# Advanced Multifield Models for Wave Propagation Analysis in Smart Composite Panels

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## Introduction

**Commercial plate models tend to underestimate the stresses to-the-thickness directions. Taking the Classical Laminate Theory (CLT) as an example:**

**CLT**

$$u_x = u_{x0} + \varphi_x z$$
$$v_y = v_{y0} + \varphi_y z$$
$$w_z = w_{z0}$$

$$\varepsilon_{zz} = \frac{\partial w_z}{\partial z} = 0$$ - zero to-the-thickness strain

$$\varepsilon_{xz} = \frac{\partial u_x}{\partial z} + \frac{\partial w_z}{\partial x} = \varphi_x$$ - constant shear strain

**Higher order plate models are required to predict the non-negligible to-the-thickness behaviour in laminated structures.**

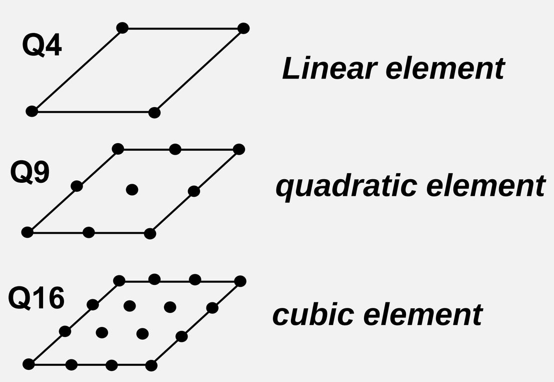
## Numerical Model

**FE Model based on the Carrera Unified Formulation (CUF), developed by the MUL2 Group**

$$U(u,v,w,\emptyset) = N_i(x,y).F_\tau(z)$$

$N_i(x,y)$

- 2D element mesh
- Can be refined in the commercial FEM tools by either refining the mesh or increasing the order of the used shape function

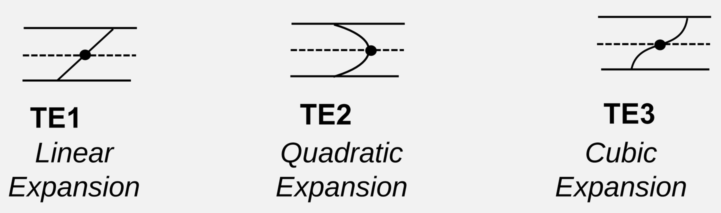



$F_\tau(z)$

- FE model kinematics
- Can be refined to a high order with:

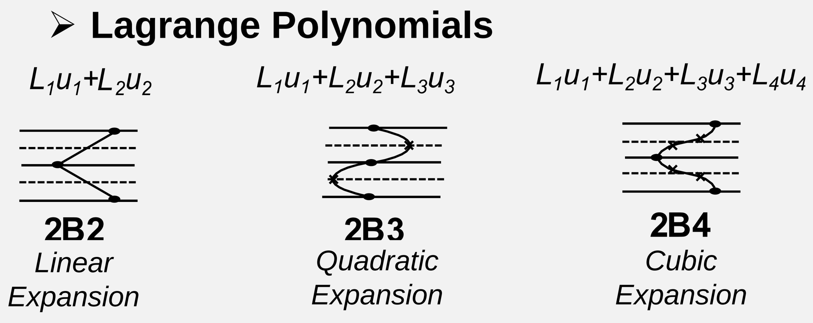
- <u>Equivalent Single Layer (ESL) expansion</u>

➢ Taylor Expansion Polynomials




- <u>Layer-Wise expansion</u>

➢ Lagrange Polynomials




## Objectives

**Modelling Lamb wave propagation in smart composite panels**

- ❖ **Orthotropic material $[0,90,90,0]_s$ with surface mounted piezoelectric transducers**
- ❖ **Coupled electro-mechanical finite element two-dimensional (2D) plate models**
- ❖ **Study the effect of using advanced higher order kinematics on the Time-Of-Flight (TOF)**
- ❖ **Reduce the computational cost by the implementation of Node Dependent kinematics**

## Benchmark Problem

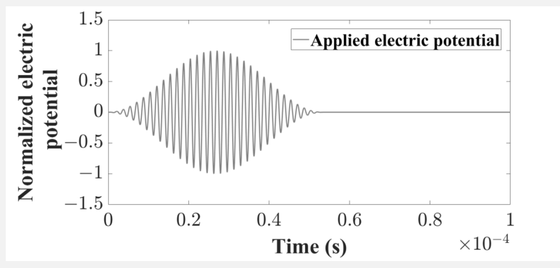



Figure 1: Actuation signal at 600 kHz

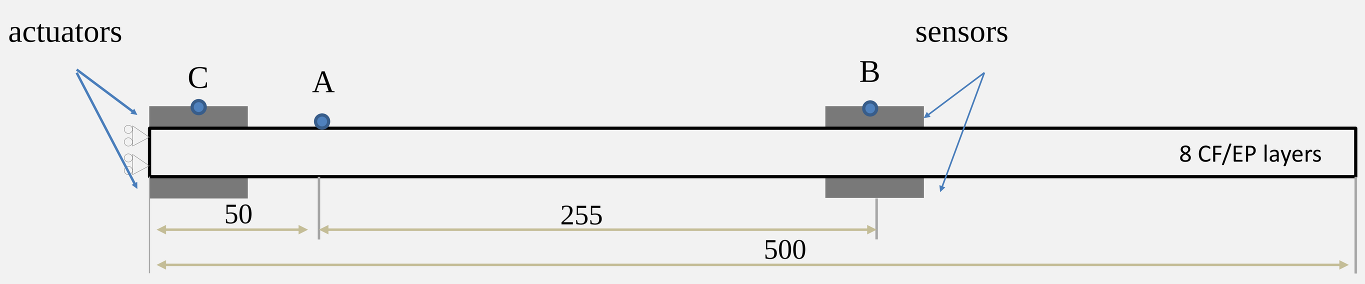



Figure 2: Benchmark problem with the actuators and sensors positioned, in mm

## Results

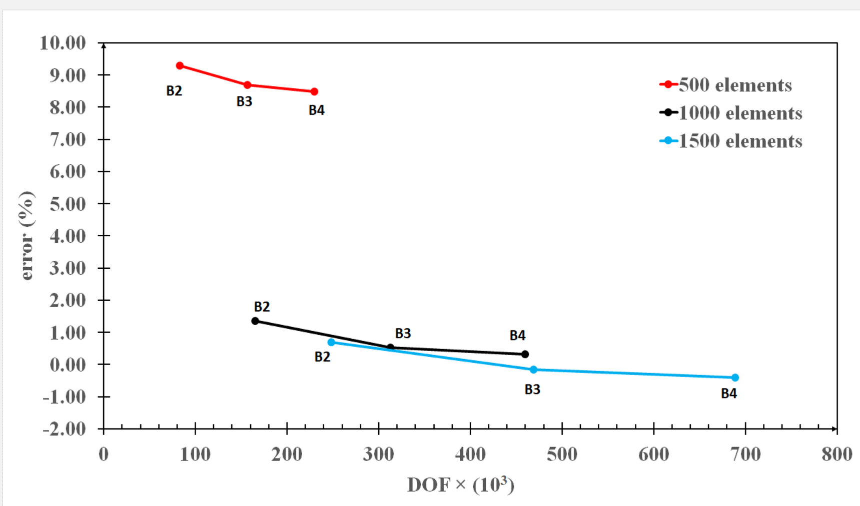



Figure 3: Antisymmetric wave propagation under refined elements and model kinematics

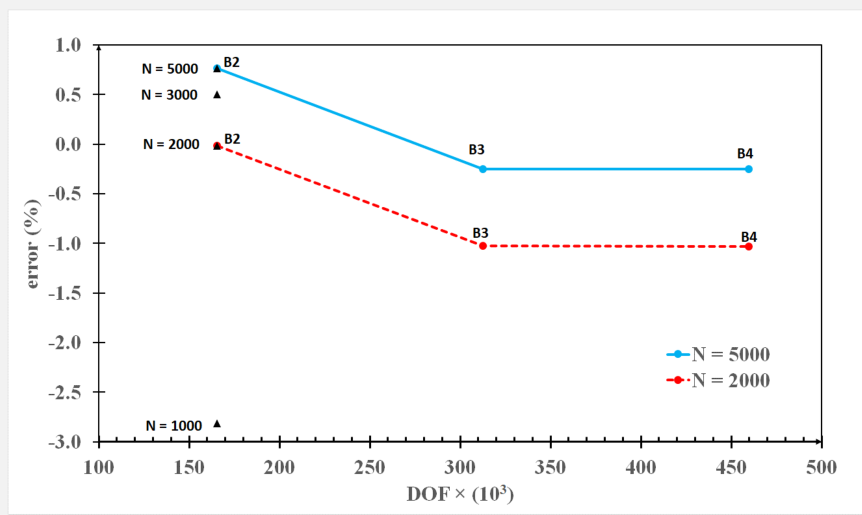



Figure 4: Symmetric wave propagation showing the number of timestep and model kinematics effect on the obtained error

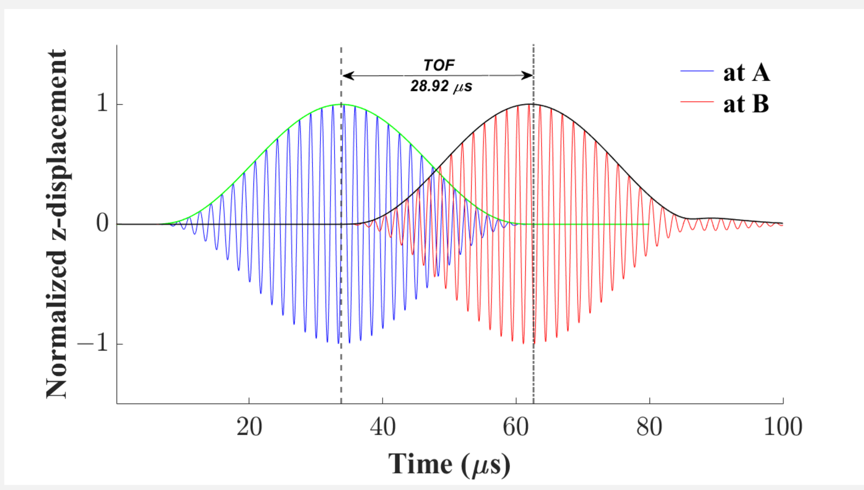



Figure 5: Wave propagation and TOF between points A and B

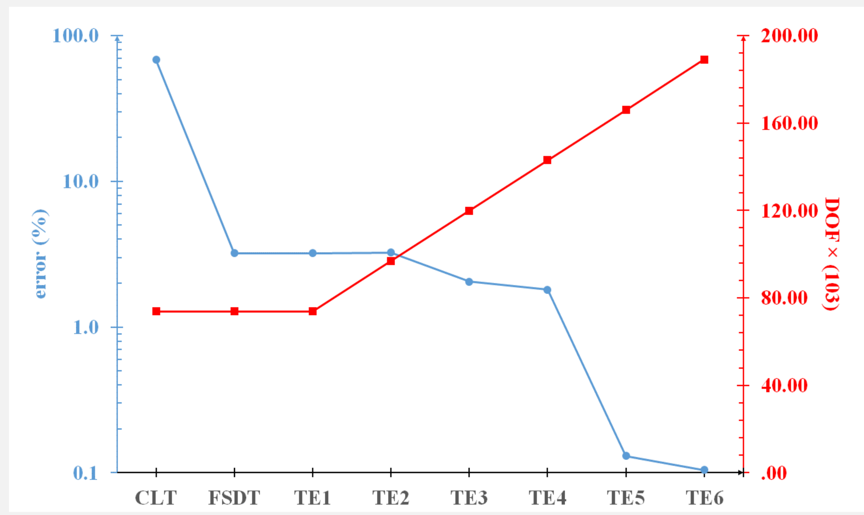



Figure 6: NDK results for a propagating $A_0$ Lamb wave

## Conclusions

- ➢ **Higher order model kinematics give satisfactory results**
- ➢ **It is essential to perform time step refinement**
- ➢ **Low order model kinematics produce positive error resulting in a stiffer structure**
- ➢ **Less timestep refinement produces a negative error**
- ➢ **The above errors may cancel out, but the problem is case dependent**
- ➢ **Using NDK for A0 reduces the computational cost by 60% with an error less than 0.15% compared to a fully refined model**

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## References

[1] T. Jollivet, C. Peyrac and F. Lefebvre, "Damage of composite materials"

[2] A. de Miguel, A. Pagani and E. Carrera, "Higher-order structural theories for transient analysis of multi-mode Lamb waves with applications to damage detection"

[3] C. Willberg, S. Duczek, J. Vivar Perez, D. Schmicker and U. Gabbert, "Comparison of different higher order finite element schemes for the simulation of lamb waves"

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