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## Design and optimisation of a vibrating wing insect-size air vehicle

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## 1-Context

State of the art:

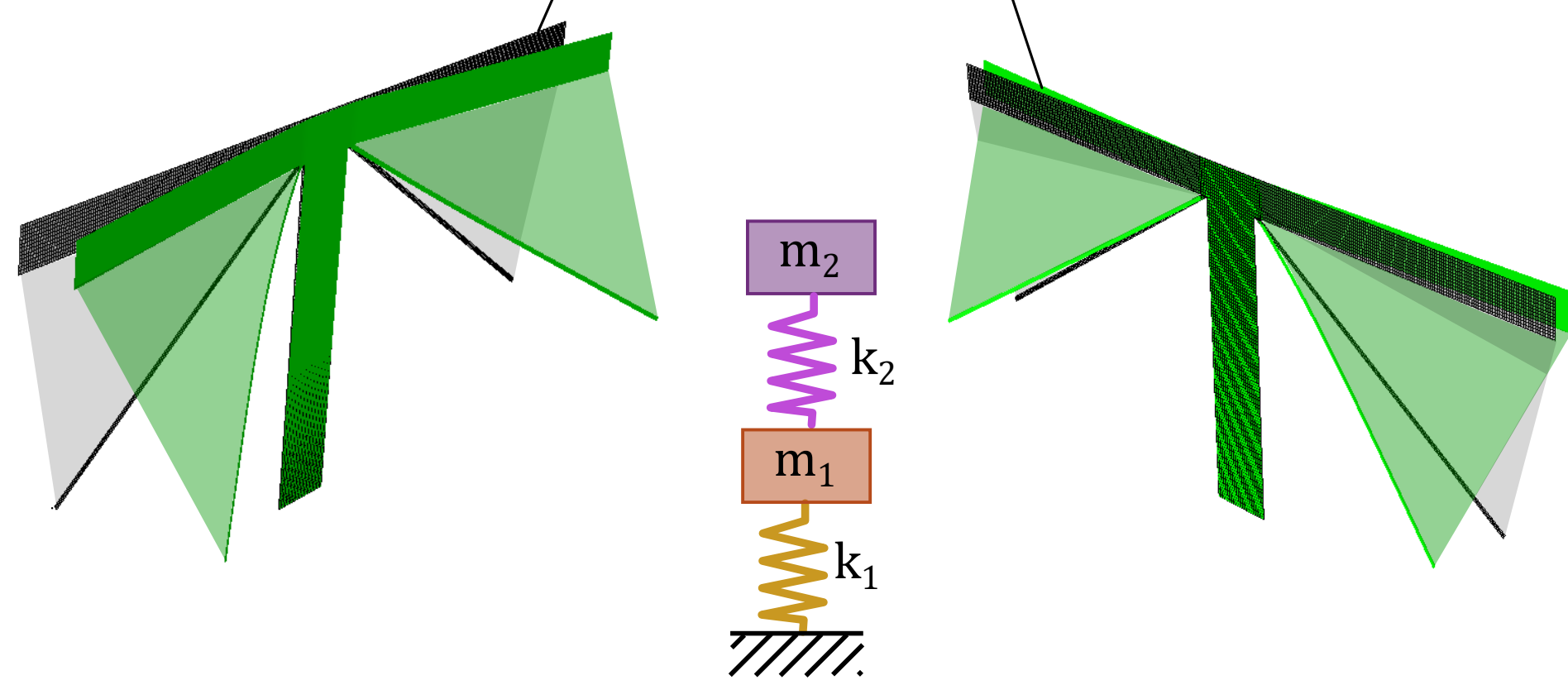
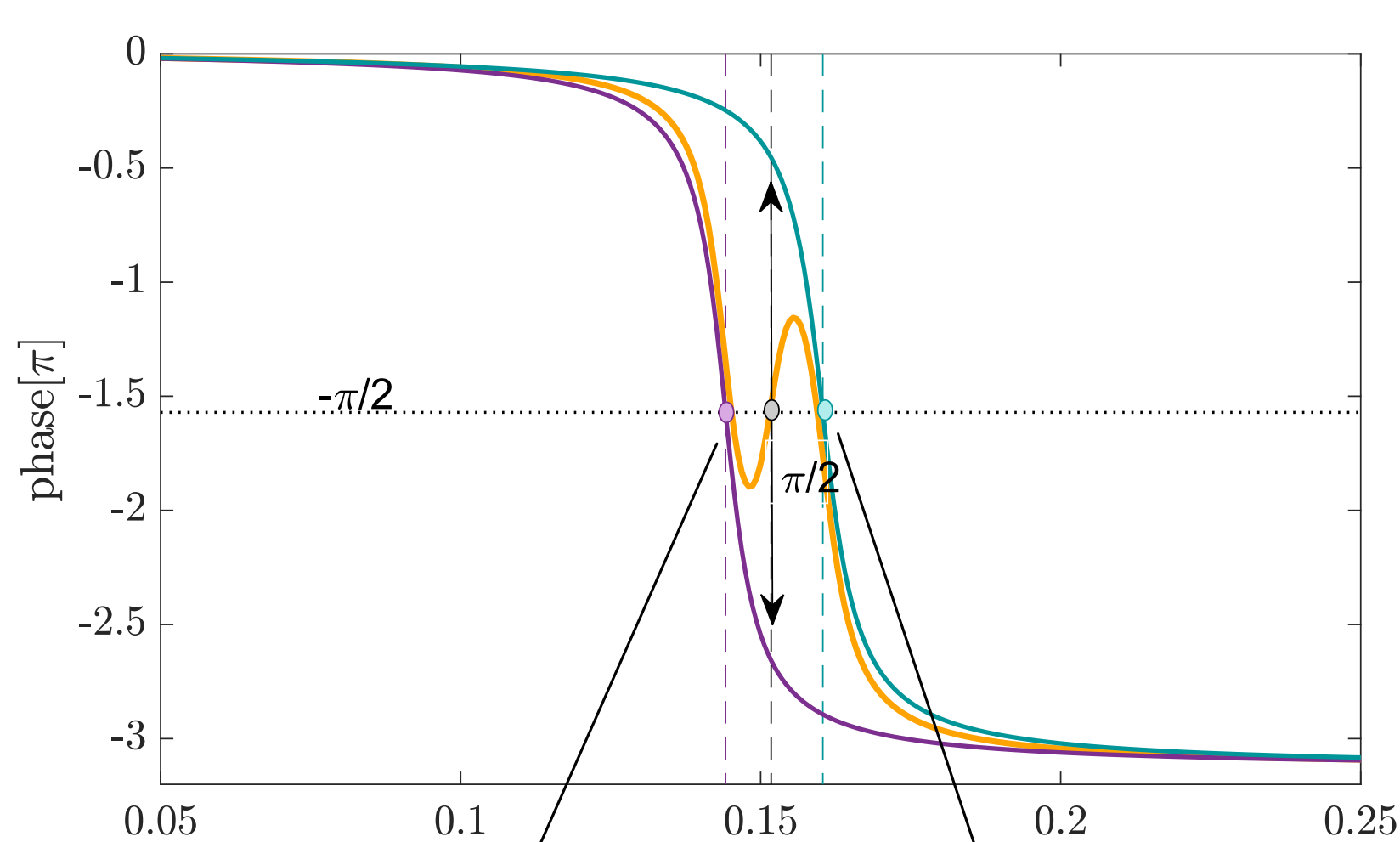
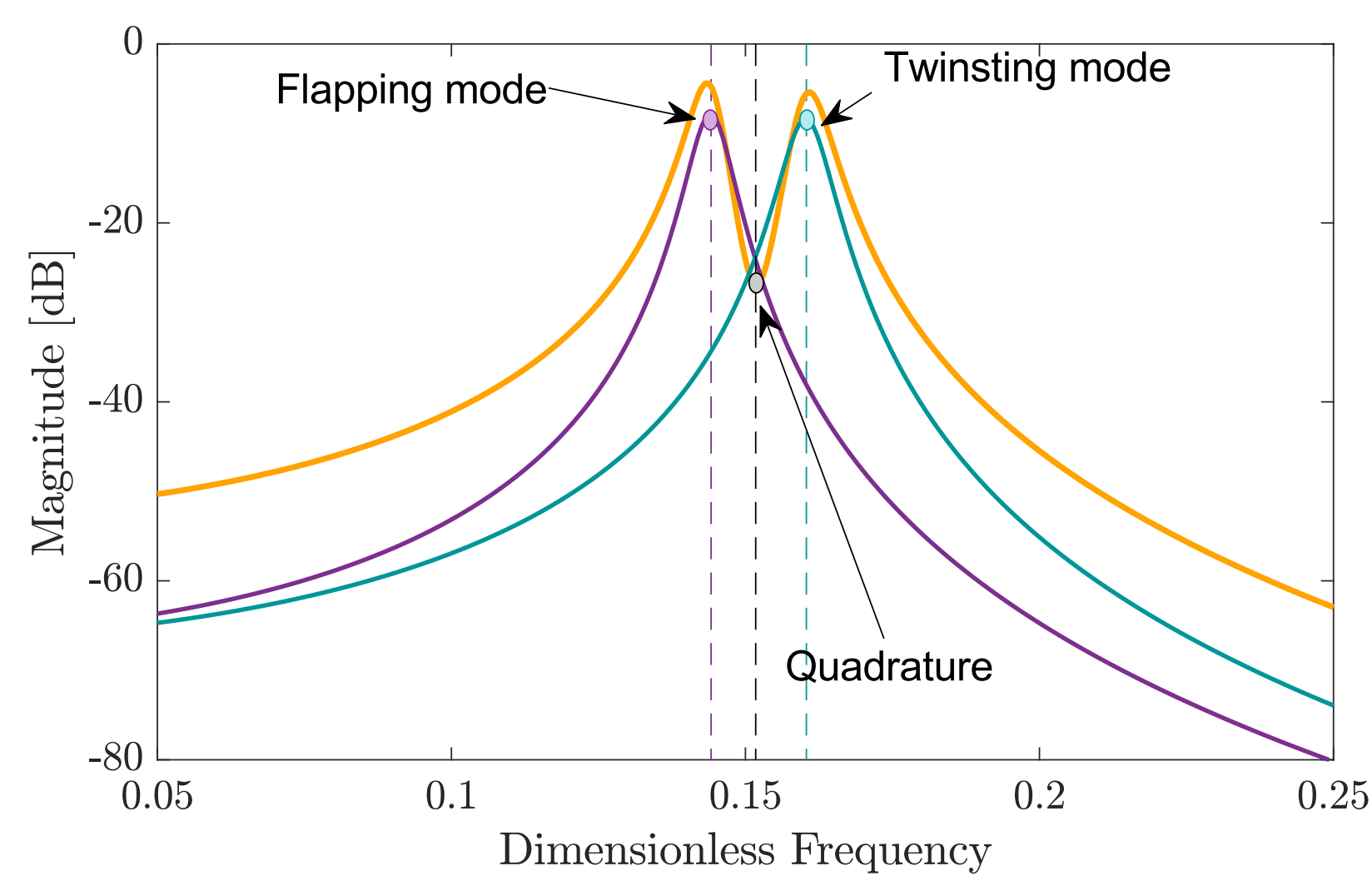
- Only 2 projects have succeeded in taking off a NAV with a mass of 100 mg: Shanghai [Zou 2018] and Harvard [Wood 2019].
- They are both based on passive twisting to imitate insect flight.

Insect flight [Dickinson 1999]

- It is a complex mechanism that can be reduced to a combination of flapping and twisting modes.
- It generates the larger lift when flapping and twisting are in phase quadrature.

## 2-Modal Superposition

We are looking for a combination of the flapping and twisting modes that gives maximum amplitude to the quadrature.



Dimensionless motion equations (2 degree of freedom):

$$\ddot{x}_1 + 2\xi_1 \dot{x}_1 + (1 + \mu\bar{\omega}^2)\bar{x}_1 - \mu\bar{\omega}^2 \bar{x}_2 = \cos(\bar{\Omega}t), \quad (1)$$

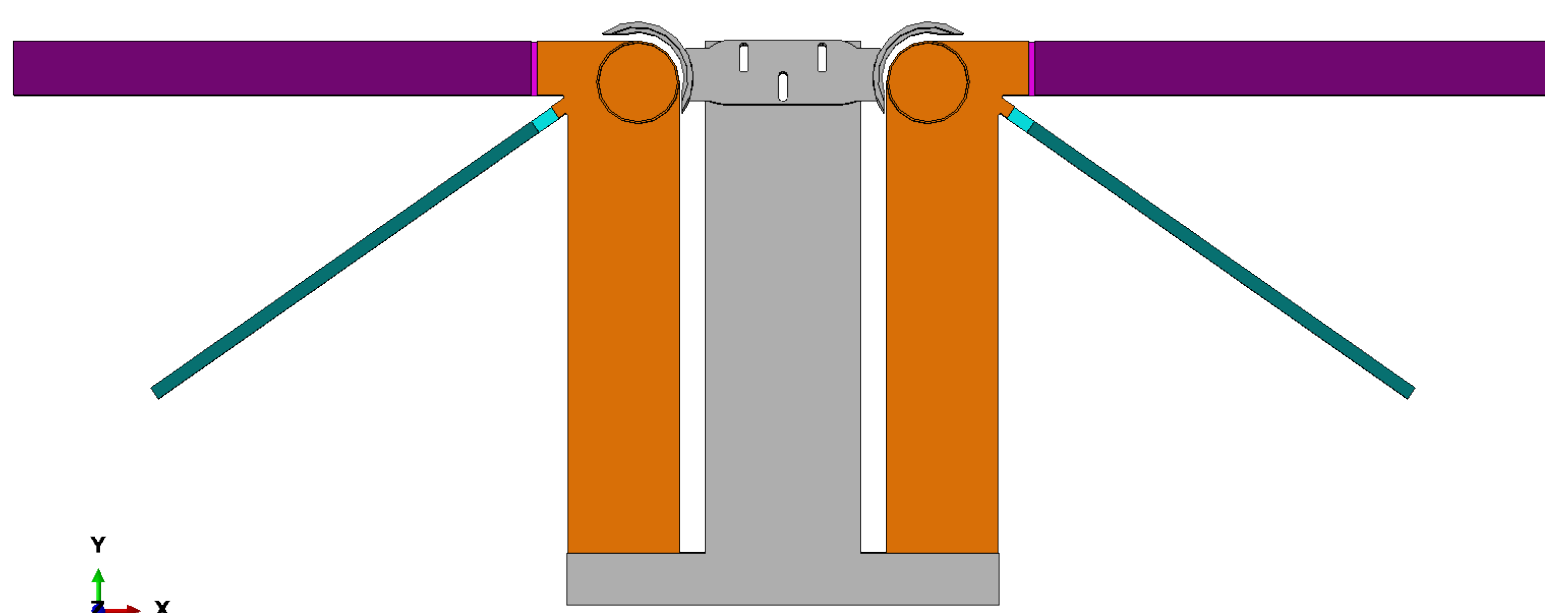
$$\ddot{x}_2 + 2\xi_2 \dot{x}_2 + \bar{\omega}^2(\bar{x}_2 - \bar{x}_1) = 0, \quad (2)$$

Criteria:

- two resonances close together and at the same amplitude
- anti-resonance with a not too low amplitude
- ratio between the amplitude of the leading edge and the magnet of  $\approx \frac{1}{6}$

## 7-Future Work

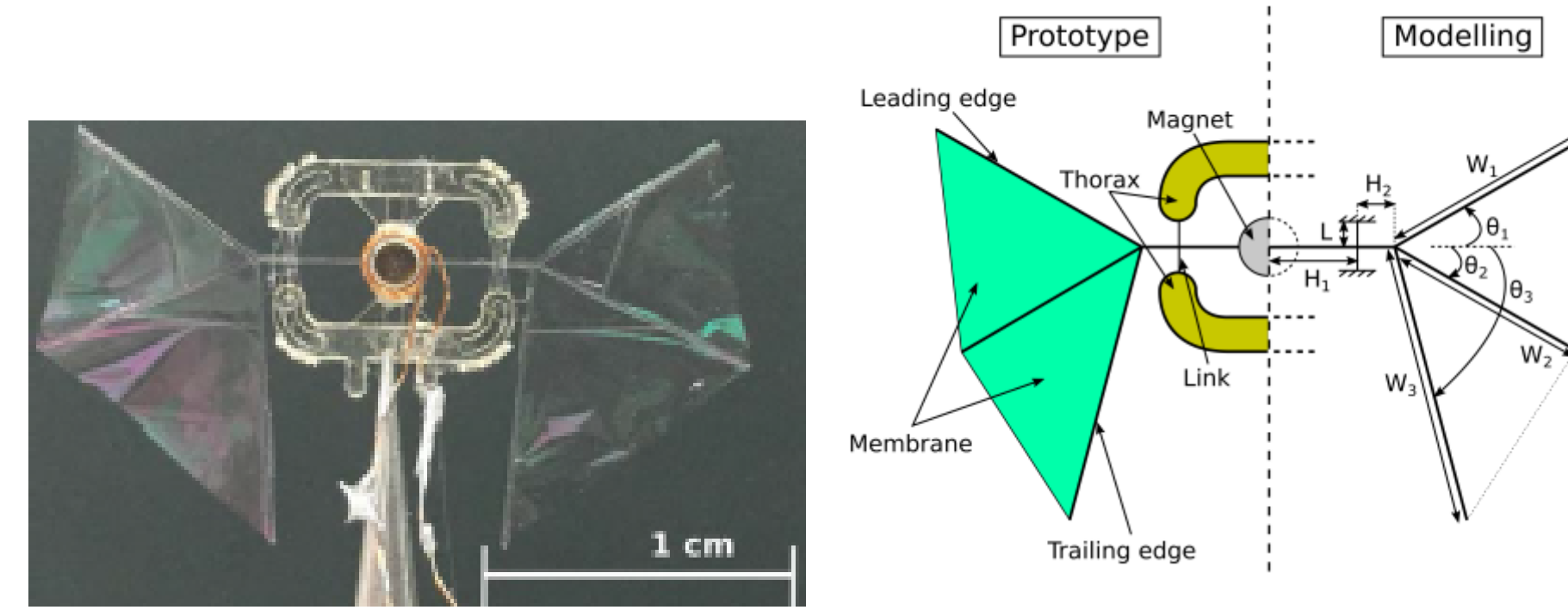
Optimisation, fabrication and testing of a new generation of NAV.



## 2-The Generations

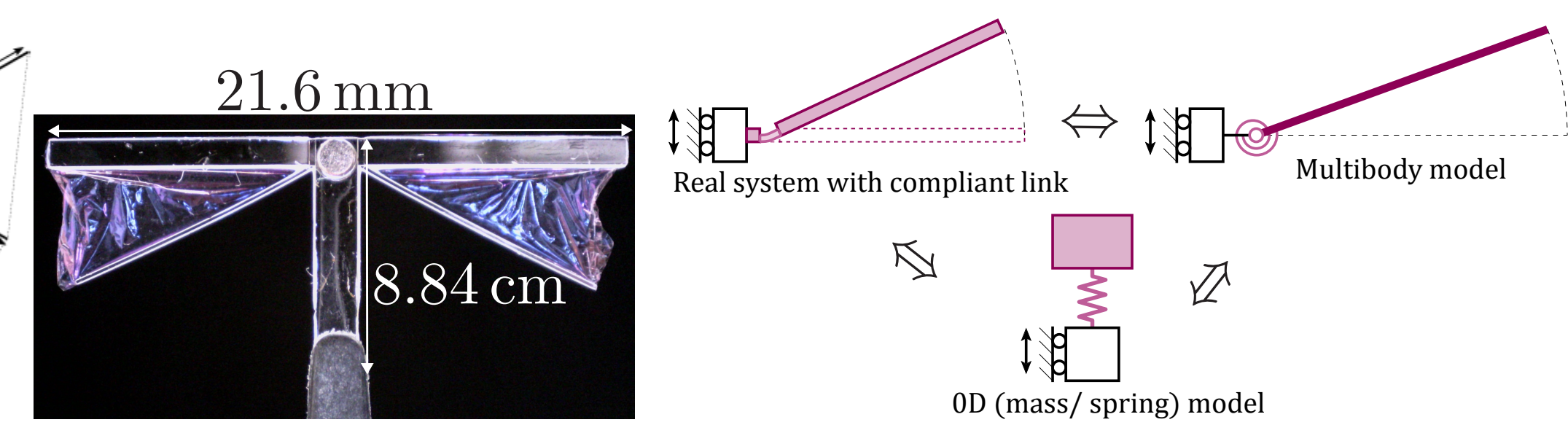
Previous work [Faux 2019]:

- Structure with fully flexible wings
- Optimised by an of Euler-Bernoulli beam model



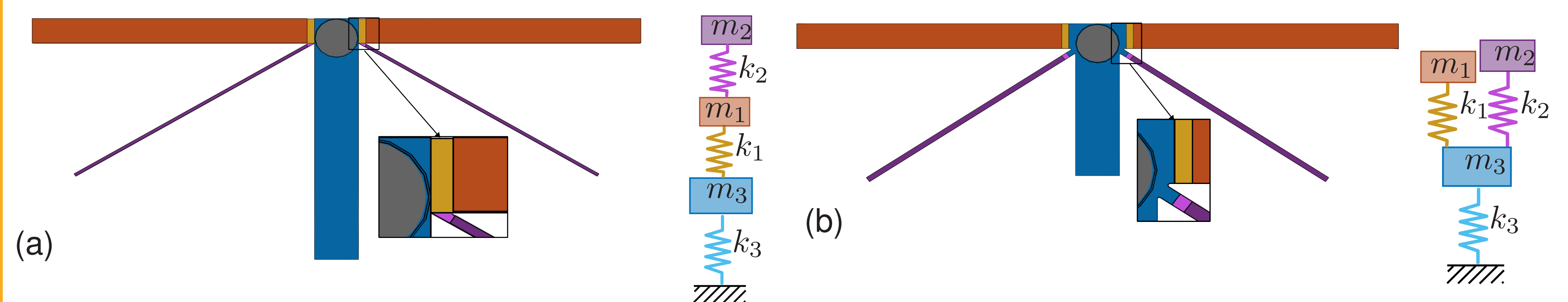
Actual Work [Colin 2021]:

- Structure with compliant links and rigid bodies
- Optimised by equivalence with a 0D model

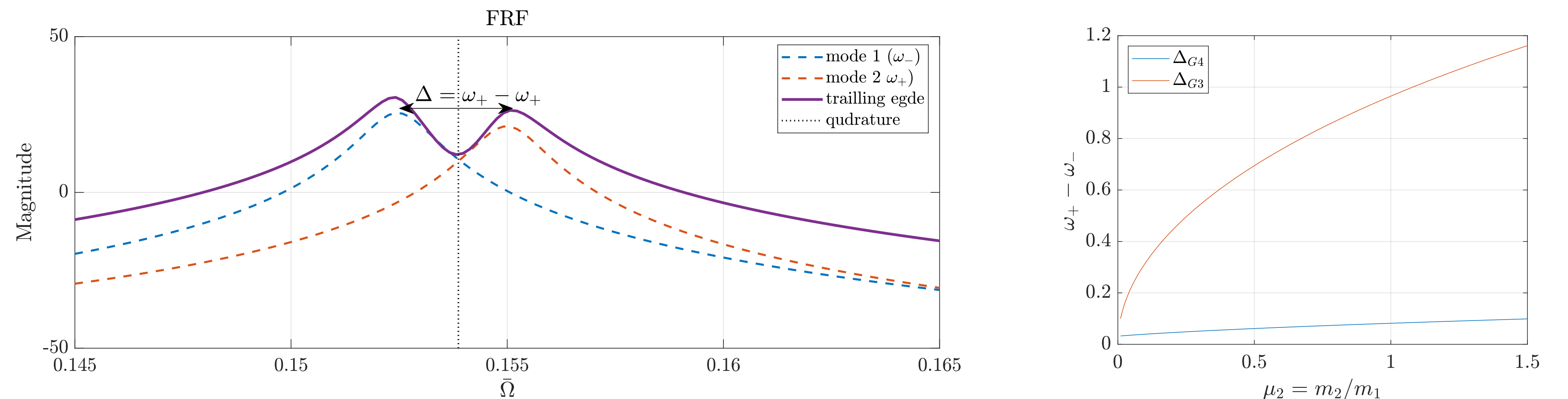


## 4-NAV Architectures

Two NAV architectures and their simplified models:

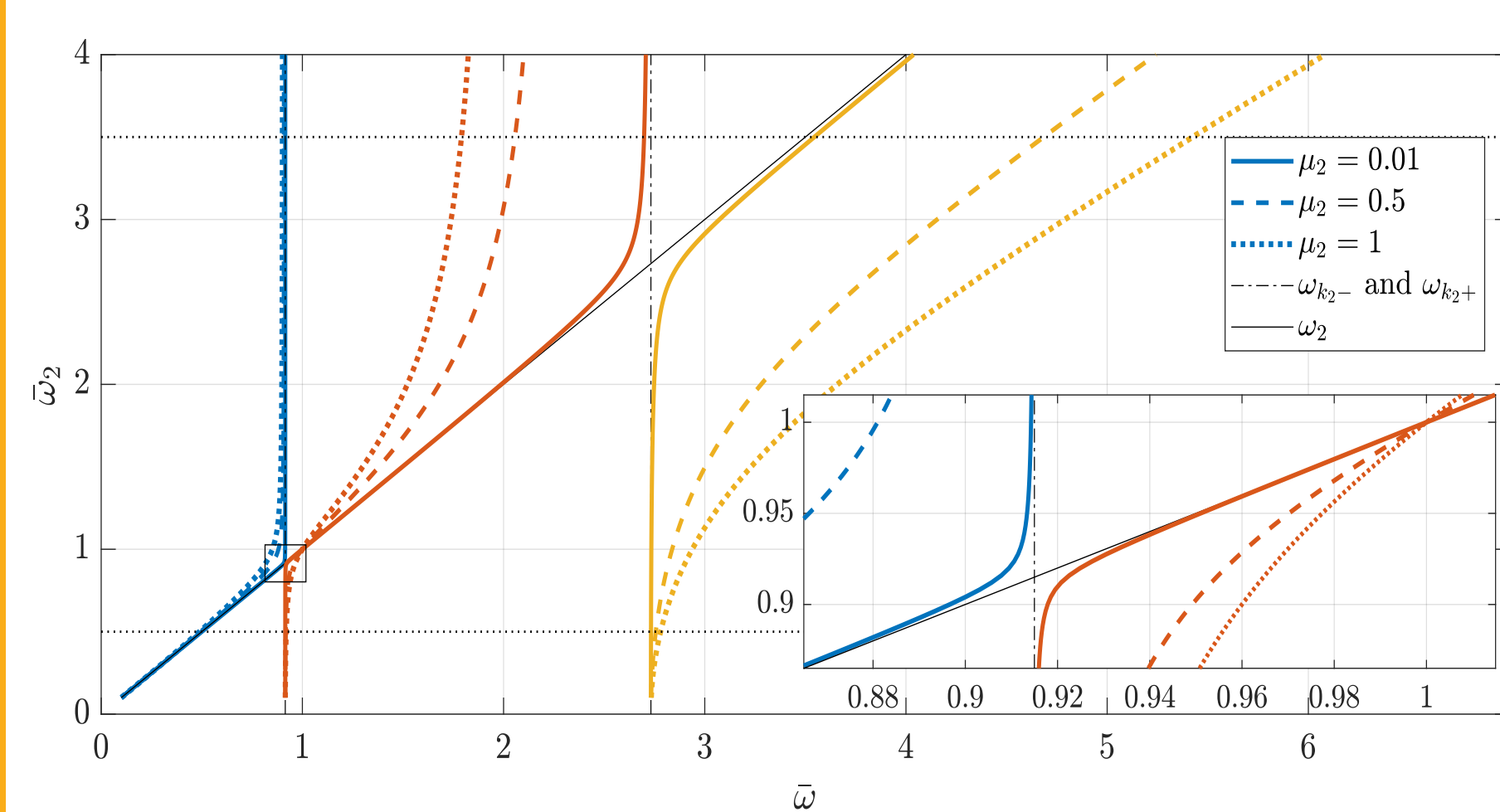


Frequency difference for the two geometries:



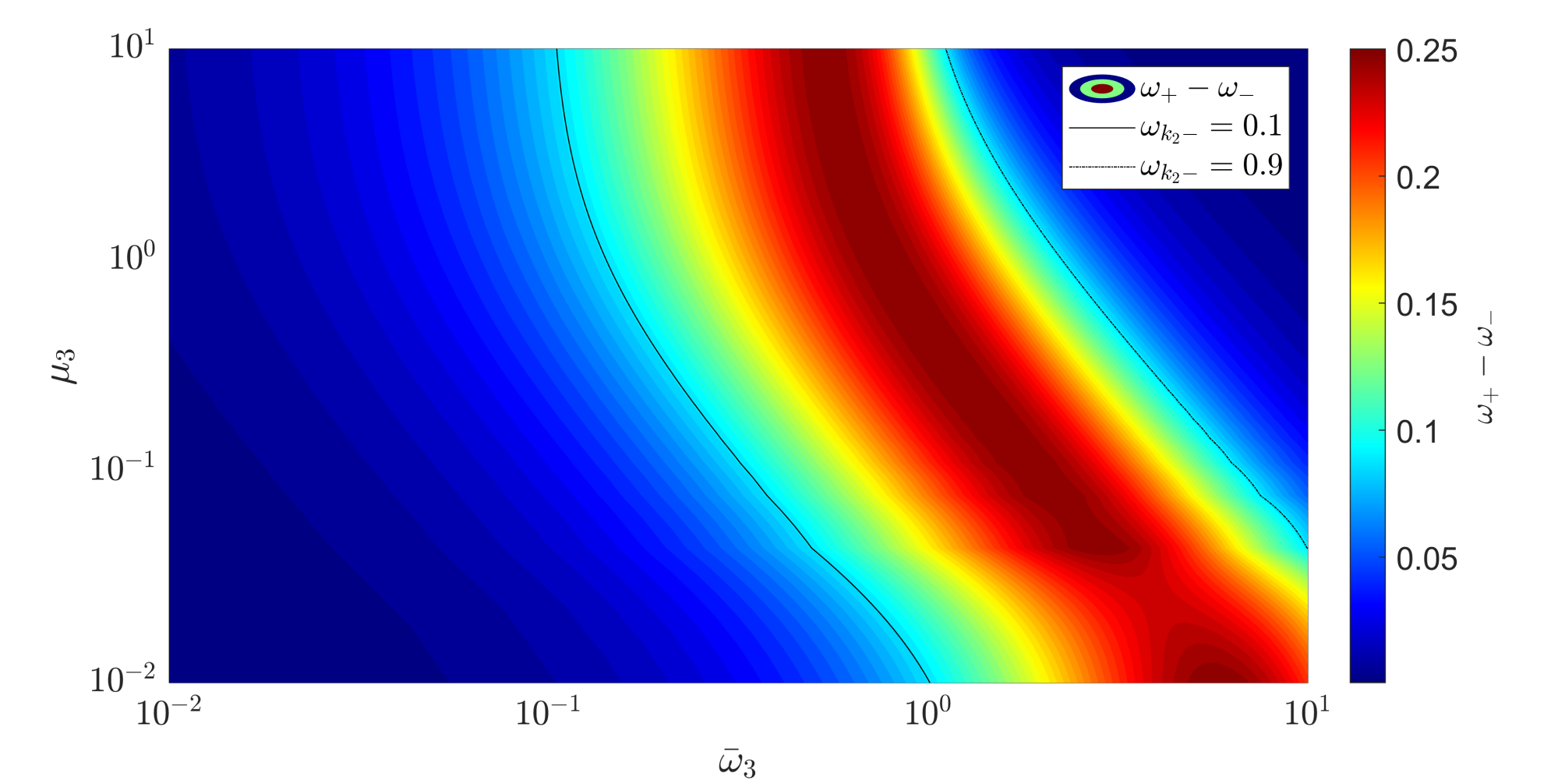
## 5-Optimisation

Study of  $\mu_2 = \frac{m_2}{m_1}$ :

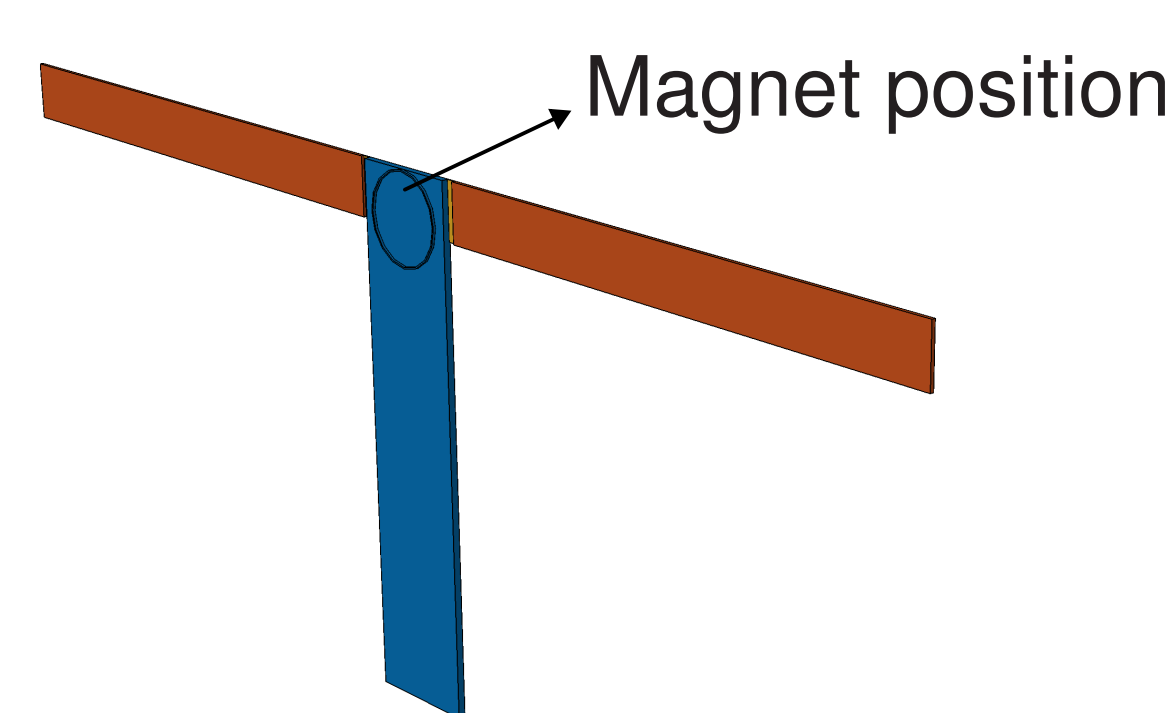


- $\mu_2 = \frac{m_2}{m_1} \ll 1$
- $\bar{\omega}_2 = \frac{\xi_2}{\omega_1}$  function of  $\bar{\omega}_3 = \frac{\omega_3}{\omega_1}$  and  $\mu_3 = \frac{m_3}{m_1}$

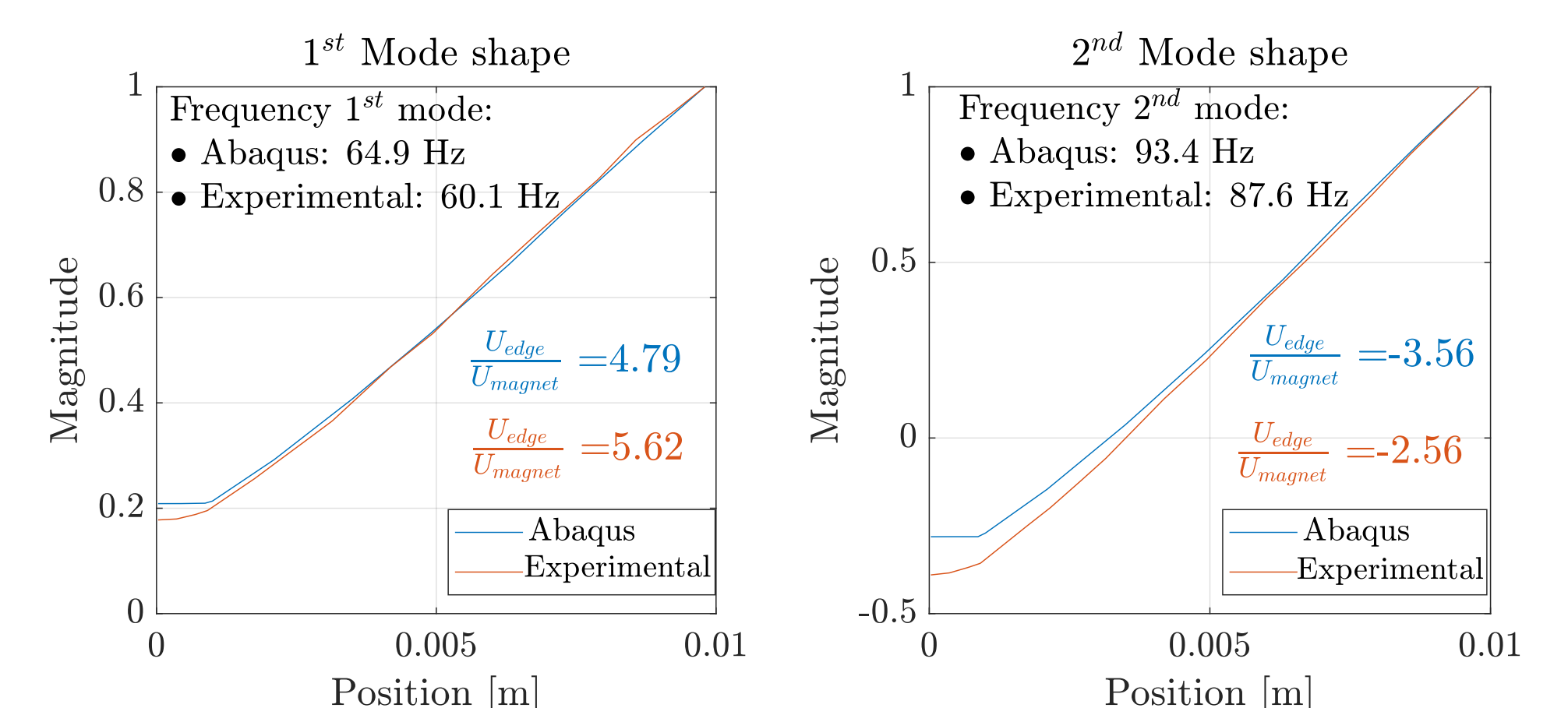
Study of  $\bar{\omega}_3$  and  $\mu_3$ :



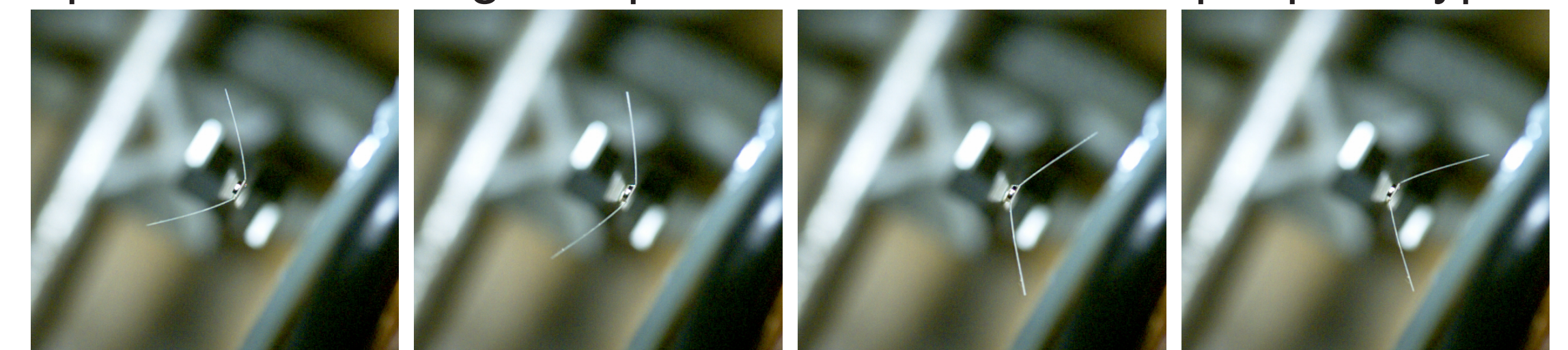
## 6-First Validation



- The rigid bodies assumption is valid: only the compliant links deform.
- We can achieve high amplitudes: angles of 70° peak to peak.



snapshots of the large amplitude motion of a simple prototype



## 8-Bibliographies

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 Dickinson, M. H. et F. T. Muijres, The aerodynamics and control of free flight manoeuvres in *Drosophila*, *Philosophical Transactions of the Royal Society B: Biological Sciences* 371.1704, 2016.  
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