Shape Adaptation of 1D, 2D, and 3D Structures to increase Eigenfrequencies

Simone Andresen, Selina K. Linemann, Laura M. Lottes,
Oleksandr Savysko & Reinhold Kienzler

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ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

DESY.

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Structure

1. Biomimetics at Alfred Wegener Institute:
   Lightweight Design & Vibration Optimization
2. Shape Adaptation to increase Eigenfrequencies
   - 1D Beam
   - 2D Plate
   - 3D Beam
   - Further 3D Structures
3. Conclusion

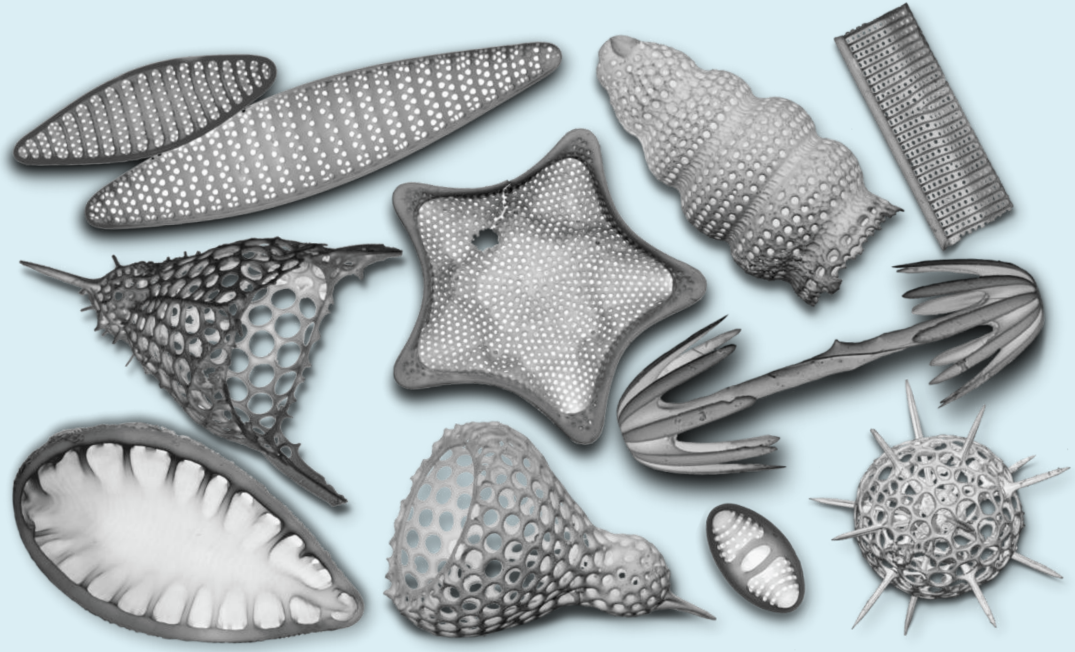
Chapter 1

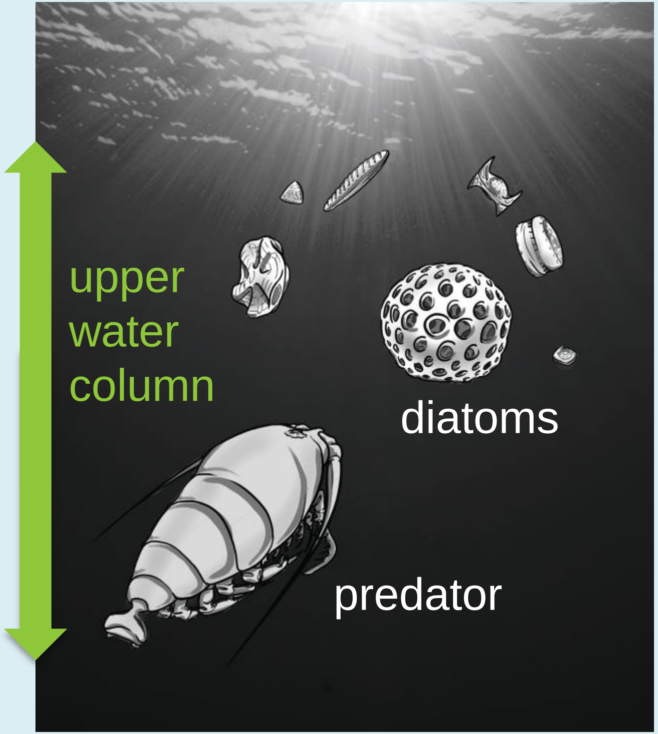
Biomimetics at Alfred Wegener Institute: Lightweight Design & Vibration Optimization

Alfred Wegener Institute

- Leading position in polar and marine research
- ~1,000 employees
- Intensifies its activities in the field of technology transfer & biomimetics

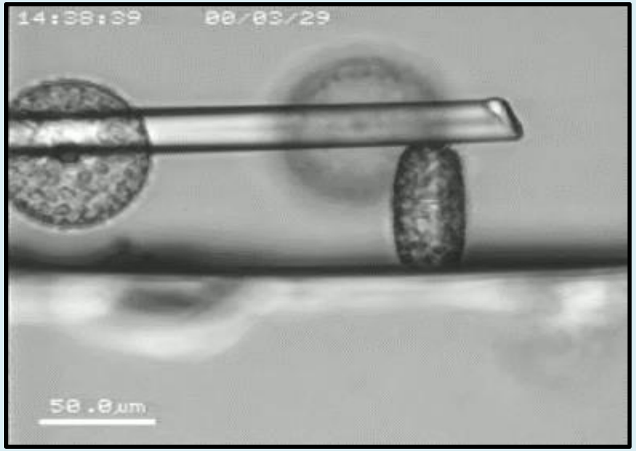
Structures of Plankton Organisms





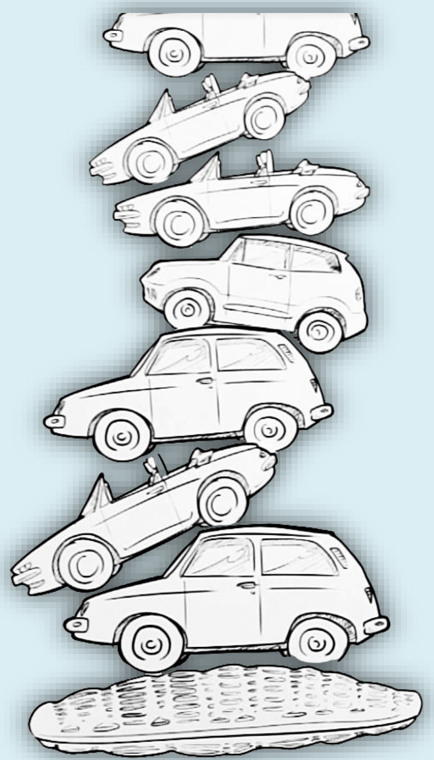
Highly efficient Lightweight Design Principles in Plankton Organisms

Diatom shells
can stand pressures
of up to **700 t m^{-2}**



(Hamm *et al.* 2003, *Nature* 421, 841-843)

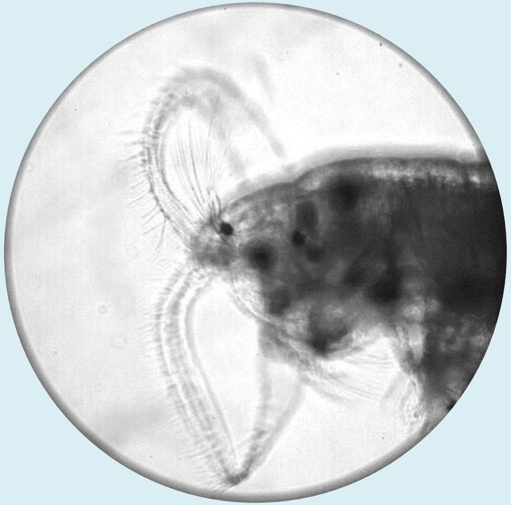
This corresponds
to 150 cars
on a manhole cover



Vibration Characteristics of Plankton Shells

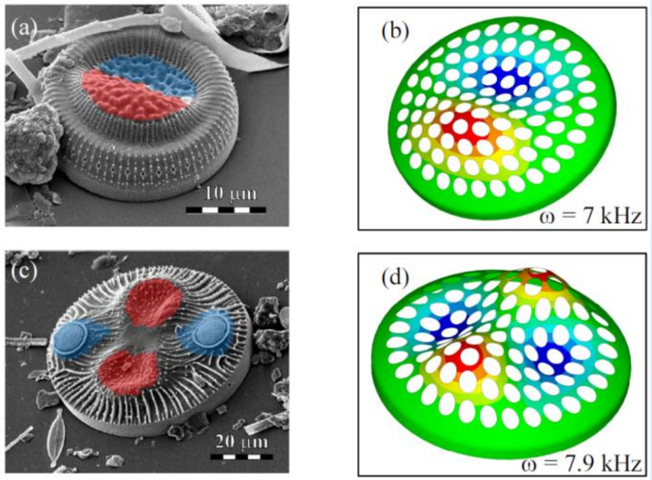
in vivo observations

Vibrating attacks of the copepods:
Diatom shells have to protect
the inner cell



Simulations of diatom shells

Deformation patterns correspond
to mode shapes

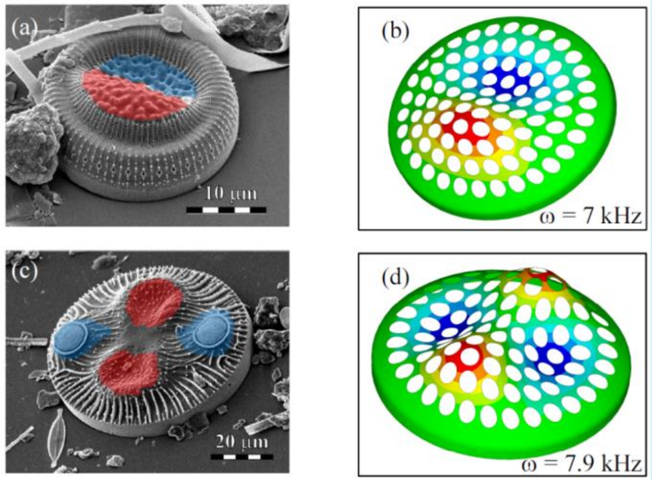


(Gutiérrez et al. 2017, *Journal of Materials Science and Engineering with Advanced Technology* 15)

Vibration Characteristics of Plankton Shells

Simulations of diatom shells

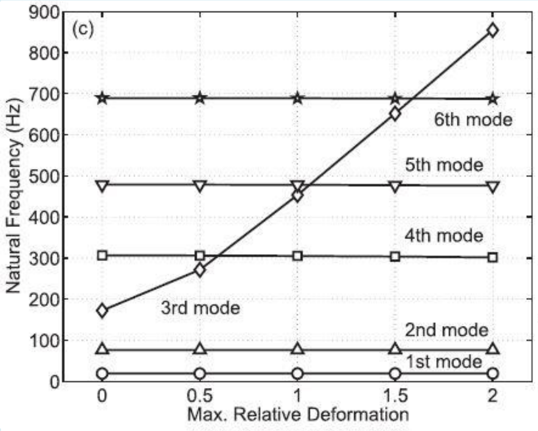
Deformation patterns correspond to mode shapes

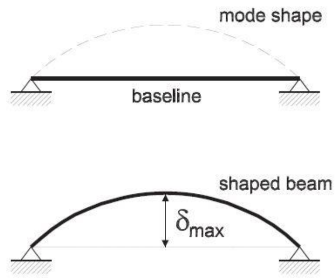


(Gutiérrez et al. 2017, *Journal of Materials Science and Engineering with Advanced Technology* 15)

Simulations of a slender 1D Beam

Beam deformation according to a mode shape to increase the corresponding eigenfrequency





(Da Silva & Nicoletti 2017, *Journal of Sound and Vibration* 397)

Objectives of this study

Further investigation on the topic studied by Da Silva & Nicoletti (2017)

- Increasing the maximum pre-deformation of the 1D beam
- Pre-deformations of the 1D beam according to mode 1-5
- Applying this method to increase eigenfrequencies to a 2D plate and a 3D beam

Chapter 2

Shape Adaptation to increase Eigenfrequencies

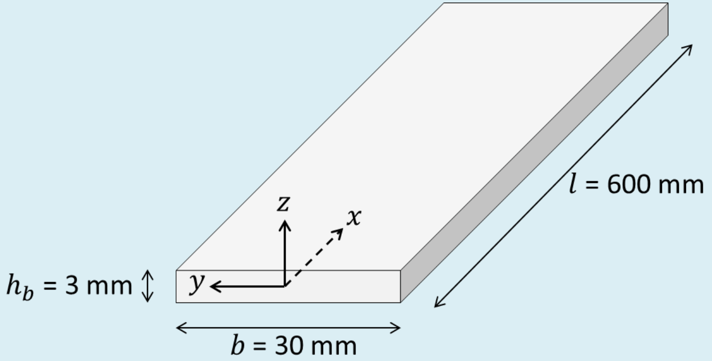
- 1D Beam
- 2D Plate
- 3D Beam
- Further 3D Structures

Shape Adaptation: 1D Beam

Mode shapes that were applied to the beam

Model assembly

- Simply supported (axially constrained)
- Constant mass (beam width adapted)

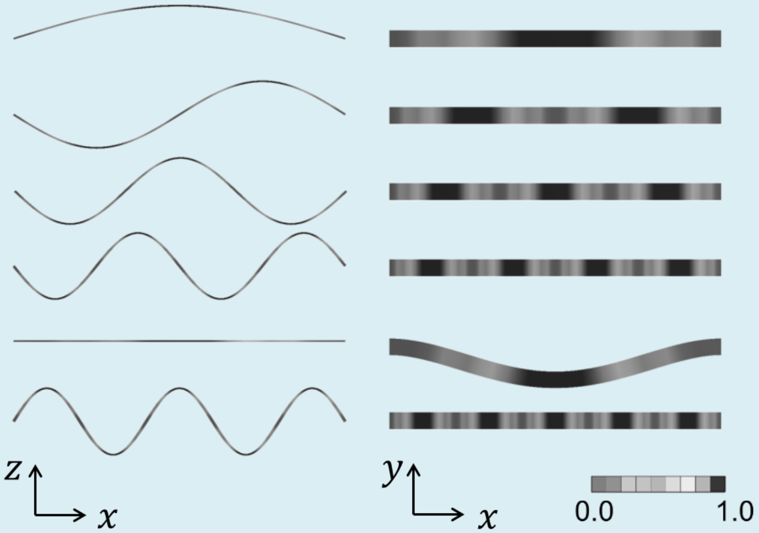


$$f_i \propto \frac{EI}{\rho A}$$

E: Young‘s modulus | I: Second moment of inertia
ρ: material density | A: cross section area

Beam mode shapes

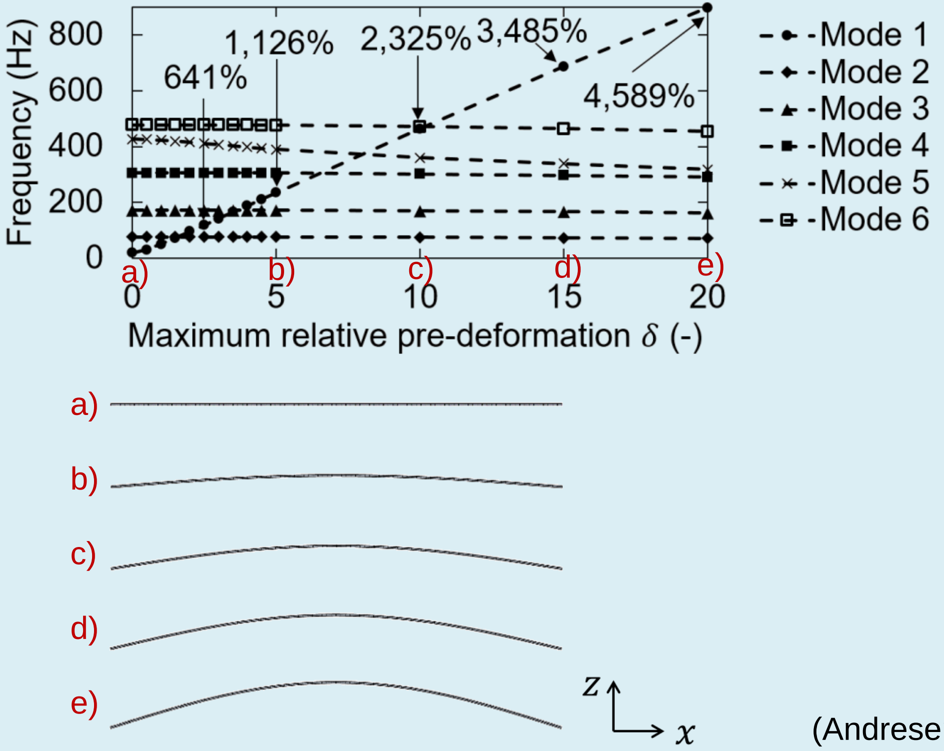
Mode 1
Mode 2
Mode 3
Mode 4
Mode 5
Mode 6



(Andresen et al 2020, *Advances in Mechanical Engineering* 12)

Shape Adaptation: 1D Beam - Results

Mode 1



Maximum relative pre-deformation:

$$\delta = \frac{\delta_{max}}{h_b}$$

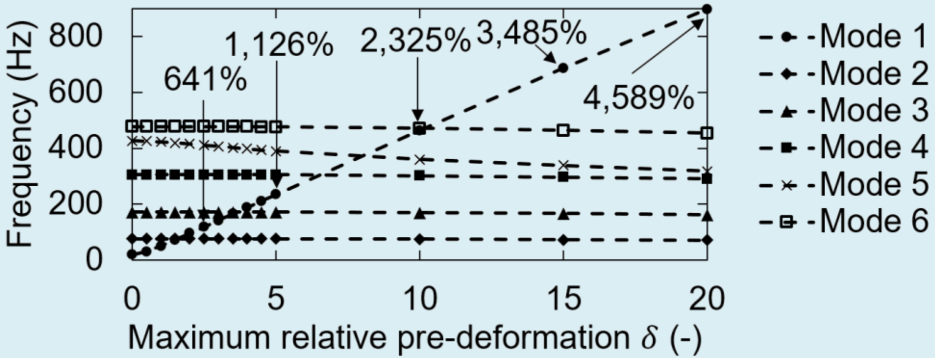
Maximum pre-deformation

Beam height

(Andresen et al 2020, *Advances in Mechanical Engineering* 12)

Shape Adaptation: 1D Beam - Results

Mode 1



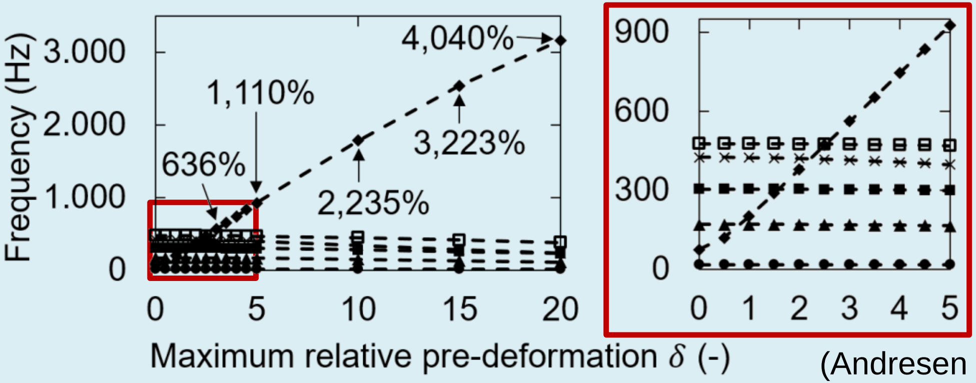
Maximum relative pre-deformation:

$$\delta = \frac{\delta_{max}}{h_b}$$

Maximum pre-deformation

Beam height

Mode 2



Shaping a beam according to the i-th (i = 1-5) mode shape strongly increases the corresponding frequency

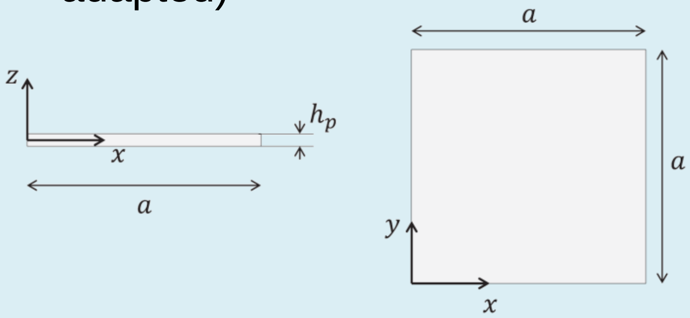
(Andresen et al 2020, *Advances in Mechanical Engineering* 12)

Shape Adaptation: 2D Plate

Mode shapes that were applied to the plate

Model assembly

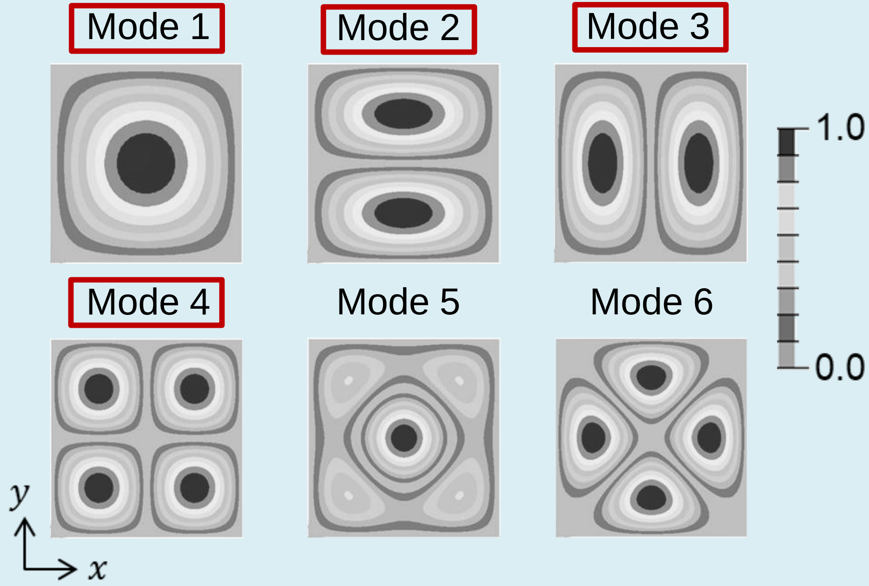
- Simply supported (axially constrained)
- Constant mass (plate thickness adapted)



$$f_i \propto \sqrt{\frac{K}{\rho h_p}}$$

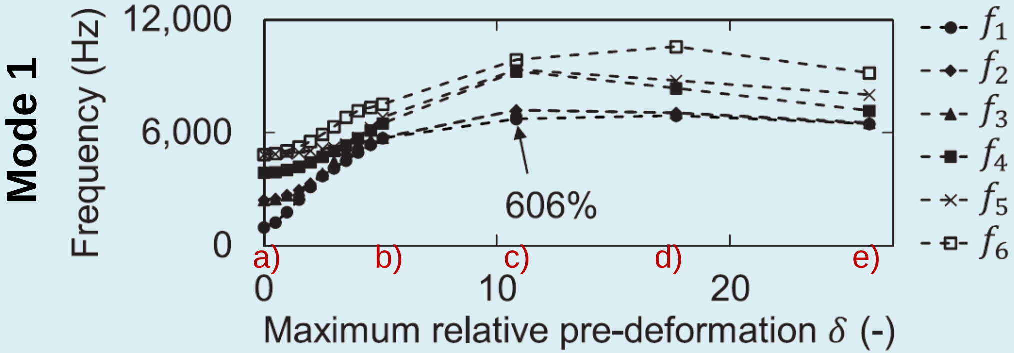
K: Plate bending stiffness
ρ: Material density

Plate mode shapes



(Andresen et al 2020, *Advances in Mechanical Engineering* 12)

Shape Adaptation: 2D Plate - Results

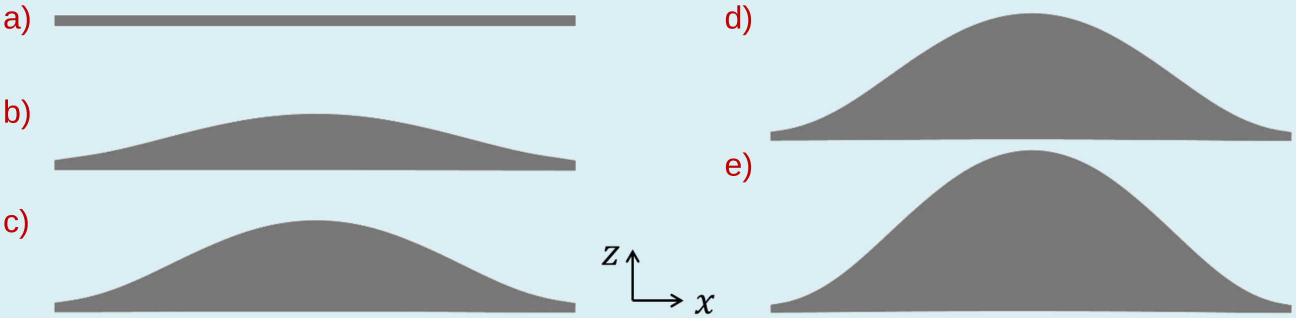


Maximum relative pre-deformation:

$$\delta = \frac{\delta_{max}}{h_p}$$

Maximum pre-deformation

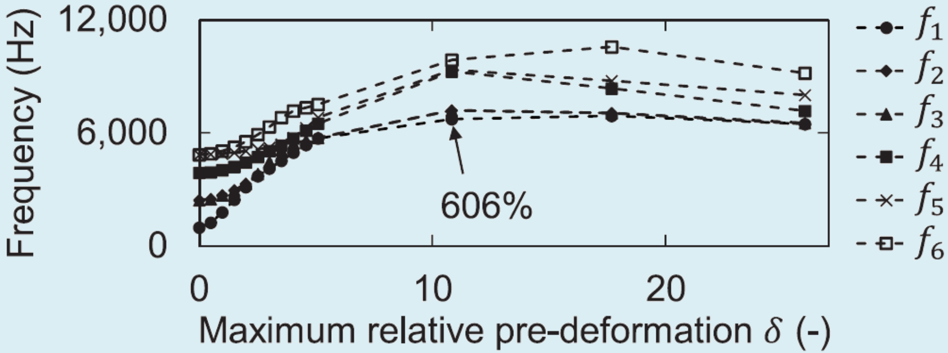
Plate thickness



(Andresen et al 2020, *Advances in Mechanical Engineering* 12)

Shape Adaptation: 2D Plate - Results

Mode 1



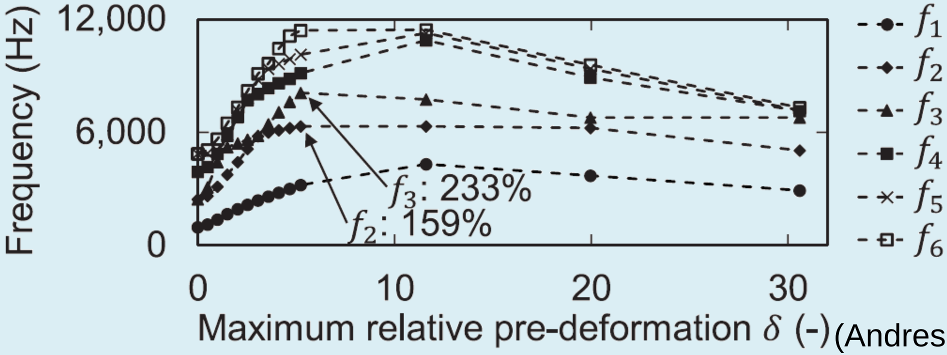
Maximum relative pre-deformation:

Maximum pre-deformation

$$\delta = \frac{\delta_{max}}{h_p}$$

Plate thickness

Mode 2/3



Shaping a plate according to the i-th (i = 1-4) mode shape strongly increases all eigenfrequencies

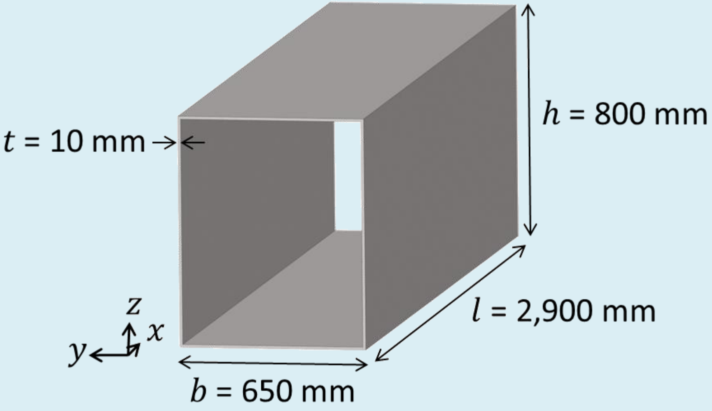
(Andresen et al 2020, *Advances in Mechanical Engineering* 12)

Shape Adaptation: 3D Beam

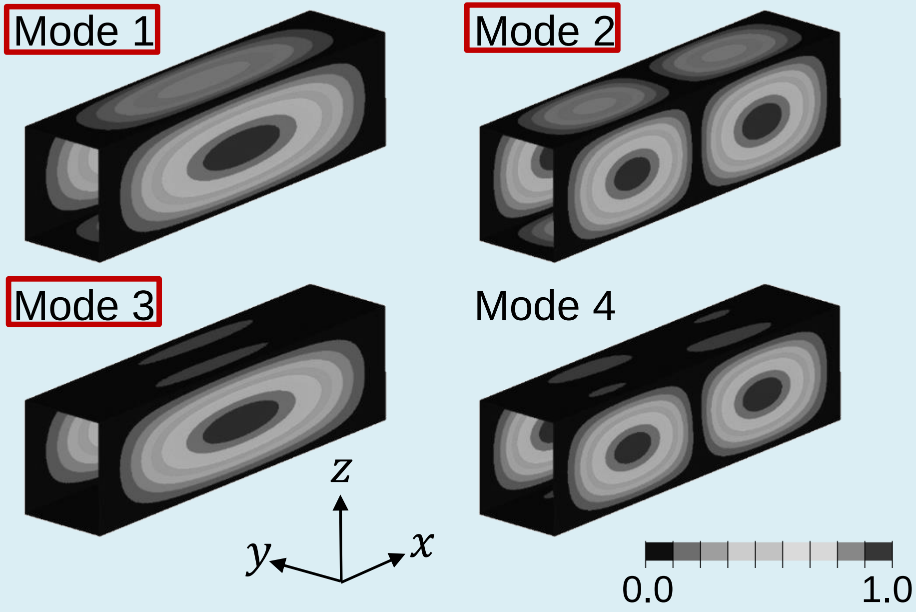
Mode shapes that were applied to the 3D beam

Model assembly

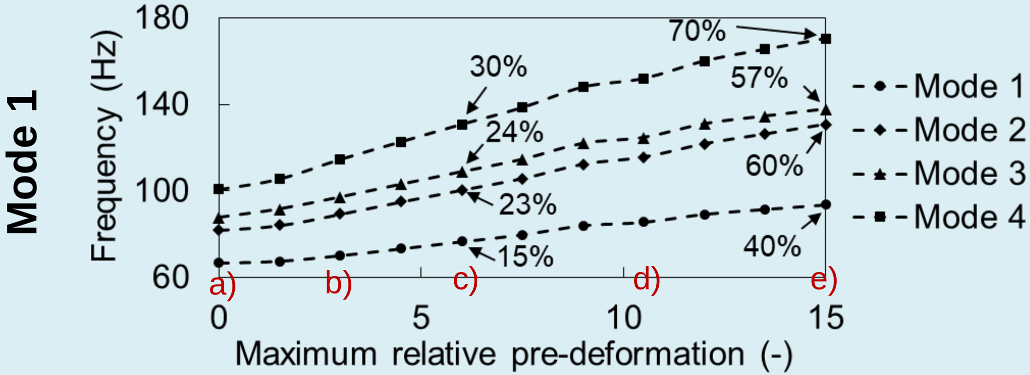
- Clamped at both ends
- Mass variation < 9%



Mode shapes



Shape Adaptation: 3D Beam - Results

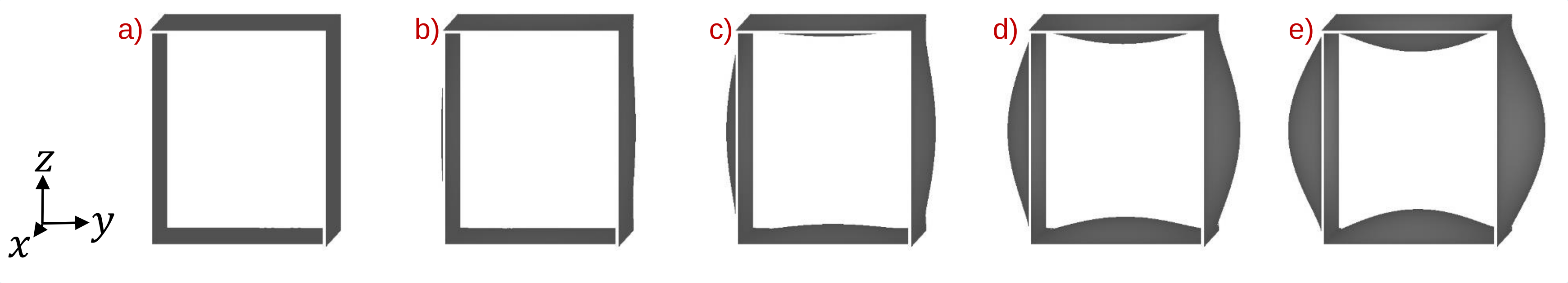


Maximum relative pre-deformation:

$$\delta = \frac{\delta_{max}}{t}$$

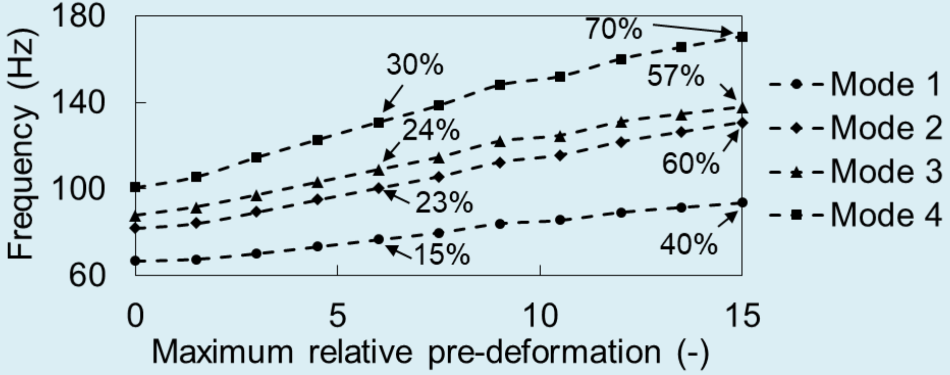
Maximum pre-deformation

Wall thickness

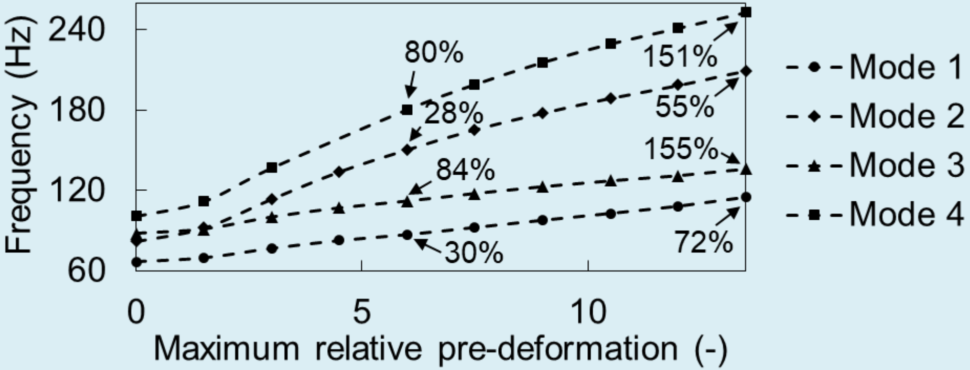


Shape Adaptation: 3D Beam - Results

Mode 1



Mode 2



Maximum relative pre-deformation:

$$\delta = \frac{\delta_{max}}{t}$$

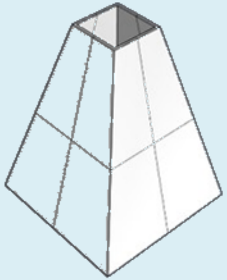
Maximum pre-deformation

Wall thickness

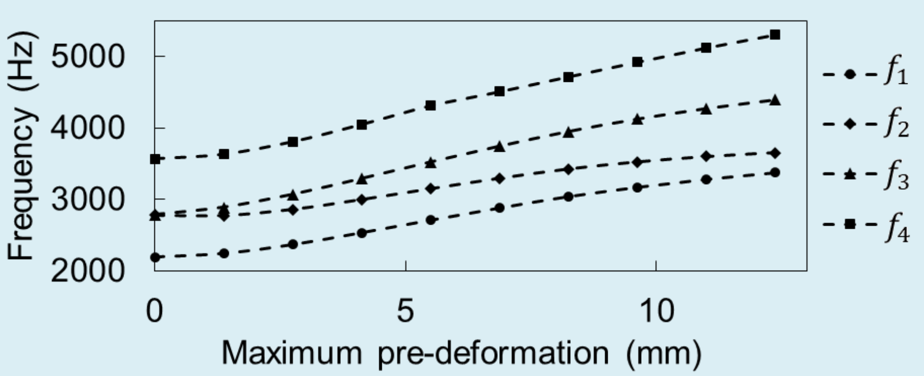
Shaping a 3D beam according to the i-th (i = 1-3) mode shape increases all eigenfrequencies

Shape Adaptation: Further 3D Structures

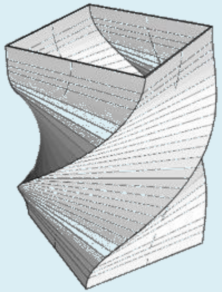
Truncated Rectangular Pyramid



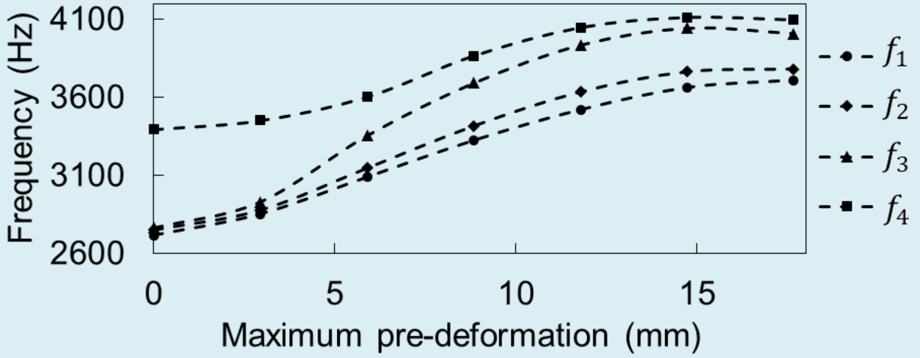
Pre-deformed according to Mode 1



Twisted Parallelepiped



Pre-deformed according to Mode 1



Chapter 3

Conclusion

Conclusion

- Shaping axially constrained 1D, 2D, and 3D structures according to their mode shapes strongly increased the eigenfrequencies
    - 1D Beam: almost exclusive increase of the i-th mode shape frequency of the beam (i = 1-5)
    - 2D Plate: all eigenfrequencies were increased by pre-deforming the plate according to the i-th (i = 1-4) mode shape
    - 3D Beam: all eigenfrequencies were increased by pre-deforming the beam according to the i-th (i = 1-3) mode shape
- Efficient and easy applicable method to strongly increase eigenfrequencies
- Application to 3D structures should be further investigated

Thank you very much for your attention.

Simone Andresen

Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research
Bionic Lightweight Design

Bussestr. 27, 27570 Bremerhaven, Germany

Phone: +49-471-4831-2827
E-Mail: simone.andresen@awi.de

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HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

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