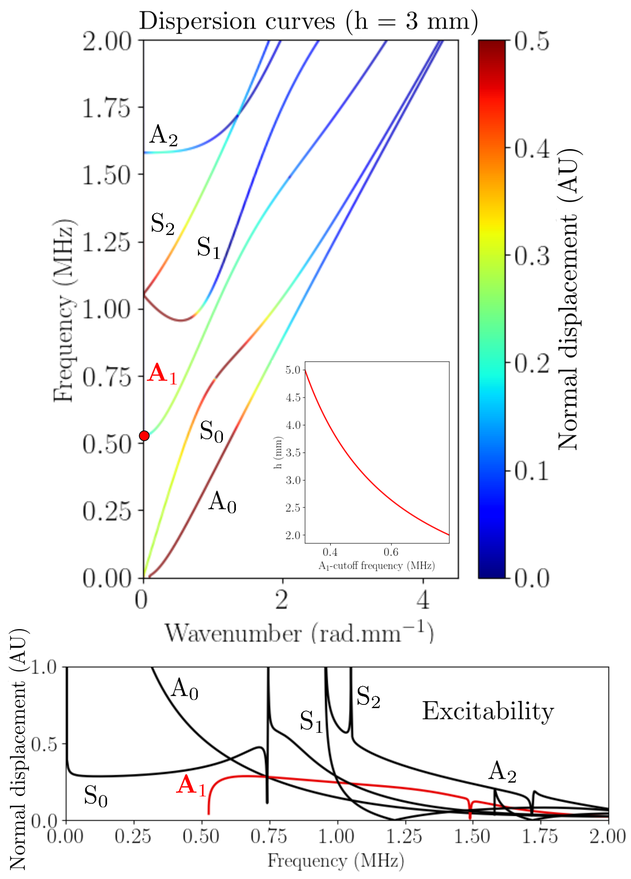


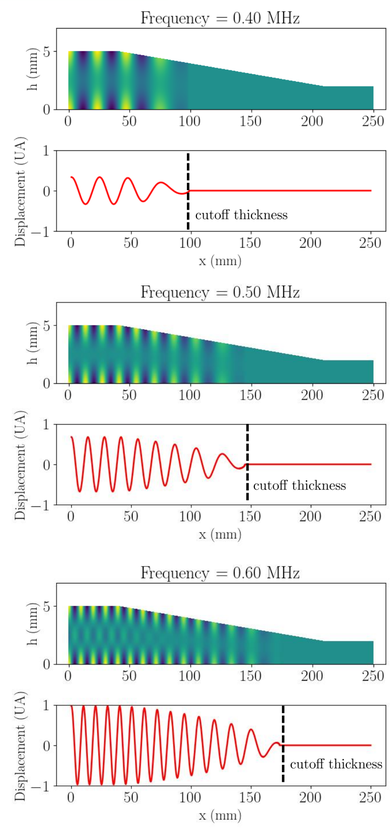
CAD profile and the elevation map of the ROI.



Experimental setup

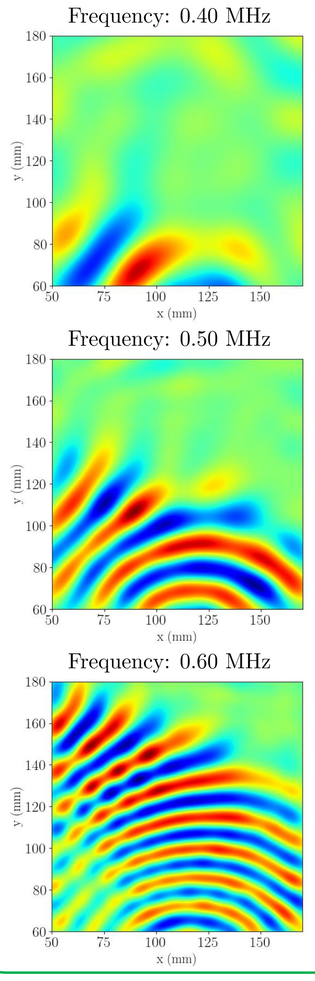
A_1-mode and the cutoff thicknesses





[5] V. V. Krylov, Acta Acustica united with Acustica, 2004.
[6] Z. Hamitouche et al, Acta Acustica united with Acustica, 2009.

A_1-mode displacement wavefield to thickness map



After filtering in the spatial Fourier domain, the A_1-mode wavefield can be extracted at different frequencies. Knowing A_1-cutoff frequencies for various thicknesses, a threshold can be applied to the wavefield. If the amplitude at a particular point is below this threshold, the thickness is below the cutoff thickness. By applying this technique for different frequencies it is possible to estimate the thickness of the elastic waveguide.

[7] A. Niclas et al, Inverse problem, 2022. [8] N. Suresh et al, J. Appl. Phys., 2022.

Conclusion and future works

- Reconstruction of waveguide shape using propagative A_0-mode and A_1-mode.
- Apply two different methods: Local phase method and A_1-cutoff frequency based method.
- Take into account the bias due to the plates' curvature.
- Parametrical study by varying the thicknesses of the waveguide numericaly, which leads to the study of the transmission/reflexion matrix.

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[2] Institut Jean Le Rond ∂'Alembert, Sorbonne Université.