Bioinspired Engineering — Sound Production Through Elastic Instabilities
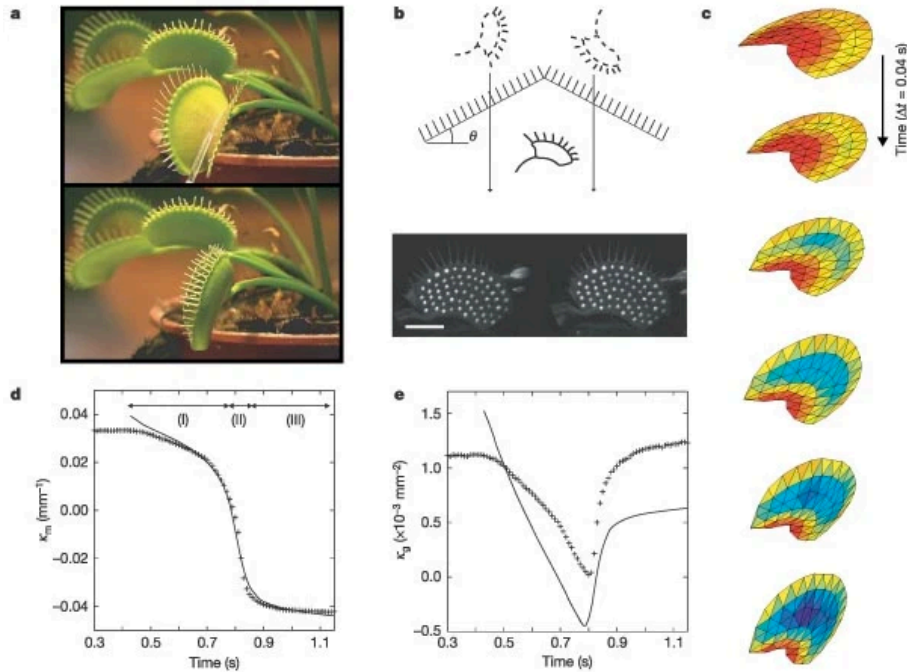
Hernaldo Mendoza Nava

Rainer Groh & Alberto Pirrera - *Bristol Composites Institute*
Marc Holderied - *School of Biological Sciences*

BCI Postgraduate Research and Training Showcase - April 13th, 2021

bristol.ac.uk/composites

Bioinspired Engineering

**Venus fly trap — Snap-buckling instability
for prey capture**

Forterre, Y. (2005)
Nature 433:421–425

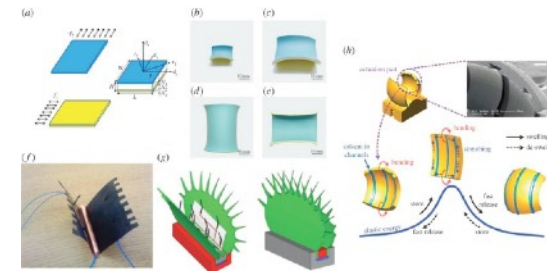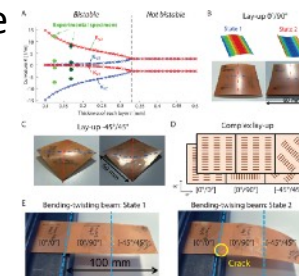Deployable
Structures

Stoychev, G. (2011)
Soft Matter
7, 3277

Morphing
Devices

Guo, Q. (2015)
J. R. Soc. Interface
12: 20150598

Programmable
Composites

Schmied, J.U. (2017)
Bioinspir. Biomim.
12:026012

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production through elastic instabilities**
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Aeroelastic Tymbal

Acoustic Spectrogram — Ultrasonic clicks
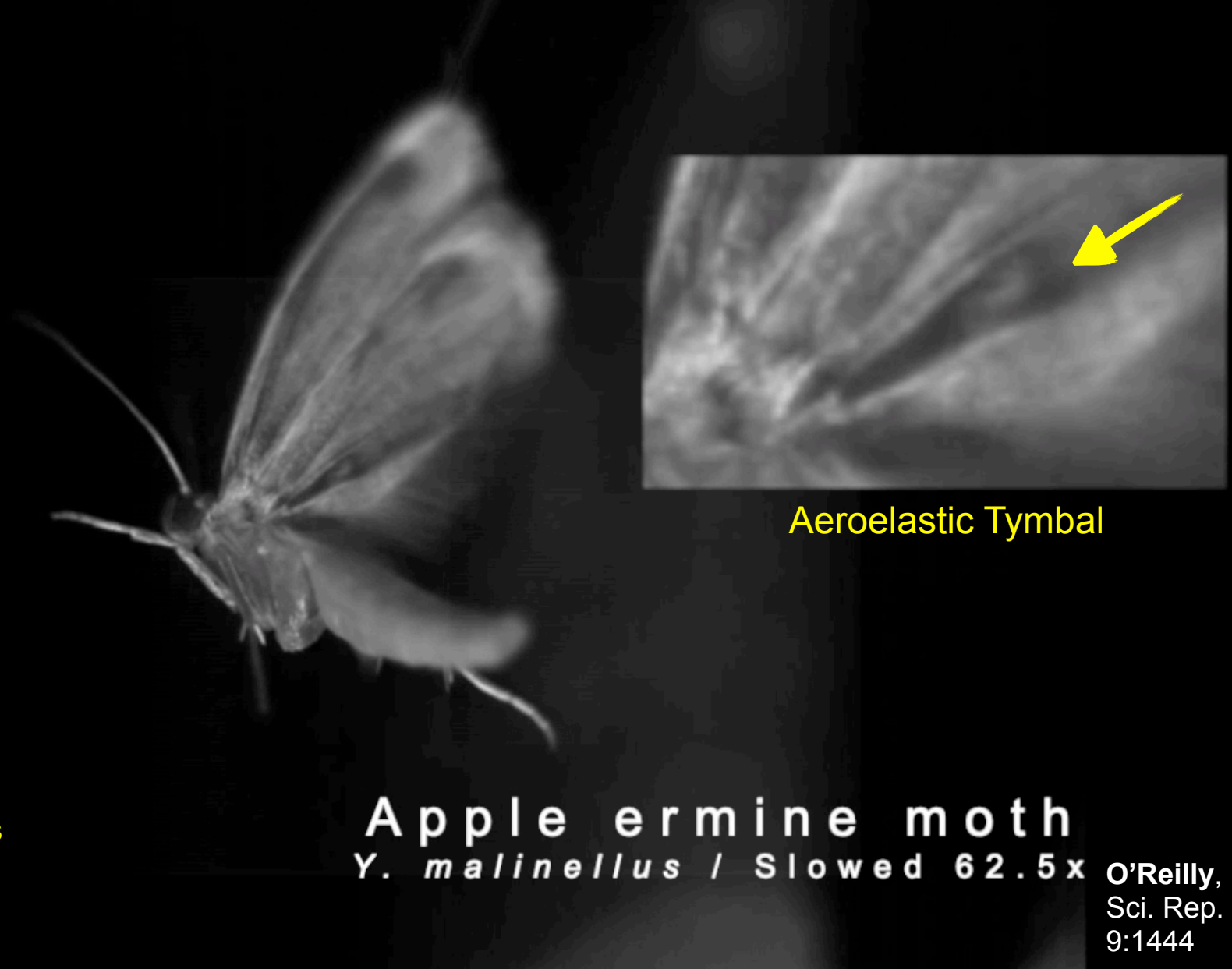
Apple ermine moth
Y. malinellus / Slowed 62.5x

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Aeroelastic Tymbal
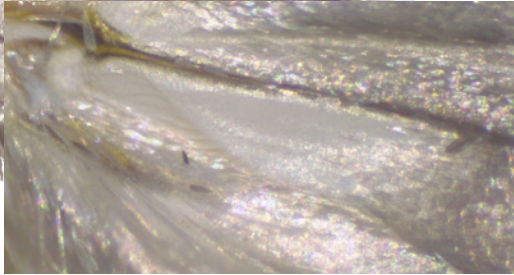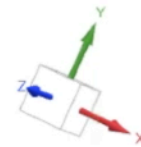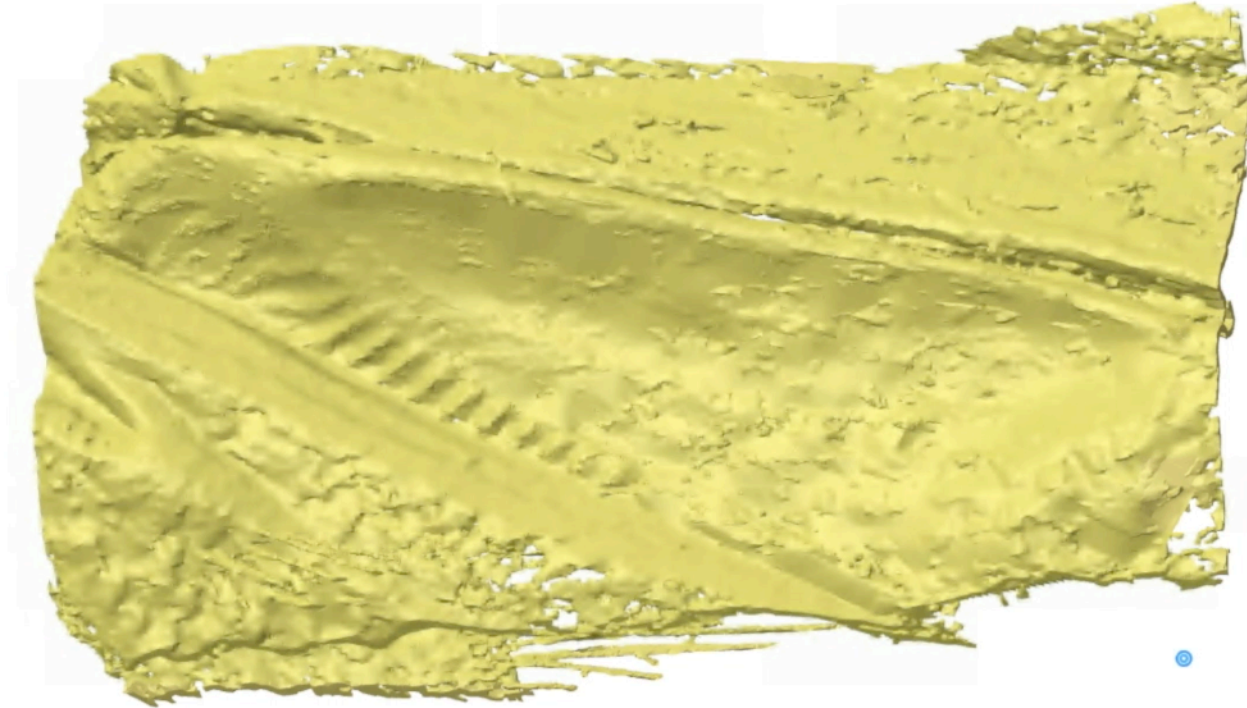

micro-CT scan
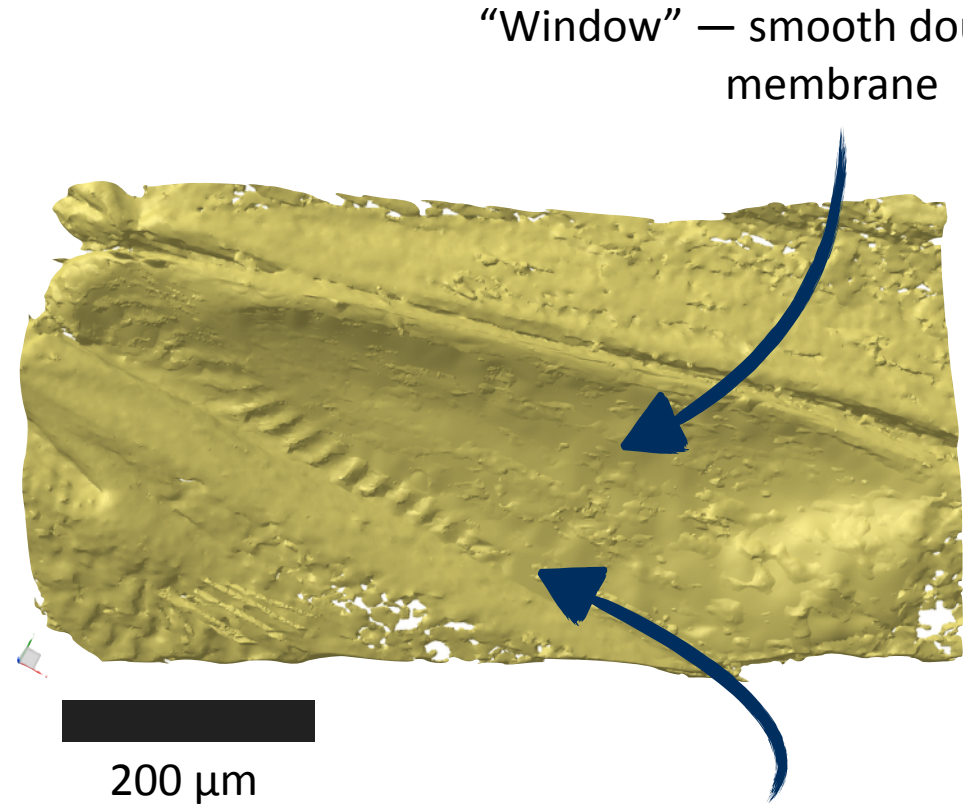
"Window" — smooth doubly curved membrane

Striated band

200 µm
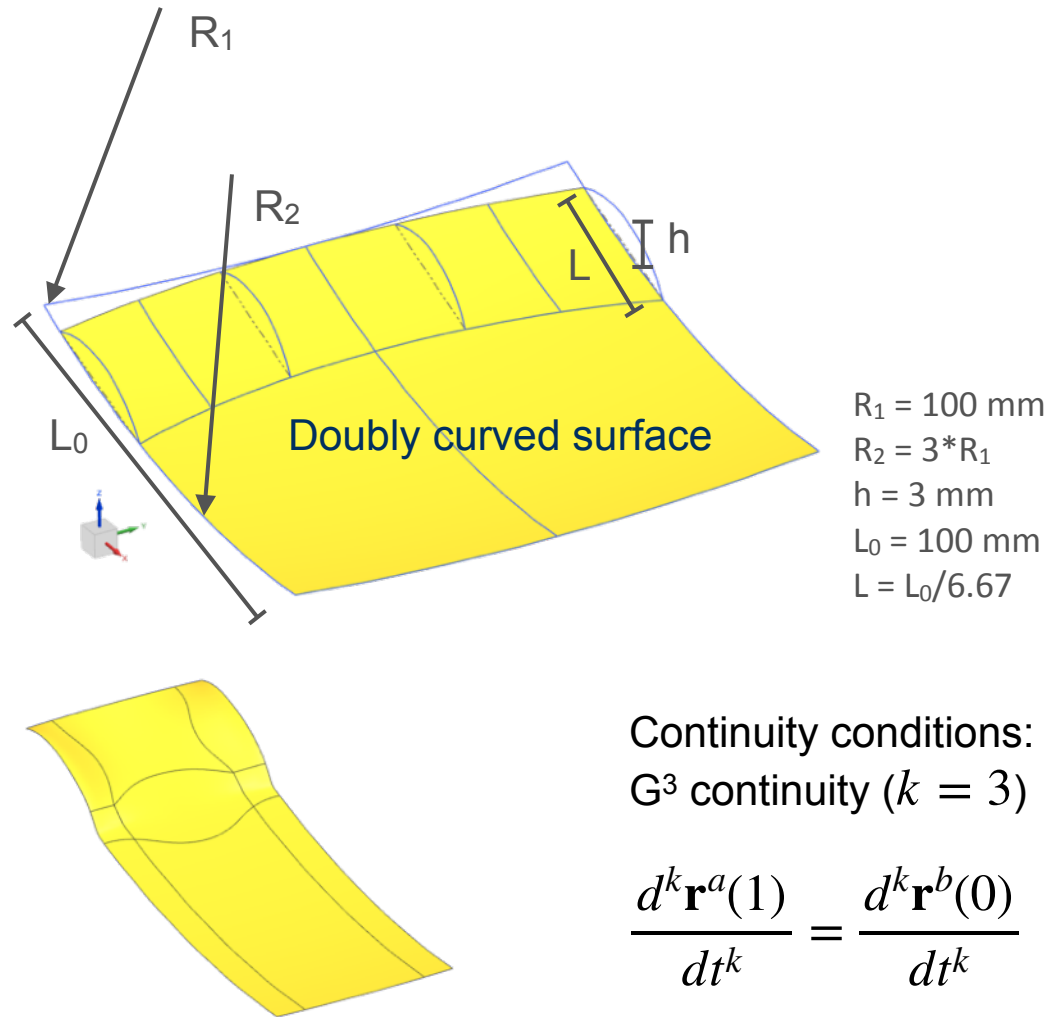
Sound from bat detector
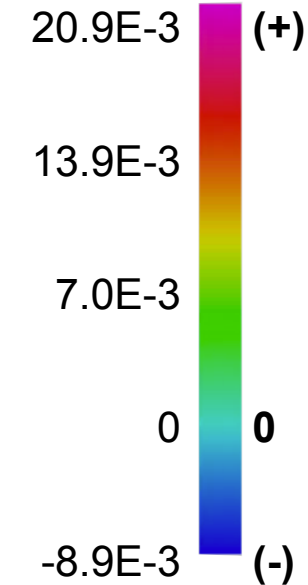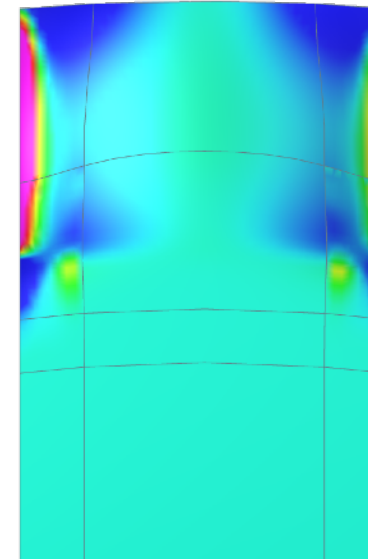
Aeroelastic Tymbal

Sound from bat detector

Bioinspired Model — Single Stria

R_1

R_2

h

L

L_0

Doubly curved surface

$R_1 = 100$ mm
$R_2 = 3*R_1$
$h = 3$ mm
$L_0 = 100$ mm
$L = L_0/6.67$

Continuity conditions:
G³ continuity ($k = 3$)

$$\frac{d^k \mathbf{r}^a(1)}{dt^k} = \frac{d^k \mathbf{r}^b(0)}{dt^k}$$

Gaussian Curvature, K

20.9E-3 (+)
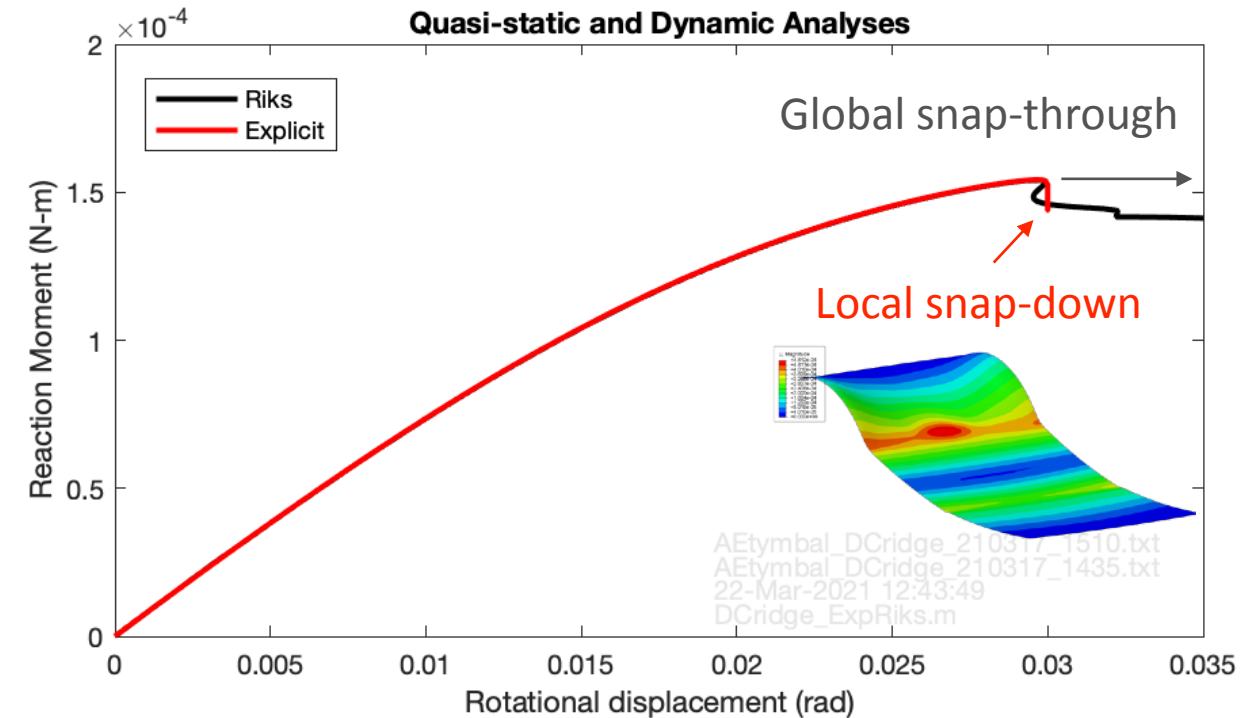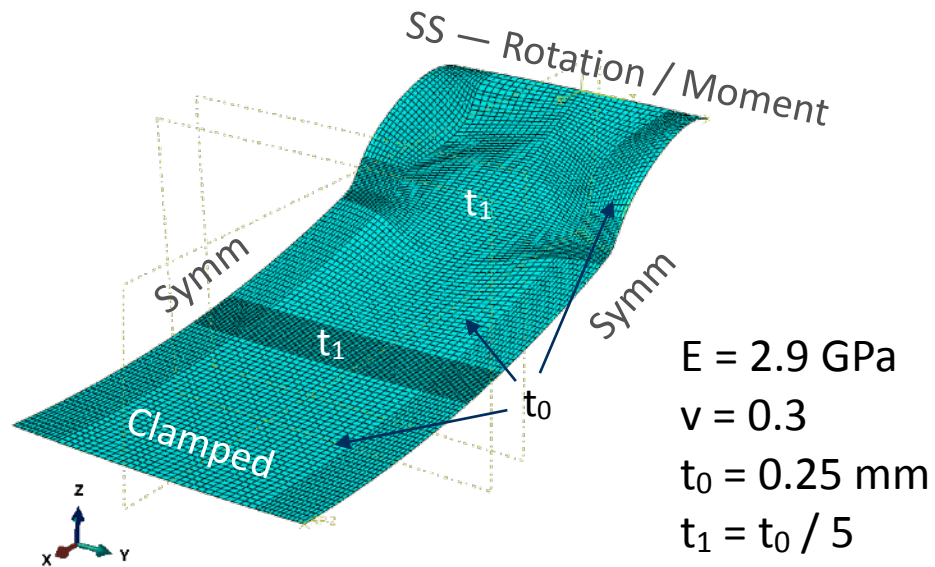
13.9E-3

7.0E-3

0 **0**

-8.9E-3 (-)

$$K = \frac{LN - M^2}{EG - F^2}$$

$E, F, G,$: First fundamental form coefficients (metric)

$L, M, N,$: Second fundamental form coefficients (curvature)

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Nonlinear Analysis

$E = 2.9$ GPa
$v = 0.3$
$t_0 = 0.25$ mm
$t_1 = t_0 / 5$

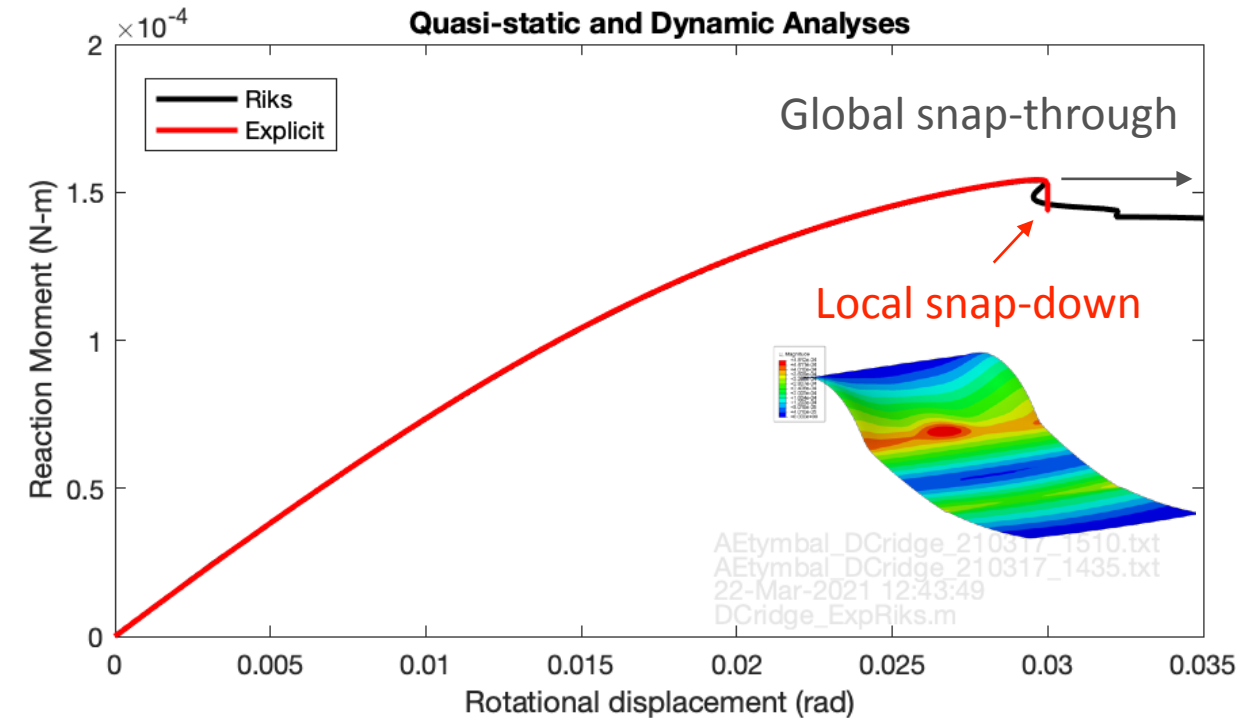

The structure shows a global and local unstable behaviour under **displacement control**.
Under **force control** the system would buckle globally.

Nonlinear Analysis

Resembling Global Buckling

Equilibrium Path: von Misses truss

Snap-through

Quasi-static and Dynamic Analyses
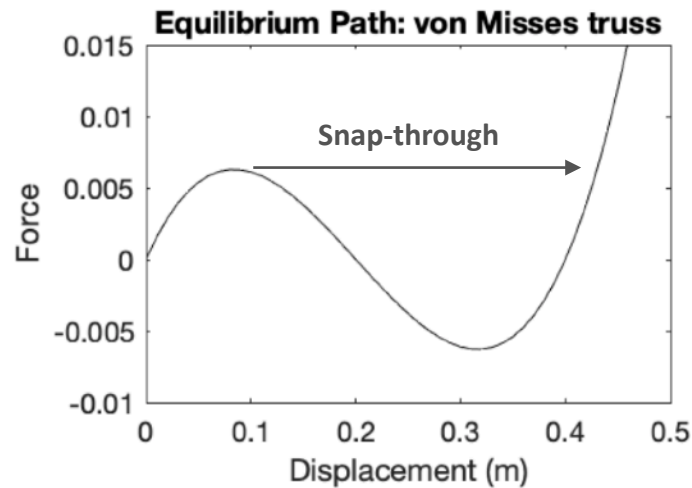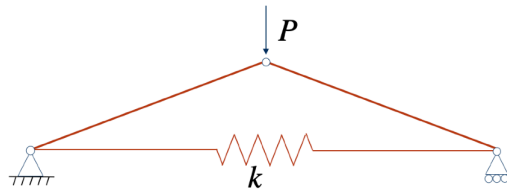
Global snap-through

Local snap-down

Riks
Explicit

The structure shows a global and local unstable behaviour under **displacement control**.
Under **force control** the system would buckle globally.

Bioinspired Model — Multi-striae
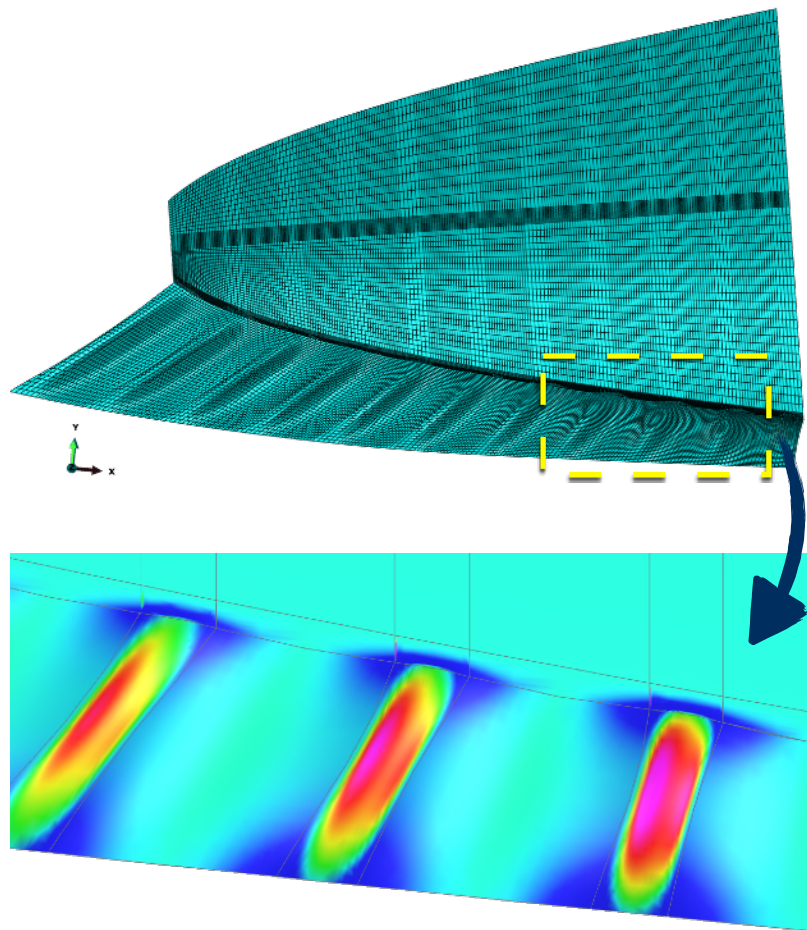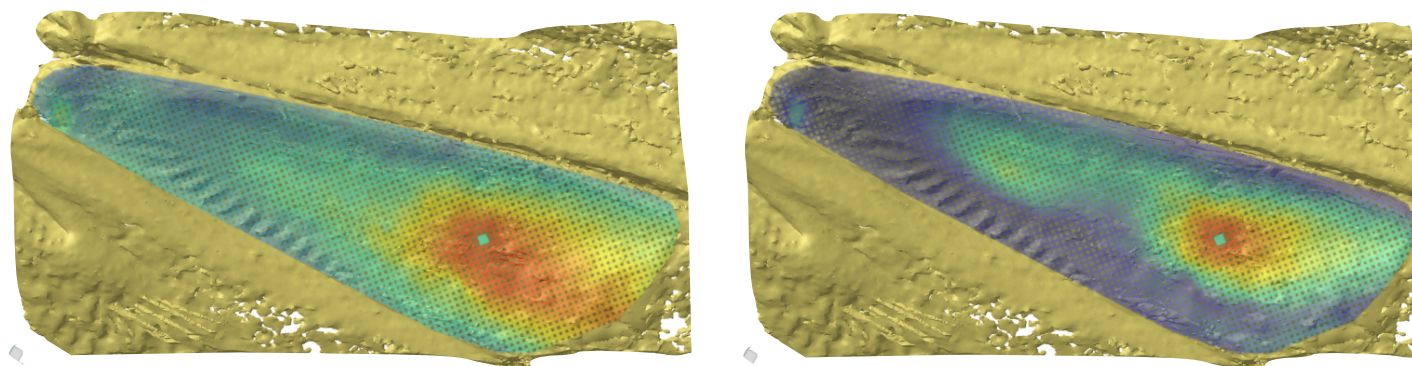

Gaussian Curvature, K

Tymbal Resonance — Laser Doppler Vibrometry

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Bioinspired Model — Multi-striae
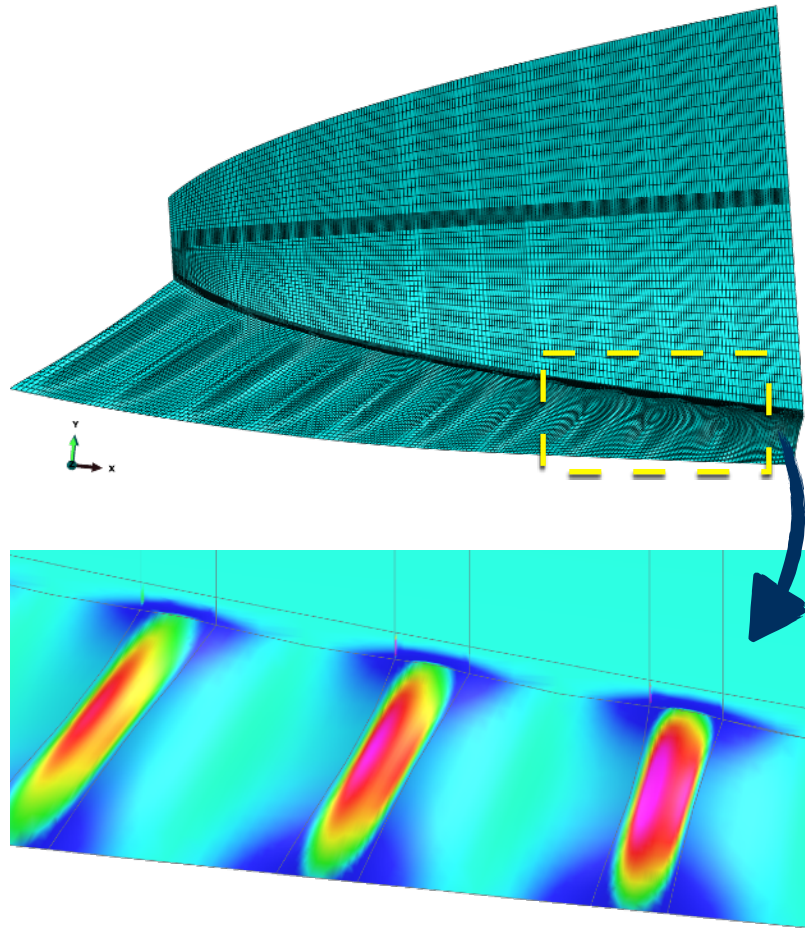
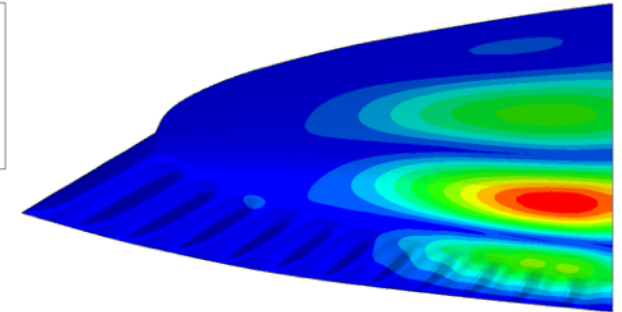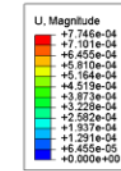

Exterior Surface — ACIN3D3
(infinite acoustic elements)
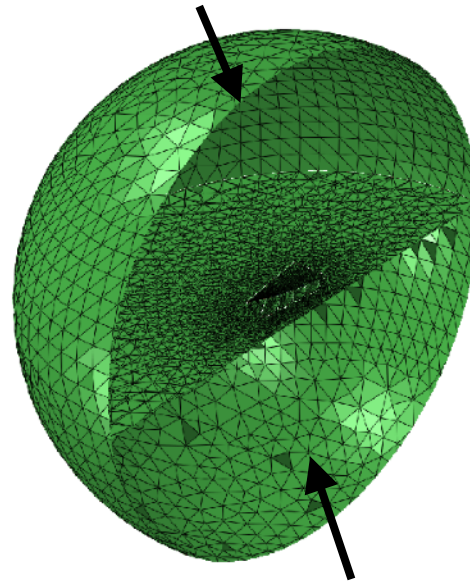
Interior volume — AC3D4
(finite acoustic solid elements)

Steady-state harmonic analysis

Gaussian Curvature, K

Structural-Acoustic Coupling

Structural-Acoustic Coupling

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Summary

Dynamic snap-buckling is likely the mechanism of sound production found in aeroelastic tymbals.

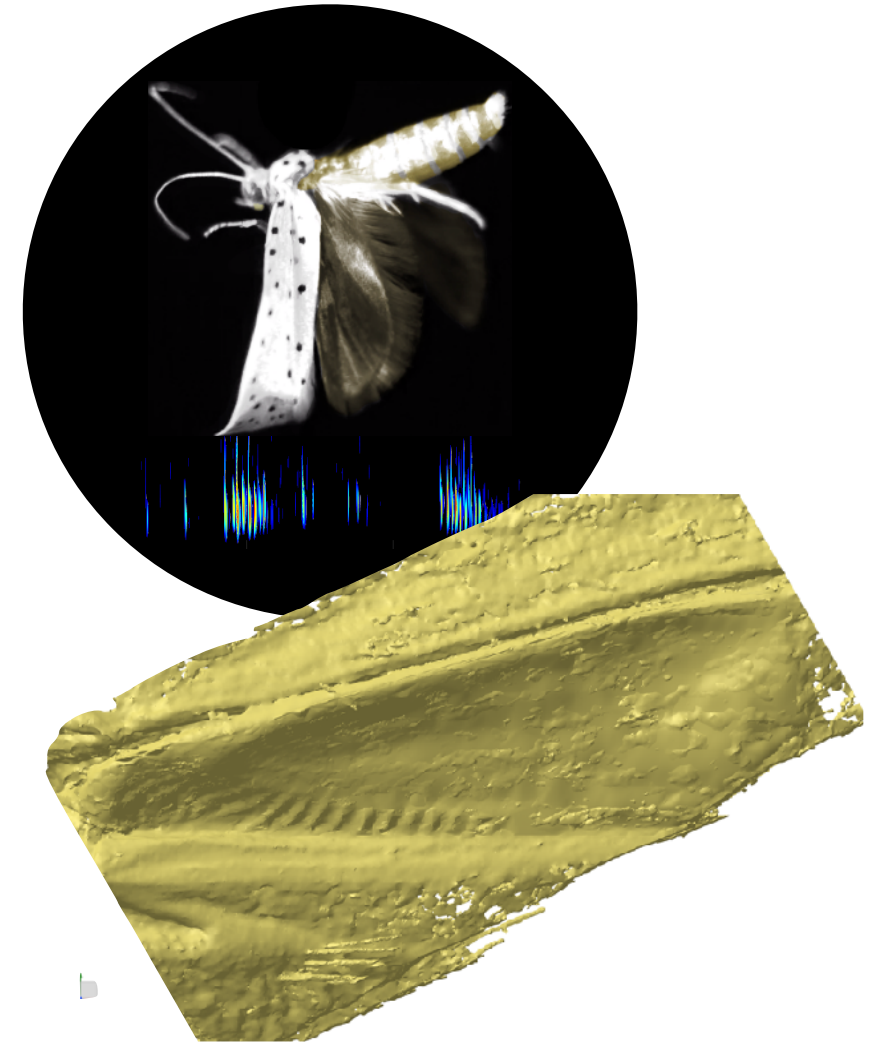Our bioinspired model supports the hypothesis that elastic instabilities at the interface trigger the sound production, while the vibrating window membrane serves as the main acoustic source.

Multi-functional non-linear biological structures

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Thank you!

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