University of BRISTOL

Vibration Isolator Incorporating a Composite Bistable Plate

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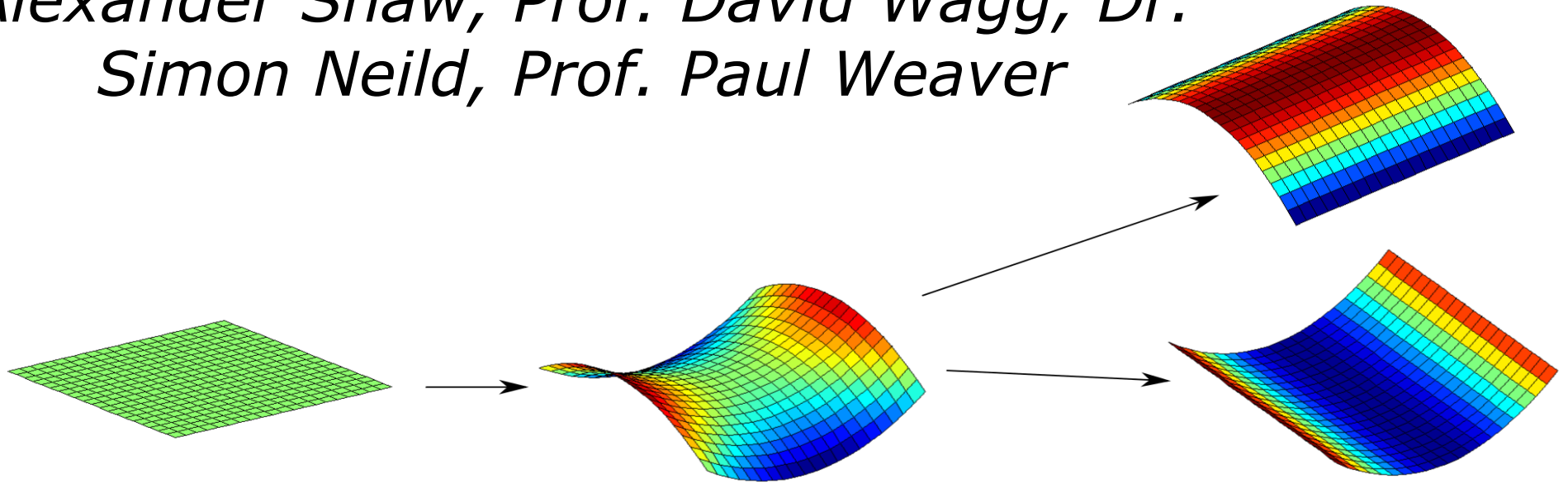

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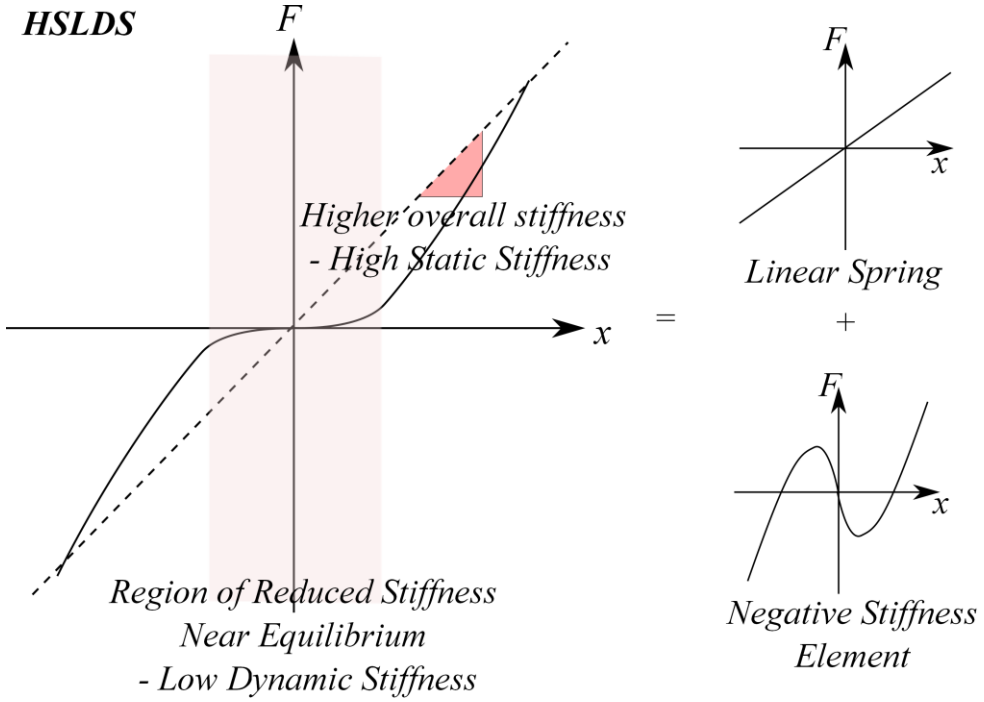
ADVANCED COMPOSITES CENTRE FOR INNOVATION & SCIENCE

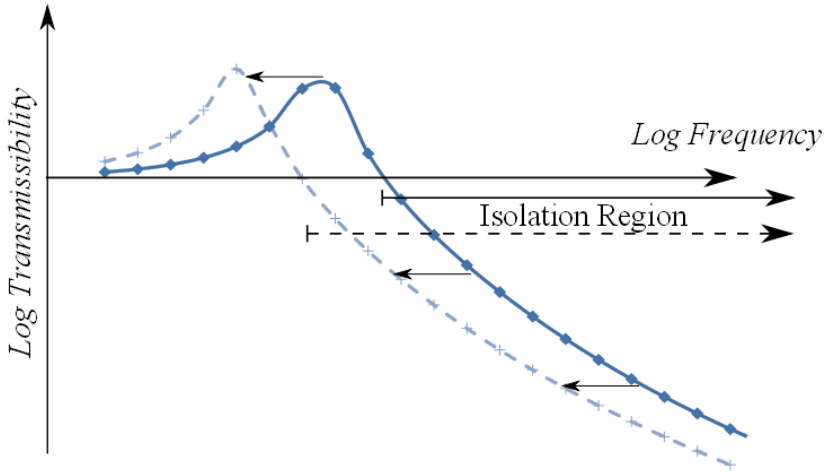
Introduction

- High Static Low Dynamic Stiffness vibration isolator
  - Theory and benefits
- Bistable Plates
  - What they are and how they work
- Quasi-static response
  - Numerical Results and Empirical formula
  - Possible path dependency and hysteresis
  - Experimental results
- Dynamic response
  - Initial tap test results
  - Modelling
- Ongoing/Future work

High Static Low Dynamic Stiffness (HSLDS)

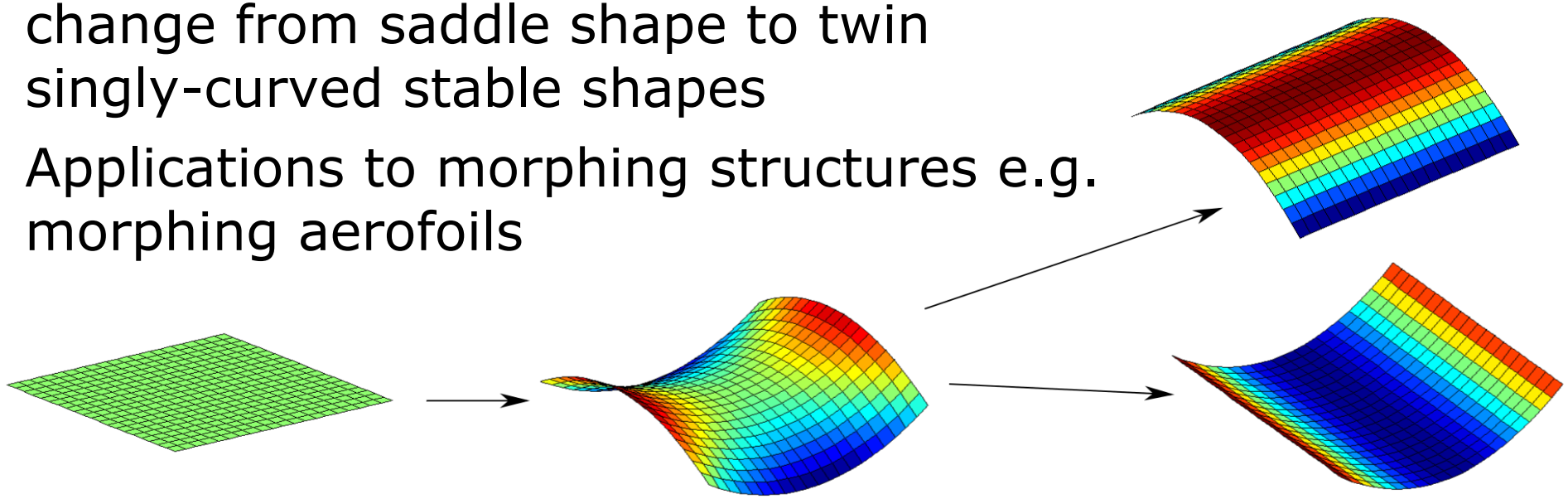
- A soft mount has a low resonant frequency – and therefore a wider isolation region
- However, low linear stiffness implies a poor weight bearing capacity
- HSLDS mount seeks to reduce stiffness at the equilibrium point whilst maintaining overall stiffness
- Profile achieved through combination of linear springs and negative stiffness elements





Bistable plates

- Plates with 2 stable curved positions
- Created flat in the autoclave
- Curvature driven by asymmetric layup and thermal contraction on cooling from cure
- Gaussian curvature change drives change from saddle shape to twin singly-curved stable shapes
- Applications to morphing structures e.g. morphing aerofoils

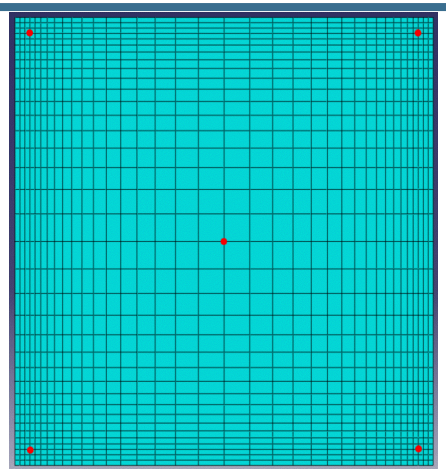


Bistable plate as negative spring

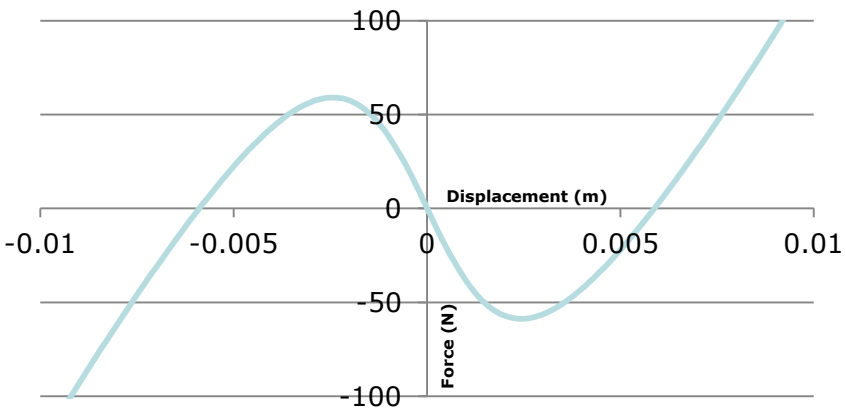
- Force/Displacement Curve produced in ABAQUS using nonlinear shell elements
- Empirical formula fits curve very well:

$$F(x) = Ax - B\tan^{-1}(Cx)$$

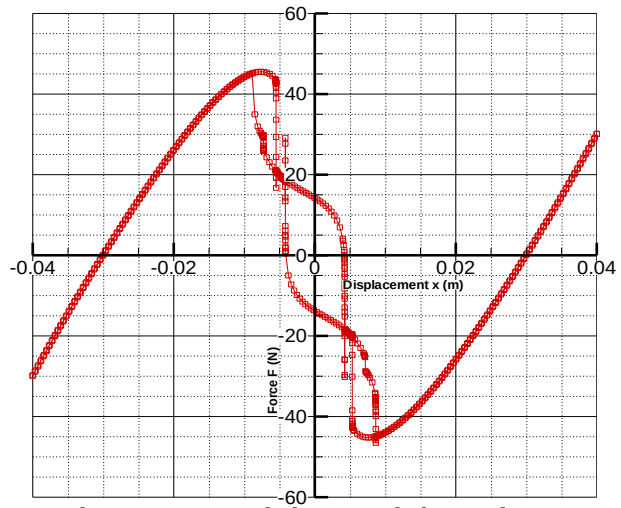
- Need to avoid ½ snap shapes



Mesh used for FEA. Red dots indicate where boundary conditions are applied



Force through plot of bistable plate from FEA – showing smooth response



Excessively curved bistable plates form ½ snap states during force through giving non-smooth response

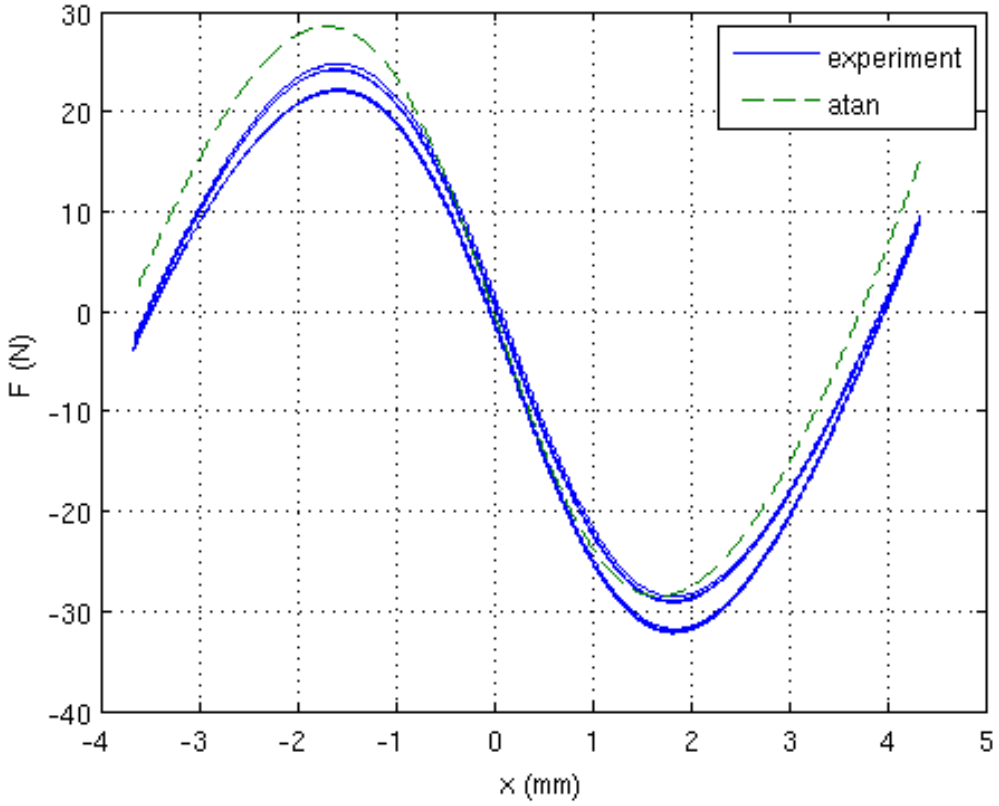
Improved design – hybrid steel/CF plate*

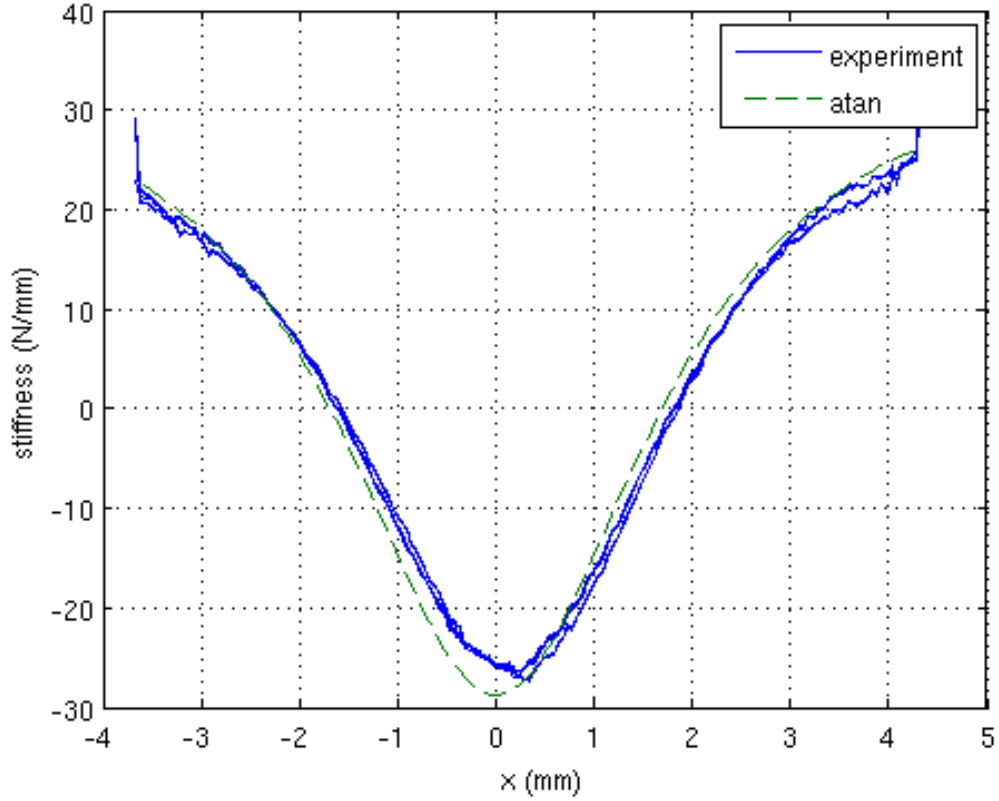
- 110mm [$0^\circ_{CF\ 3}$, 0°_{steel} , $90^\circ_{CF\ 3}$] plate
- Steel has high $E\alpha$ – creating large thermal contraction forces on cool, which couples with the asymmetric stiffness to create far greater bistable effect
- More compact
- 'Half snap' shapes are not stable with this lay up/geometry – so no hysteresis
- Good agreement with ATAN model

*See *Daynes S, Weaver P, Analysis of unsymmetric CFRP–metal hybrid laminates for use in adaptive structures, Composites: Part A , 2010, Vol 41, Issue 11, p1712-1718*

Hybrid steel/CF plate experimental results

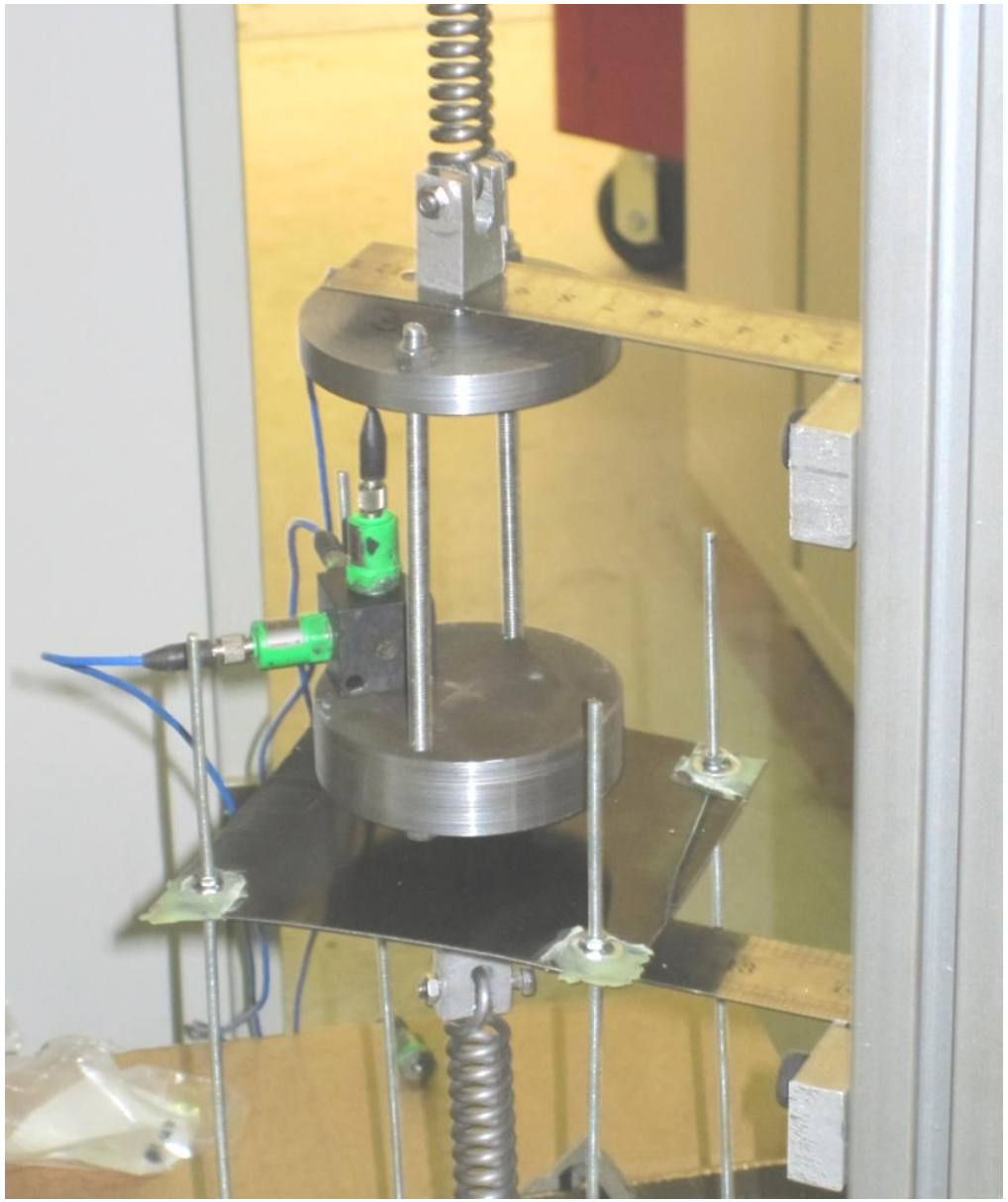
- Good match with ATAN model for displacement
- Stiffness plot shows quality of agreement better
- Ideal for implementation in HSLDS





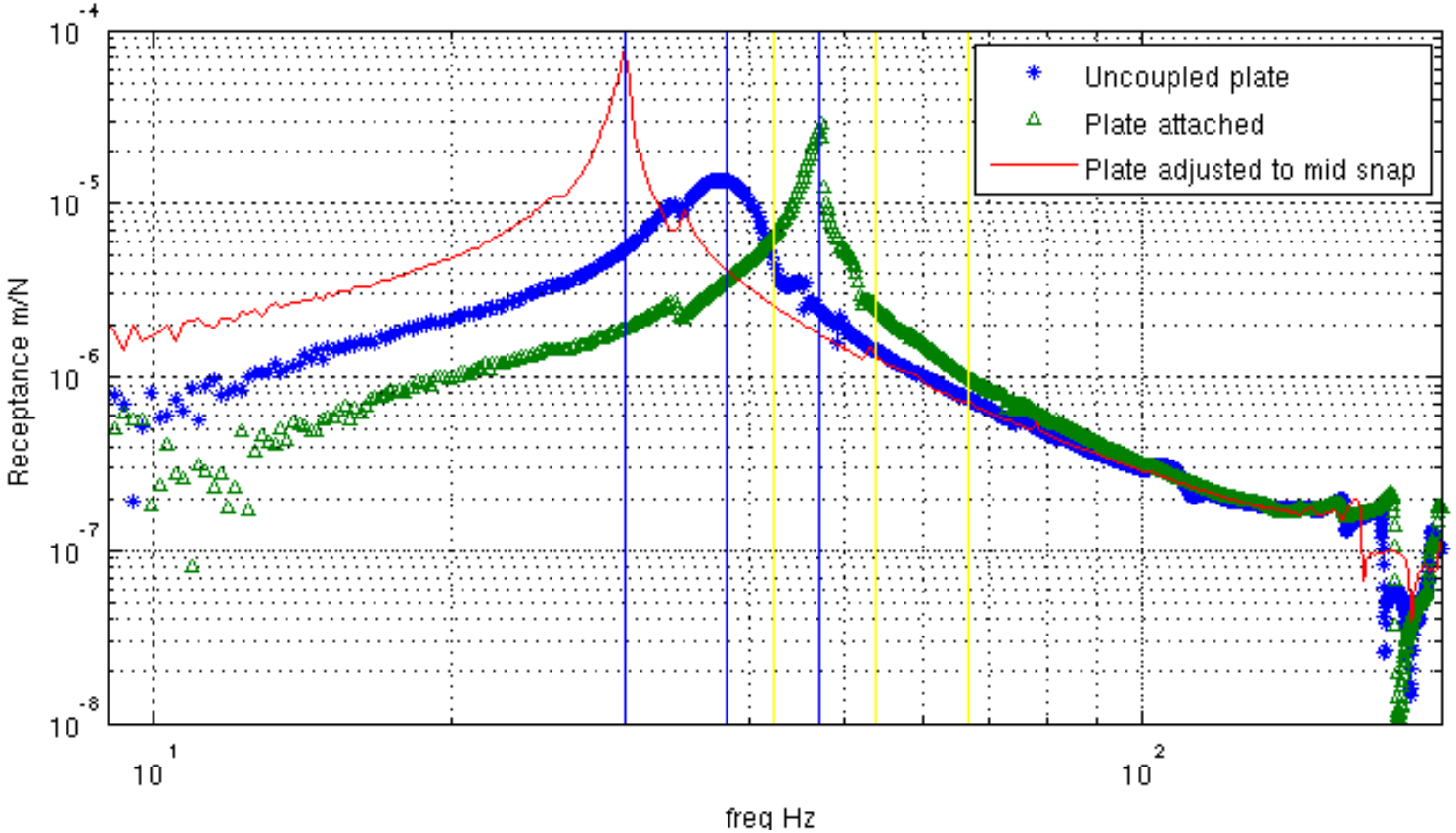
Force / displacement (left) and stiffness / displacement (right) graphs of hybrid bistable plate.

HSLDS Demonstrator



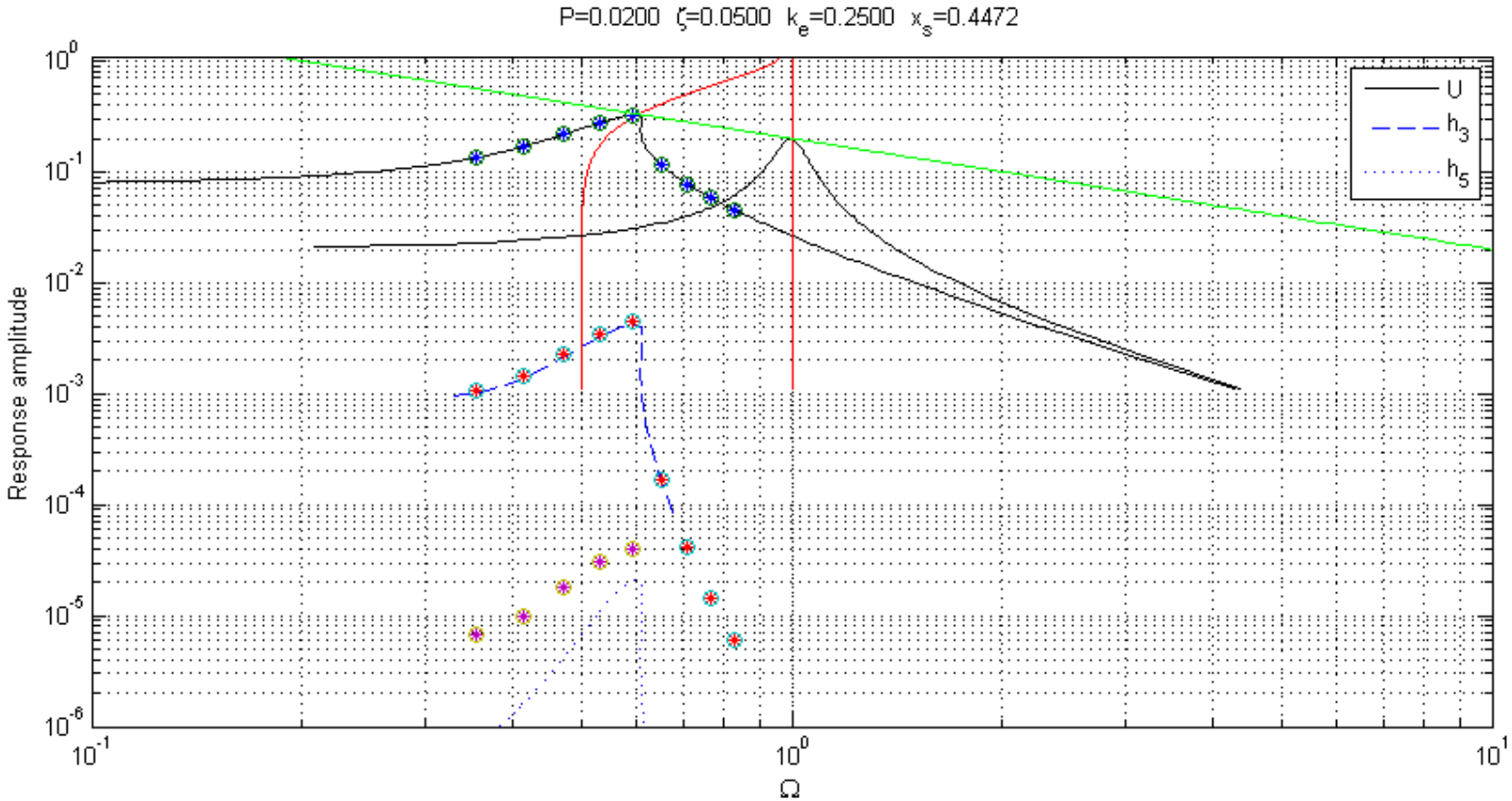
HSLDS – Tap Test Results

- Good match with theory - reducing linearised stiffness reduces natural frequency and increases peak response to forcing



FRF result from tap test on mount showing natural frequency reduction. (Blue line to red)

HSLDS – dynamical analysis



Prediction for 5th order polynomial HSDLS with forced excitation. h_3 and h_5 are 3rd and 5th harmonics. Markers show numerical simulation results.

- Normal Forms used to model response
- Higher order polynomial allowing different stiffness polynomials
- Established useful performance limits of mount

Future work

- Extend dynamic experimentation to more realistic excitation
- Modelling of plate phenomena (force through response and ½ snaps)
- Consider different types of bistable plate to achieve more consistent response, easier manufacturing and elimination of external springs from the mount

The End

Thank you

Any Questions?