

# Vibrational Evaluation of Reeds (Arundo Donax L) via Hierarchical Microstructure Analysis

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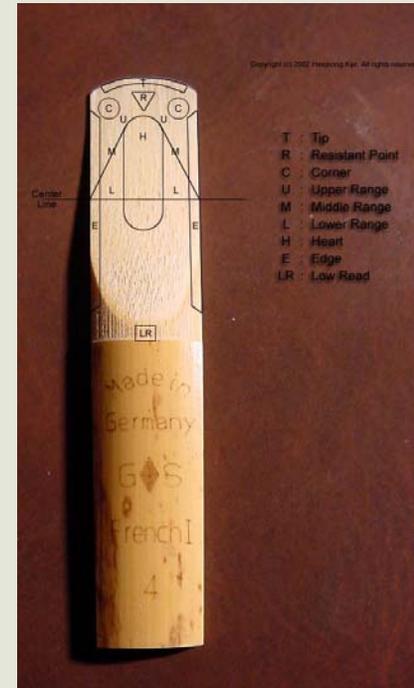
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# General Overview

- Woodwind Reeds
- Arundo Donax L (ADL)
- Geometric Model
- Modeling Approaches
  - Microstructural Hierarchy
- Parametric Investigations
  - Modal Analysis
  - Frequency Response
- Discussion
- Conclusions/Future Work

# Woodwind Reeds - Introduction and Motivation

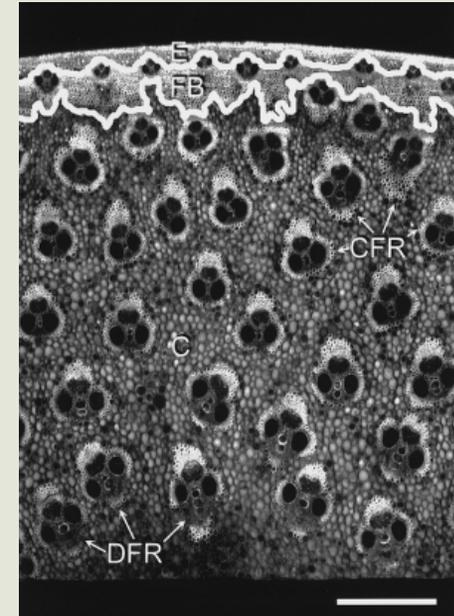
- Reeds are clamped on the mouthpiece and vibrate to produce sound
  - Variability in manufactured stiffness
    - Desirable qualities (per box)
- Geometric constancy
- Problems with current composites
- Materials approach to design



Source:  
<http://www.usefulweb.org/clarinet/reeds.html>

# Arundo Donax L.

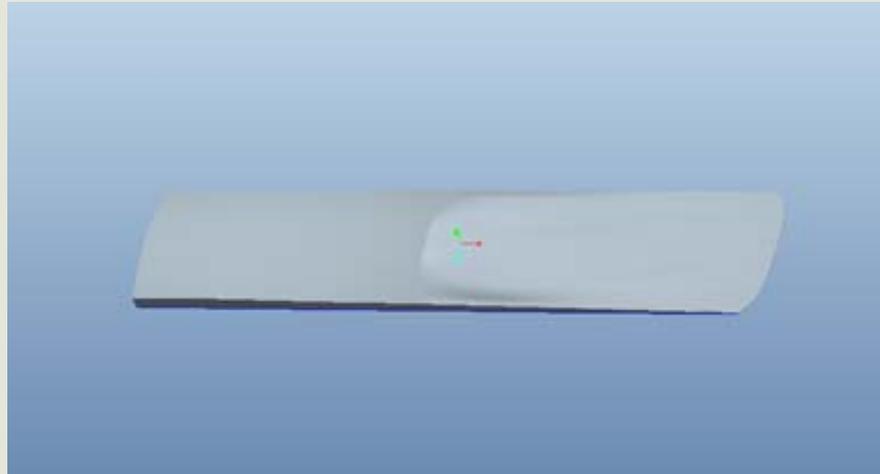
- Natural composite material
  - Hollow stem (similar to bamboo)
  - High level of porosity (20 – 50%)
- Modeled as orthotropic
  - Longitudinal, radial and tangential
- Microstructure with multiple inherent length scales
- Primary zone of interest for reeds
  - Inner cortex



Source: (Kolesik et al. 1998)

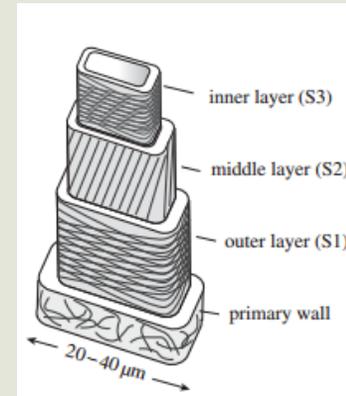
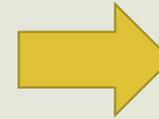
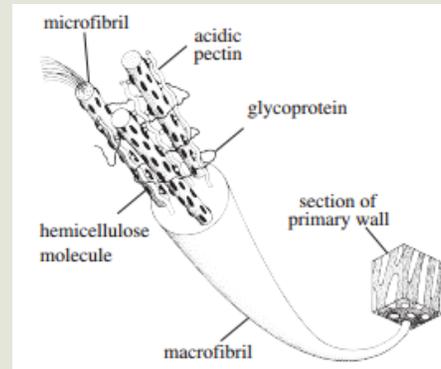
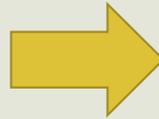
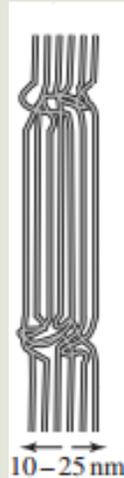
# Geometric Model

- 3D reed reconstructed using physical measurements from alto saxophone reeds
- Geometry from CAD used as base input for finite element
- Ensure macroscopic level is representative of real reeds



# Modeling Approaches

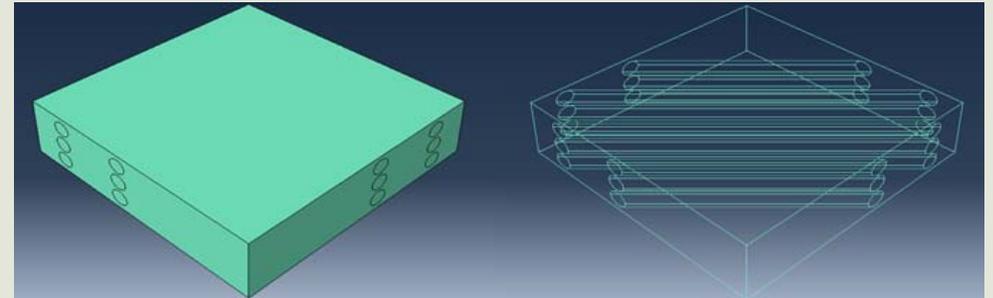
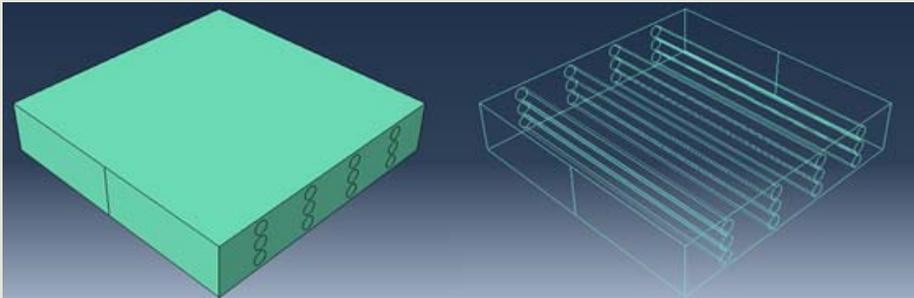
- Structural hierarchy of ADL
  - Macro-level mechanical properties from several micro-level contributions
- Literature on bamboo and ADL
- Volume fraction of constituents and porosity
- Morphology of vascular bundles



Source: Adapted from (Gibson 2012)

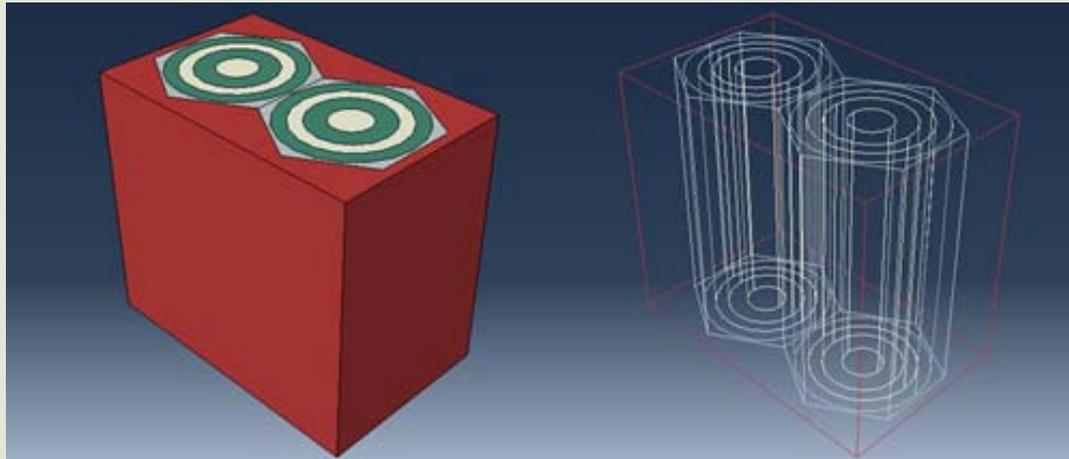
# Modeling Approaches - FE

- Cell wall scale
- Cellulose fiber and lignin matrix composite
- Mori-Tanaka for average matrix stresses and elastic strains
- Volume fractions: 2.1:1 ratio of Cellulose to Lignin (Ververis et al. 2004, Neto et al. 1997, Persson 2000)
- Simulate several loading conditions to obtain orthotropic stiffness matrix



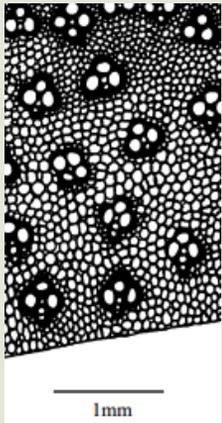
# Modeling Approaches - FE

- Vascular bundle culms
  - Provide stiffness support around porous vessels
- Periodic matrix of cell walls
- Use stiffness matrix from previous step and periodic boundaries

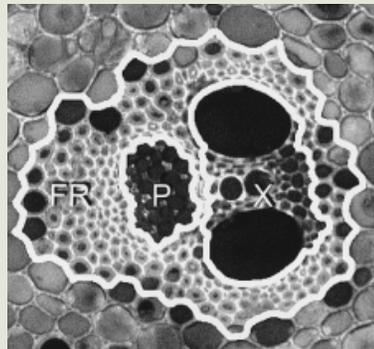


# Modeling Approaches - FE

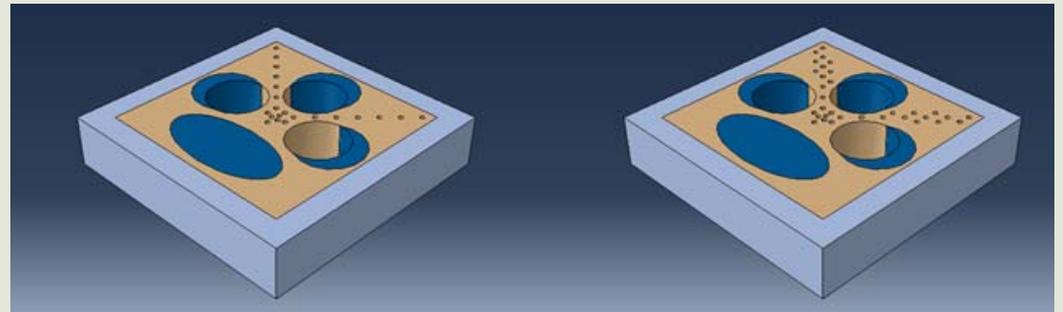
- Meso-level microstructure using the new orthotropic stiffness matrix
- Morphology taken from optical and SEM images of ADL cross-sections
- Constituent volume fractions and porosity:
  - 47% cellulose, 31% hemicellulose and 22% lignin (Gibson 2012)
  - 20 – 40% porosity (Dider et al. 2012, Kahlil et al. 2007)



Source: (Spatz et al. 1997)



Source: (Kolesik et al. 1998)



# Summary of Hierarchy

6.386557	1.687459	4.112341	0	0	0
1.687459	8.33951	4.256705	0	0	0
4.112341	4.256705	10.54161	0	0	0
0	0	0	0.27089	0	0
0	0	0	0	2.5726	0
0	0	0	0	0	2.5726

Cell Wall



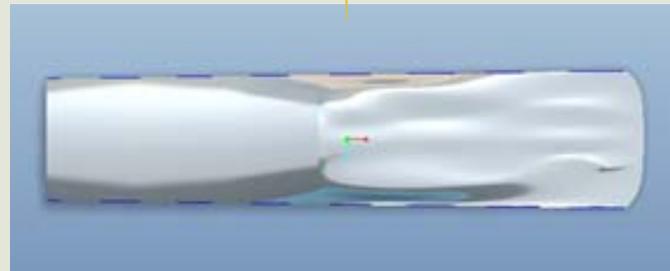
8.653924	0.274188	1.616661	0	0	0
0.274188	30.32296	0.638735	0	0	0
1.616661	0.638735	8.664899	0	0	0
0	0	0	2.8827	0	0
0	0	0	0	1.3947	0
0	0	0	0	0	1.3947

Fiber Culm



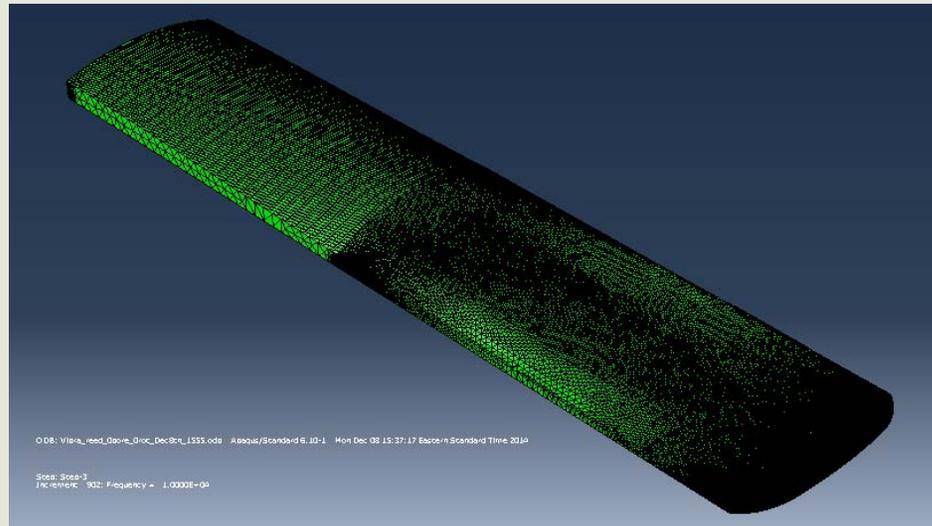
0.462911	0.661936	0.050856	0	0	0
0.661936	1.820198	0.086556	0	0	0
0.050856	0.086556	0.226306	0	0	0
0	0	0	0.2205	0	0
0	0	0	0	0.4444	0
0	0	0	0	0	0.4444

Meso-Matrix



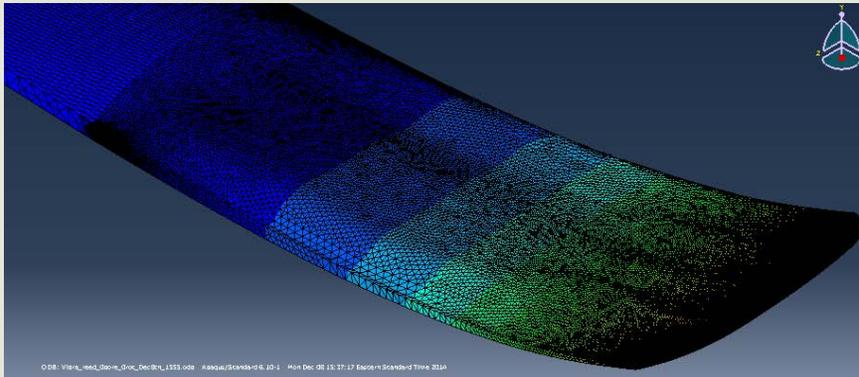
# Vibration Analysis

- Modal analysis of macro-scale reeds up to 10000Hz (Abaqus)
- Parametric variations in porosity and vascular bundle orientation

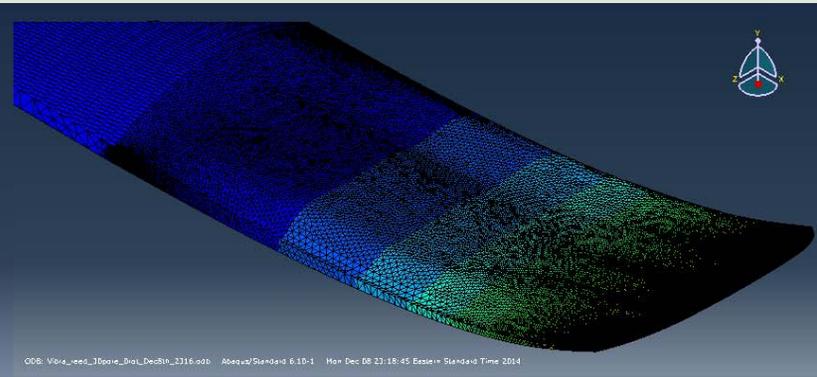


# Modal Analysis – Mode Shapes

- 20% Porosity Mode 1:  
 $f = 213 \text{ Hz}$



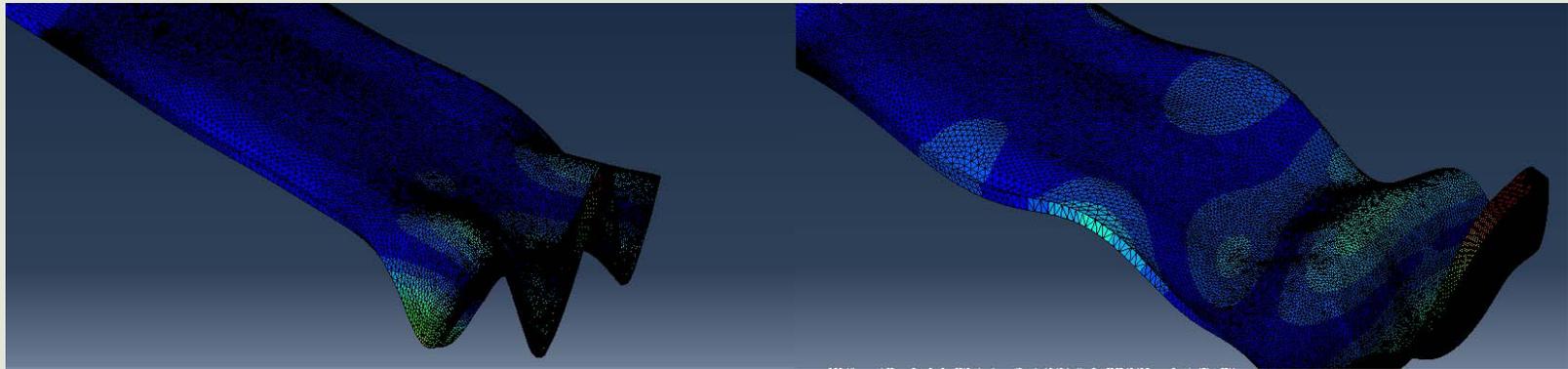
- 30% porosity Mode 1:  
 $f = 272 \text{ Hz}$



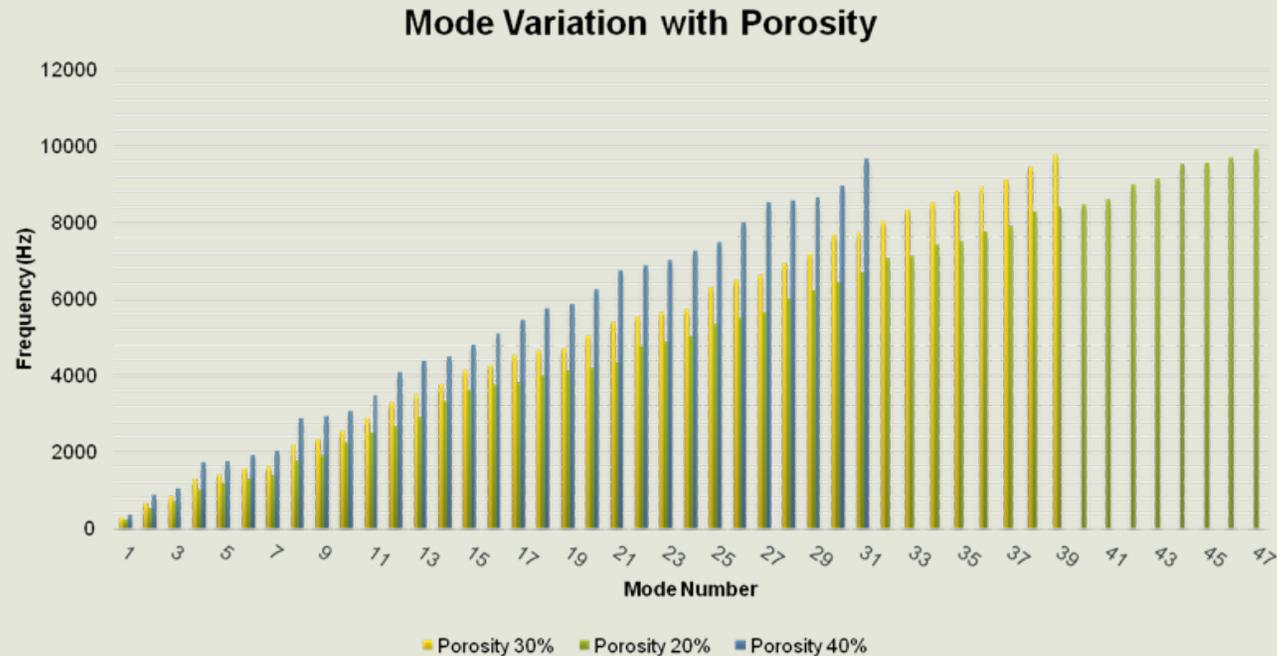
# Modal Analysis - Tip

- 20% Porosity Mode 27:  
 $f = 5660 \text{ Hz}$

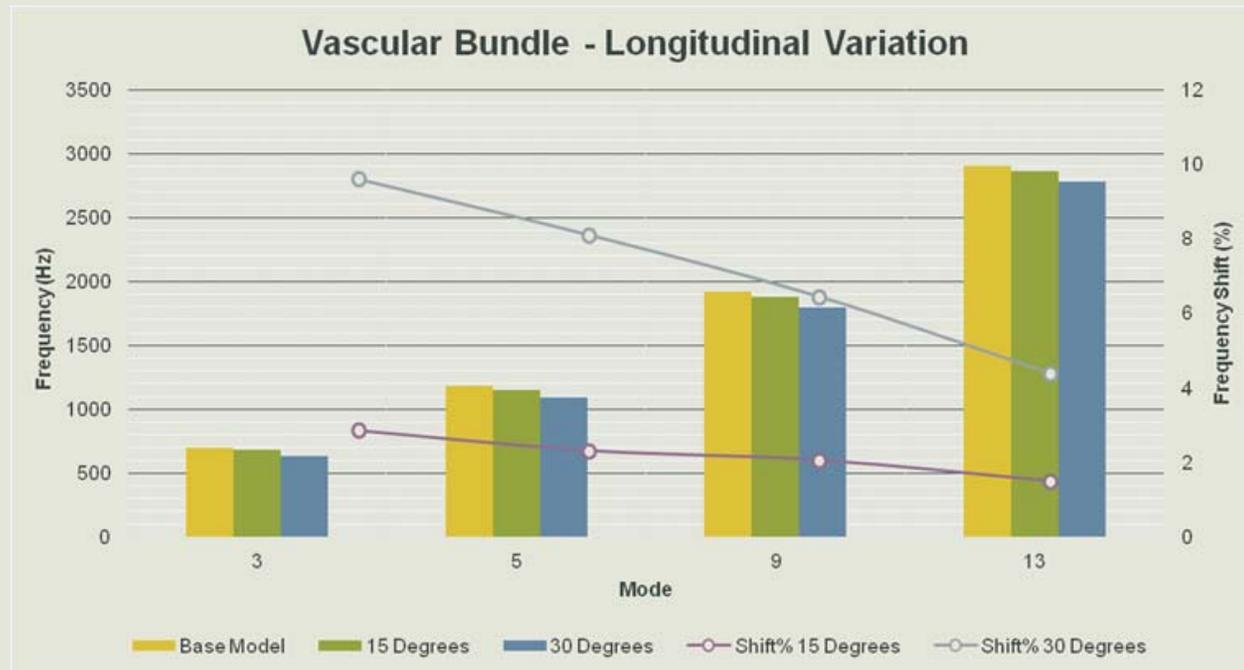
- 30% porosity Mode 27:  
 $f = 6630 \text{ Hz}$



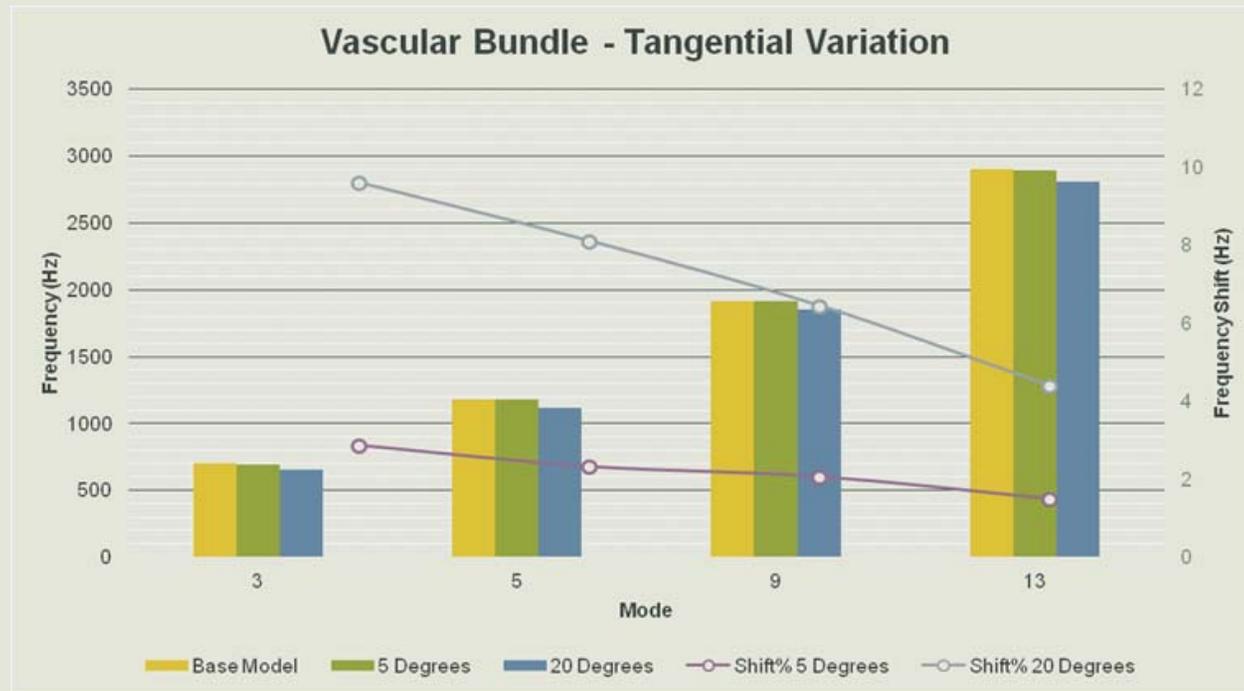
# Modal Analysis – Porosity Trends



# Modal Analysis – Vascular Bundle Trends

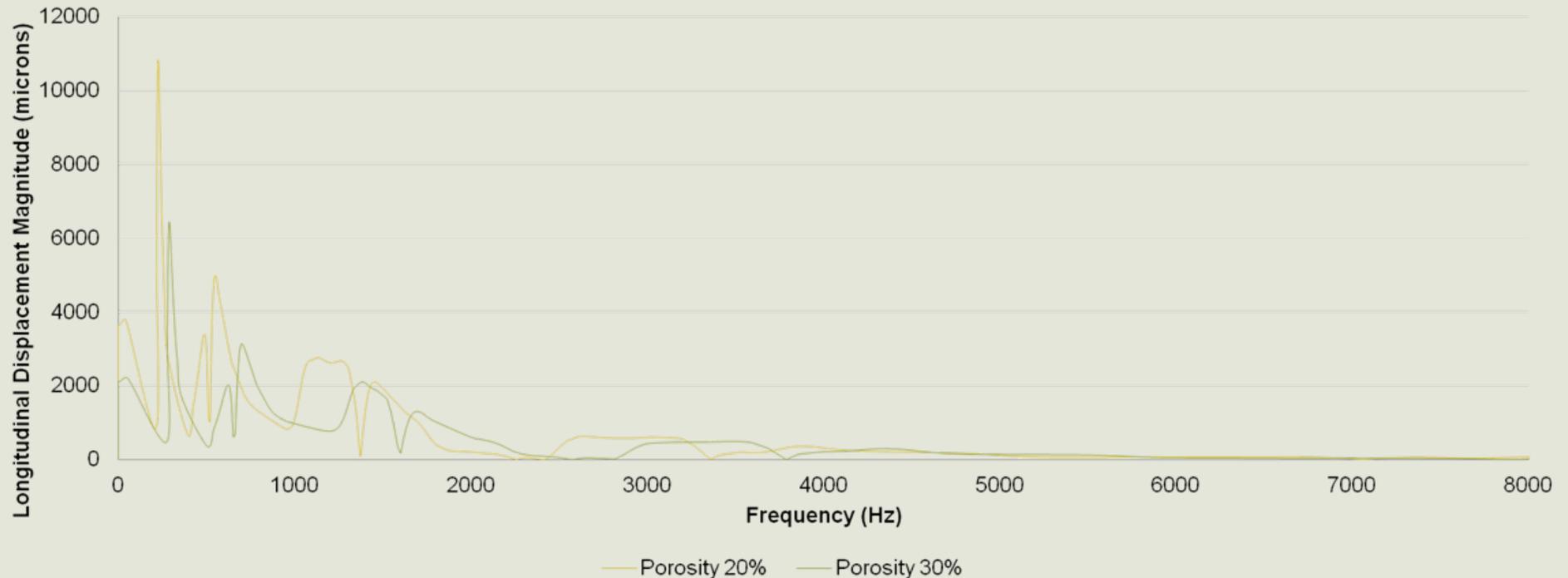


# Modal Analysis – Vascular Bundle Trends



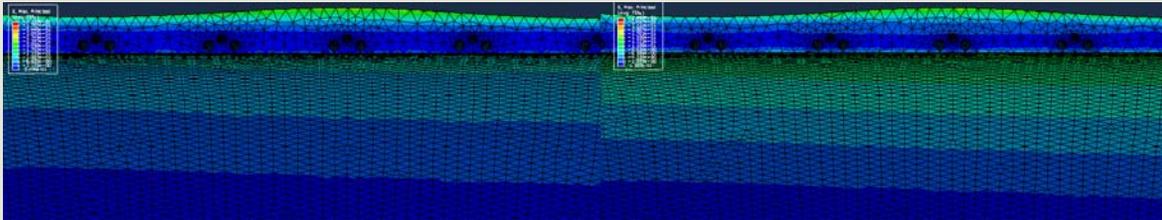
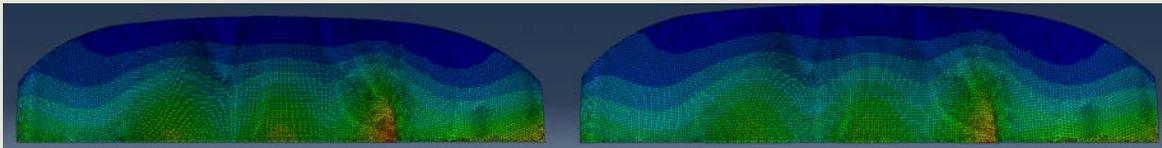
# Modal Analysis – Frequency Response

## Frequency Response



# Tip Analysis– Bending Simulation

- Tip deflection simulations were completed using an applied pressure similar to that provided by a musician
- Boundary conditions were imposed such that the results reflect a full-size reed

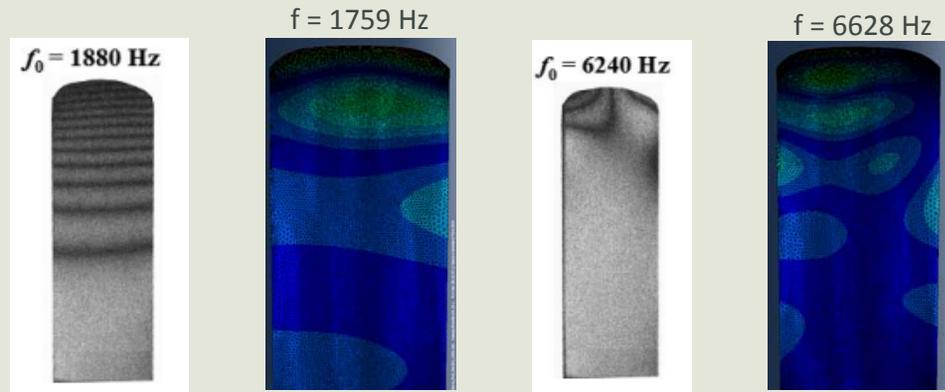


## Elastic Strain



# Discussion

- Material values obtained from hierarchical modeling compare favourably with those observed in bamboo (a similar material to ADL)
  - Longitudinal modulus of culm fibers of 30.2 GPa from FE and 36 GPa from literature (Li and Shen 2011)
- Modal results compared with measurements taken from real reeds (Picart et al. 2010)



- Vibration is most sensitive to vascular bundle variations in the longitudinal direction, as expected
- Increases in porosity appear to decrease the complexity of reed resonances, potentially due to increased internal damping
- The influence of transverse vibrations along the tip are suspected to be highly influenced by the anisotropy ratio between longitudinal and tangential modulus (as seen from variations in porosity)

# Future Work

- Load sharing between the cellulose fibers and lignin matrix are expected to have a large influence on vibrational behaviour
  - Investigation of the interface between these two phases is currently being completed
- Comparison of obtained homogenized results with other models (self-consistent) and experimental results of micro- and nano-hardness testing
- Experimental investigation of the parenchyma matrix (surrounding the vascular bundles)
- Experimental reed resonant frequency comparison with FE results
- The type of porosity present will contribute to damping via pore fluid viscosity
  - Micro CT of raw ADL samples will reveal the interconnectivity level of pores

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# References

- P. Kolesik, A. Mills, and M. Sedgley, “Anatomical Characteristics Affecting the Musical Performance of Clarinet Reeds Made from *Arundo donax* L. (Gramineae),” *Ann Bot*, vol. 81, no. 1, pp. 151–155, Jan. 1998.
- H.-C. Spatz, H. Beismann, F. Brüchert, A. Emanns, and T. Speck, “Biomechanics of the giant reed *Arundo donax*,” *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 352, no. 1349, pp. 1–10, Jan. 1997.
- H. P. S. A. Khalil, M. S. Alwani, and A. K. M. Omar, “Chemical composition, anatomy, lignin distribution and cell wall structure of Malaysian plant waste fibers,” *BioResources*, vol. 1, no. 2, pp. 220–232, Aug. 2007.
- C. Ververis, K. Georghiou, N. Christodoulakis, P. Santas, and R. Santas, “Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production,” *Industrial Crops and Products*, vol. 19, no. 3, pp. 245–254, May 2004.
- K. Persson, “Micromechanical Modelling of Wood and Fibre Properties,” Ph.D. Thesis, Lund University, Sweden, 2000.
- F. Dider, F. Ngagoue, M. Mpressa, and T. Tamo Tatietsé, “Physical characterization of two Cameroon bamboo species: *Arundinaria alpina* and *Oxytenanthera abyssinica*,” *IJET*, vol. Vol 4, no. 2, pp. 82–92, May 2012.
- P. Picart, J. Leval, F. Piquet, J. P. Boileau, T. Guimezanes, and J. P. Dalmont, “Study of the Mechanical Behaviour of a Clarinet Reed Under Forced and Auto-oscillations With Digital Fresnel Holography,” *Strain*, vol. 46, no. 1, pp. 89–100, Feb. 2010.
- L. J. Gibson, “The hierarchical structure and mechanics of plant materials,” *Journal of The Royal Society Interface*, p. rsif20120341, Aug. 2012.
- H. Li and S. Shen, “The mechanical properties of bamboo and vascular bundles,” *Journal of Materials Research*, vol. 26, no. 21, pp. 2749–2756, Nov. 2011.
- C. P. Neto, A. Seca, A. M. Nunes, M. A. Coimbra, F. Domingues, D. Evtuguin, A. Silvestre, and J. A. S. Cavaleiro, “Variations in chemical composition and structure of macromolecular components in different morphological regions and maturity stages of *Arundo donax*,” *Industrial Crops and Products*, vol. 6, no. 1, pp. 51–58, Feb. 1997.