Jet installation noise reduction using a flexible trailing edge

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Outline of the presentation

1. Introduction
2. Experimental setup
3. Results
   - Flexibility effect on far-field noise
   - Jet-plate distance effect
4. Conclusions

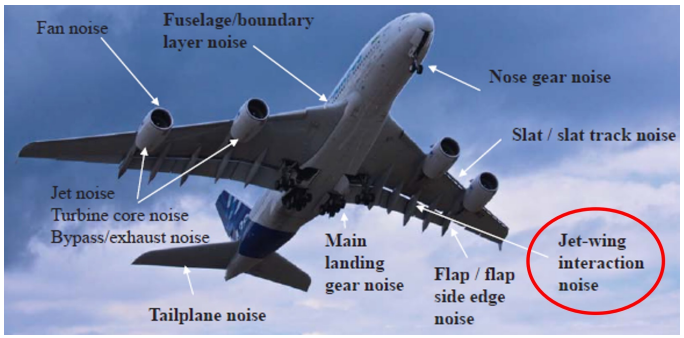
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Installed jet noise

Stronger jet-airframe interaction for new HBPR & UHBPR engines

- concerns for noise emissions
- installation effects must be mitigated



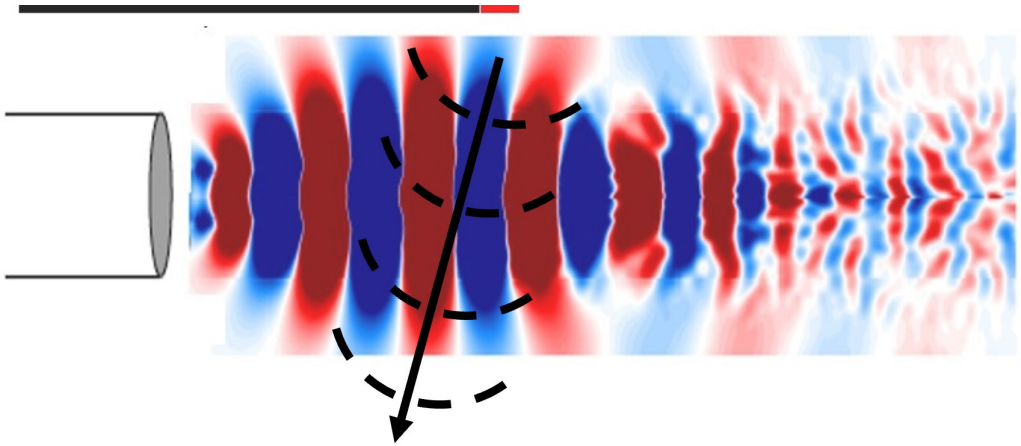
EU DJINN project

Conceive NRT through

- improved physical understanding
- flow modelling
- prediction & control tools

Aim of 5 dB noise reduction of installed jet noise

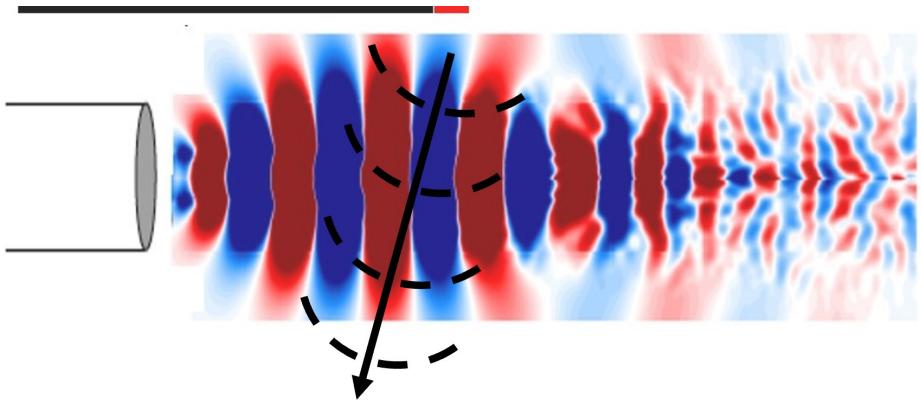
Jet-Surface Interaction (JSI) noise



Noise generation mechanism

- Scattering of wavepackets by the trailing edge (Cavalieri *et al.* 2014, Piantanida *et al.* 2016, Nogueira *et al.* 2017)
- Well described by linear models
  - Far-field noise estimated via Wiener-Hopf estimation from near-field pressure calculated by PSE (Faranosov *et al.* 2019)

JSI noise reduction approach



Noise reduction strategies

- Reduce wavepacket amplitude
- 'Break' or reduce the dipole source efficiency at the TE

Passive devices

Chevron, tabs

- mostly limited to free jets (Zaman *et al.* 2011)

Active devices

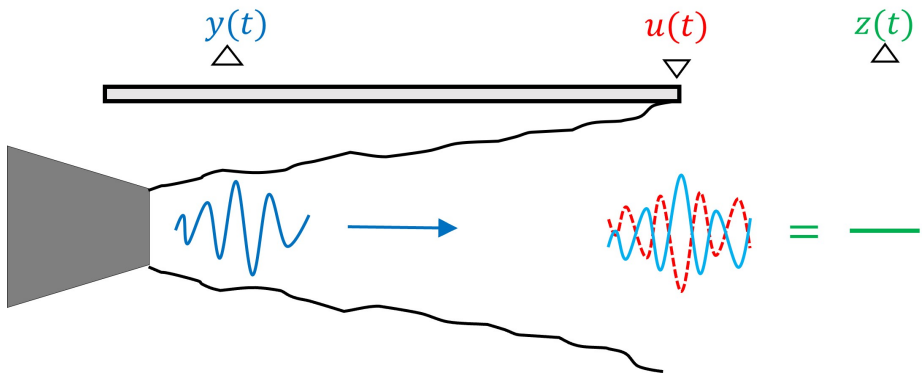
Closed-loop harmonic control

- (Bychkov *et al.* 2019, Kopiev *et al.* 2020)

Pprime's task within DJINN

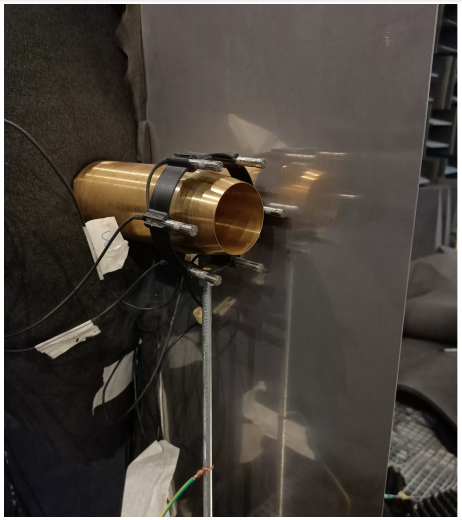
Develop lab-scale control demonstrator

Linear-reactive control strategy (Sasaki *et al.* 2018, Maia *et al.* 2021)

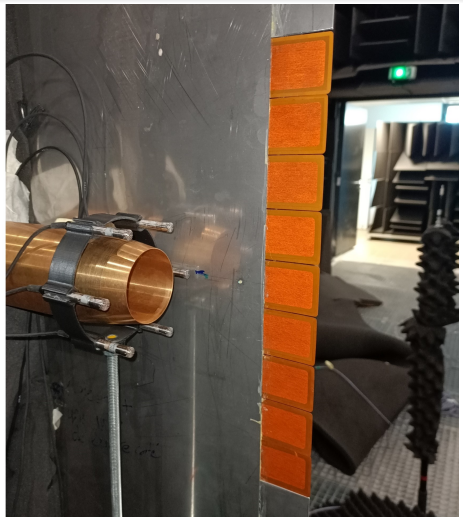


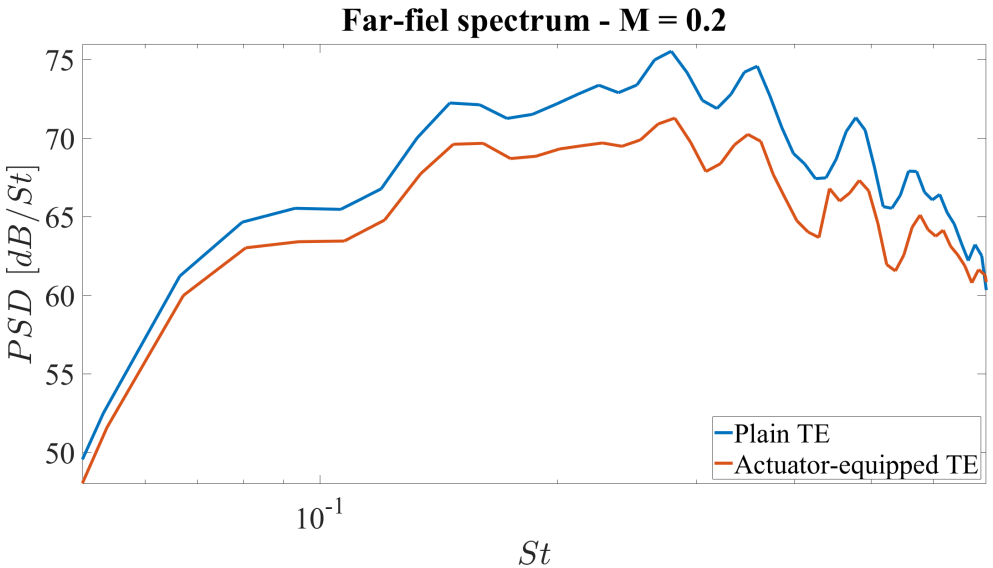
- Near-field sensors
- Actuators at the TE
- Far-field observer

Plain rigid plate vs actuator-equipped plate



VS





Actuator-equipped plate

Significant broadband noise reduction

- up to 5 dB
- Effect of flexible TE?

Spin-off research activity

Explore flexible TE as passive NRT for JSI noise

Parametric analysis in a systematic fashion addressing the effect of

- different lengths of the flexible insert
- different flow conditions
- different flexible materials
  - different stiffness
- different flexible plate geometry
  - one-piece flexible TE
  - snipped flexible TE
    - additional degree of freedom along the span
    - makes the plate 'permeable' to the jet pressure fluctuations

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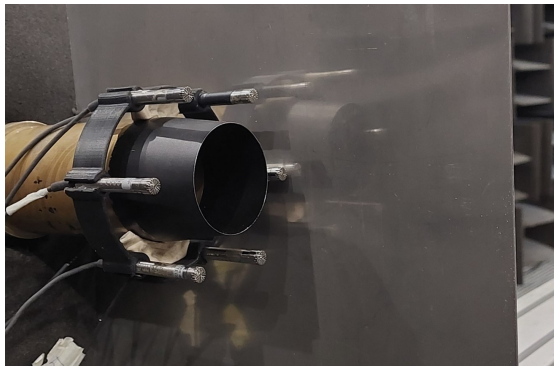
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Experiments at *Bruit & Vent* facility



(a) Plain rigid plate



(b) One-piece flex plate



(c) Snipped flex plate

- Plate position
  - TE at $x/D = 2$, jet-plate distance $H = 1D$, $H = 1.5D$
- Near-field mics
  - 6-mic azimuthal array at $x = 0D$ & $r = 0.9D \longrightarrow m = 0$ mode
- Far-field mics at TE axial position at $r = 26D$ from TE on shielded & unshielded sides
- Jet flow conditions $M = [0.15, 0.75]$
- Flexible length
  - $l/D = [0.1, 1.2]$

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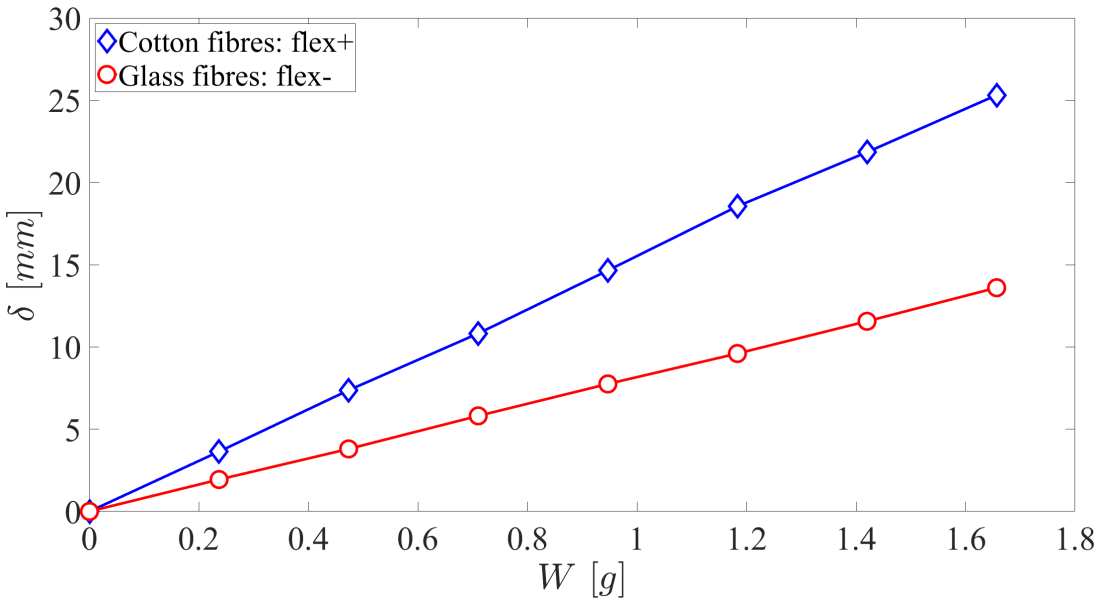
Flexible material characterisation

Two types of composite materials: epoxy matrix with

- (i) cotton fibres (flex+), (ii) glass fibres (flex-)

Stiffness characterisation

- Slender slice of material ($l/h \approx 10$)
- Cantilever beam loaded with a known mass $W \longrightarrow \delta$
  - Bernoulli-Euler theory to evaluate E from $\delta \Longrightarrow E = \frac{mgl^3}{3\delta I}$

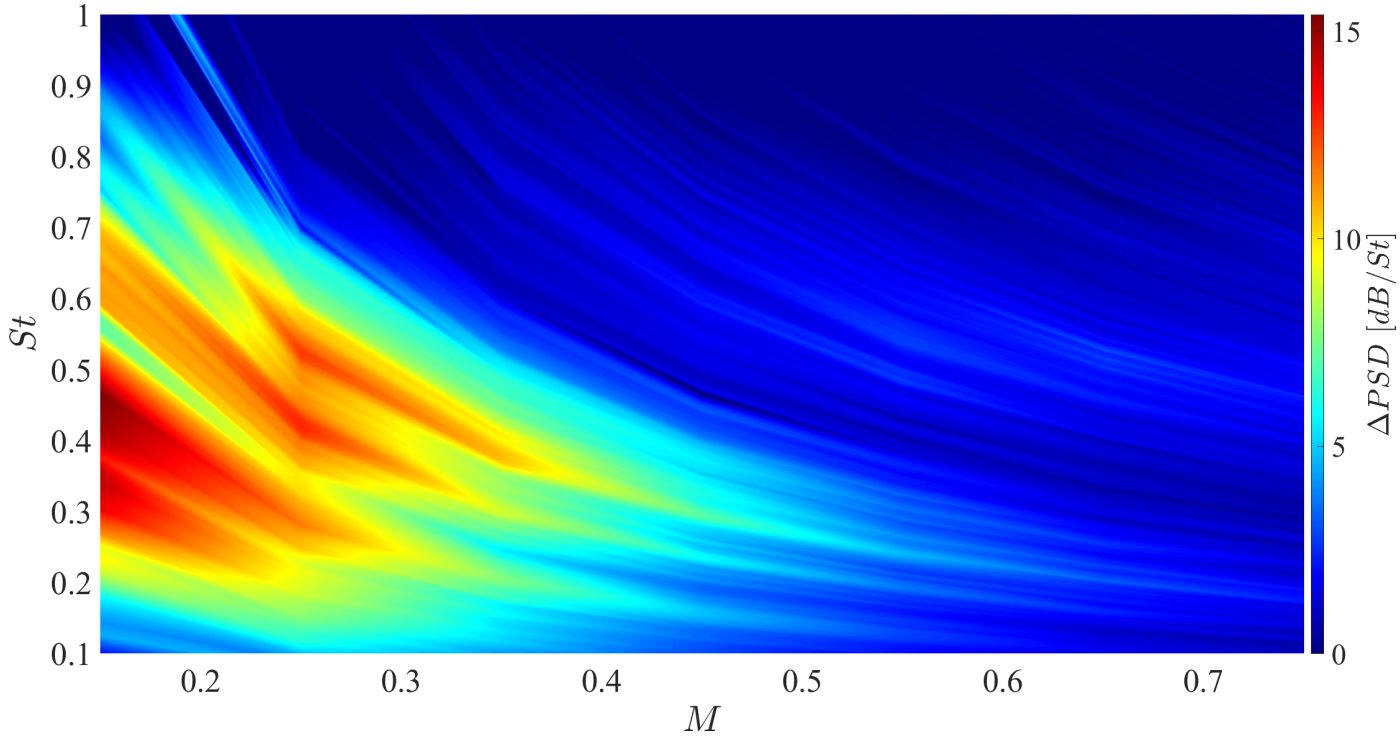


Linear response of the material

- flex+: $E = 6.1 \cdot 10^9 Pa$
- flex-: $E = 1.1 \cdot 10^{10} Pa$

JSI noise identification: far-field, shielded side $H = 1D$

$$JSI\,[dB/St] = PSD_{installed} - PSD_{isolated}$$



JSI noise dominant for

- $St = [0.1, 0.8]$
- low M
  - Ascribed to relative dominance of direct/scattered sound

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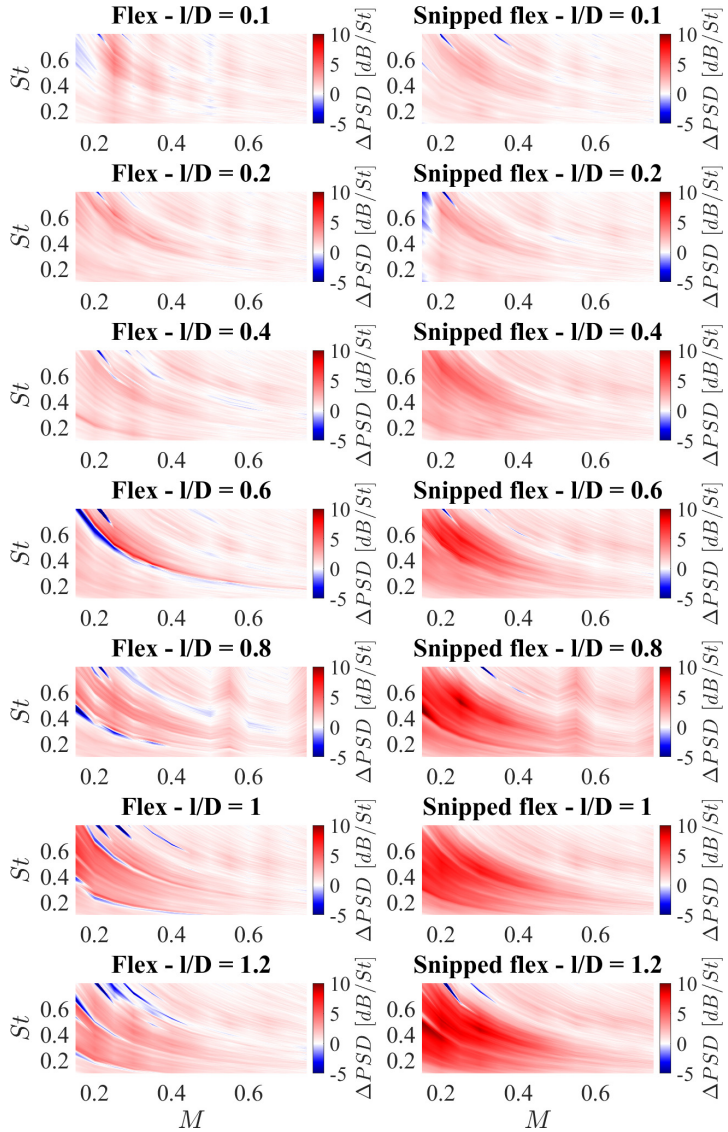
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ΔPSD map, flex+



Flexibility effect $[dB/St]$

$$PSD_{rigid} - PSD_{flexible}$$

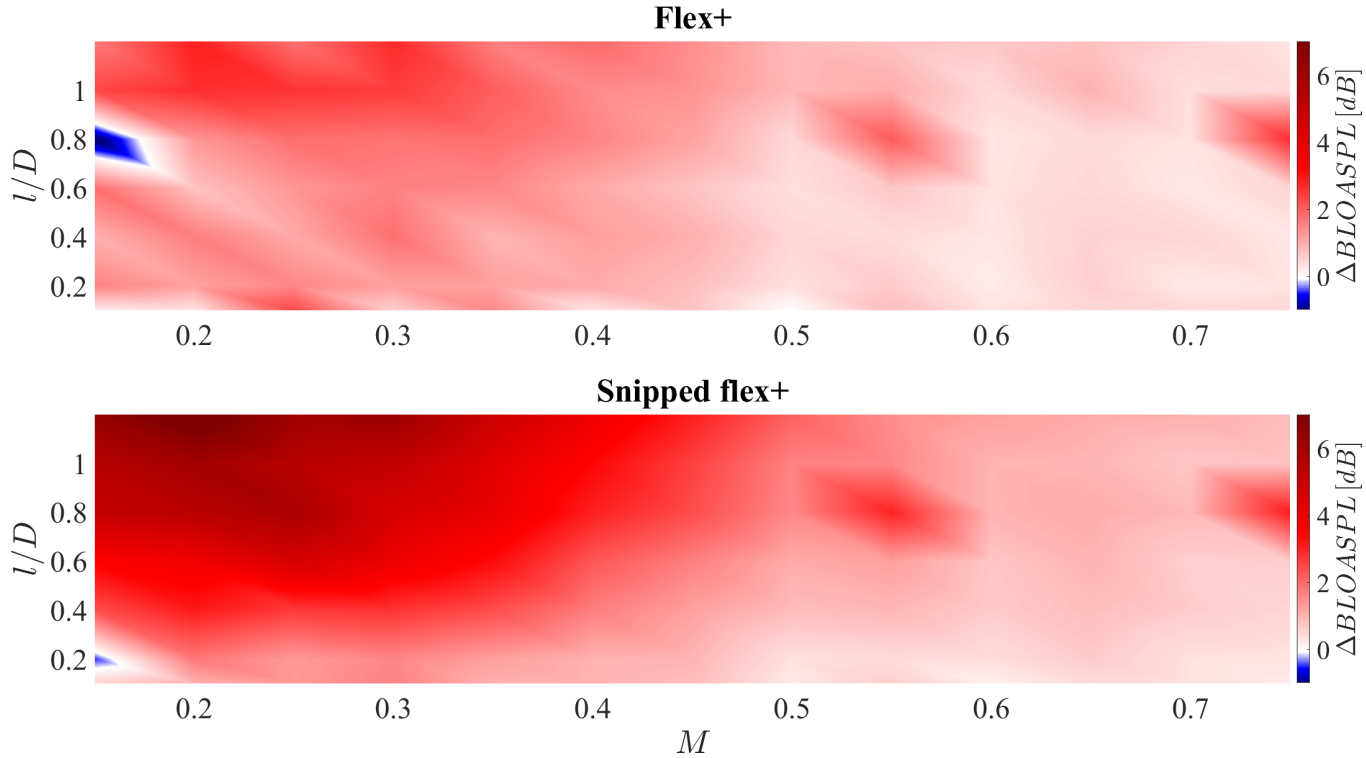
Flexibility does reduce JSI noise

- More significant for $l/D \uparrow$
  - Maximum reduction for $l/D \approx 1$
    - Size of the large-scale coherent structures most efficient for noise emissions
- More significant for $M \downarrow$
- Snipped geometry more efficient than one-piece geometry
  - Snips remove peaks related to vibration modes of the material

$\Delta BLOASPL$ for $St = [0.1, 0.8]$

Flex+ material

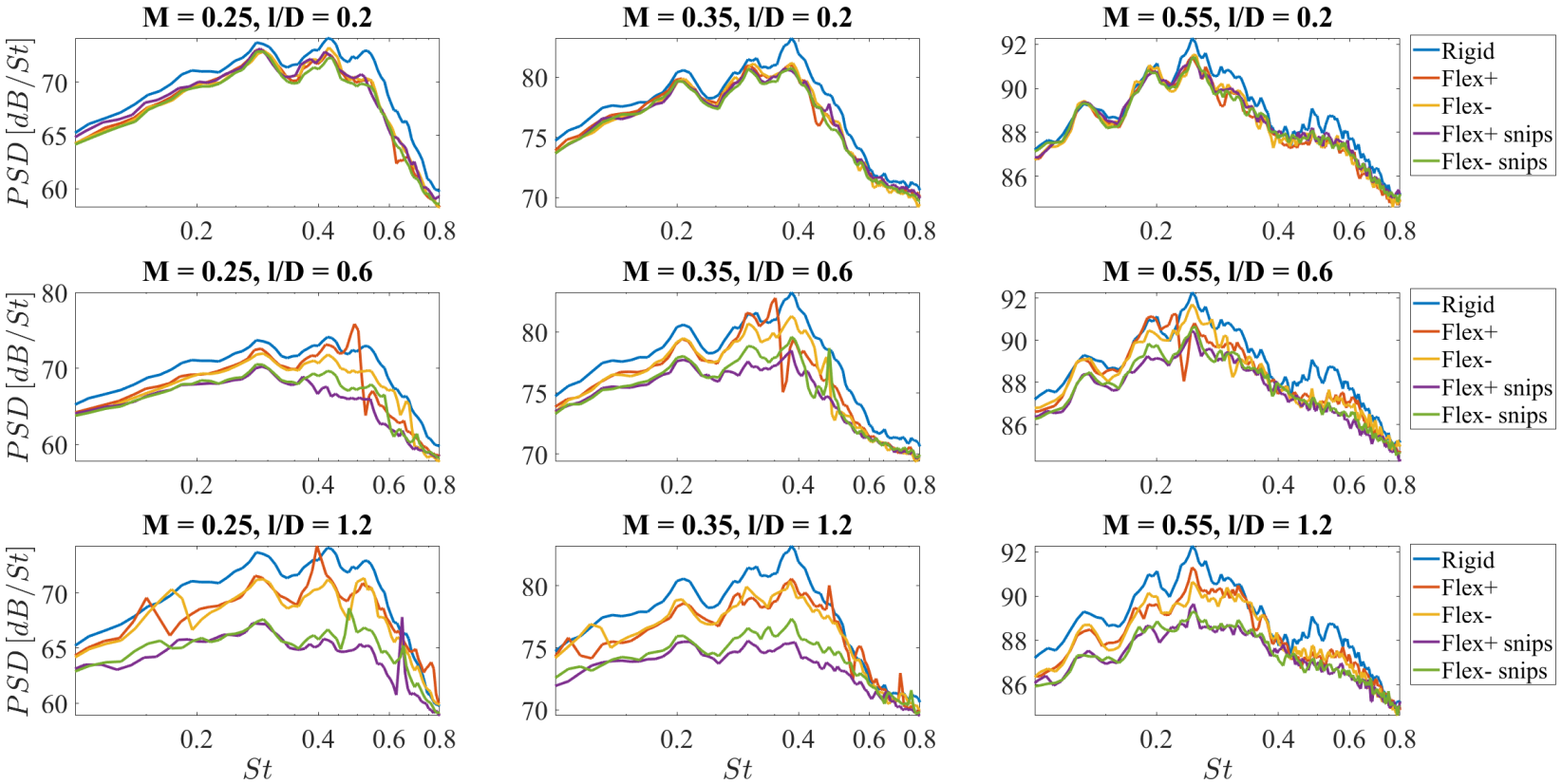
$$\Delta BLOASPL = BLOASPL_{rigid} - BLOASPL_{flexible}$$



Snipped geometry provides up to 7.5 dB of noise reduction

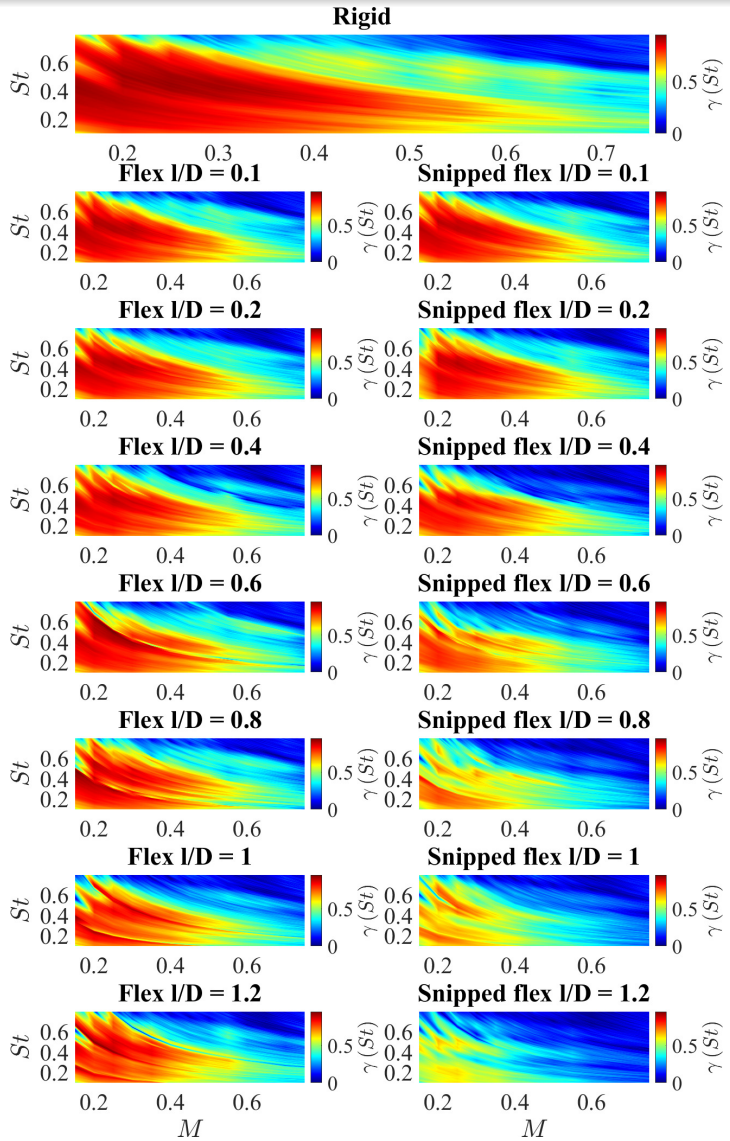
- low M & high l/D

Stiffness effect on the noise reduction



- Evidence of the resonance suppression due to snips
- Slightly larger noise reduction for flex+
  - Less stiff material provides larger reduction

Far-field (FF)-$m = 0$ coherence maps, flex+



Objective

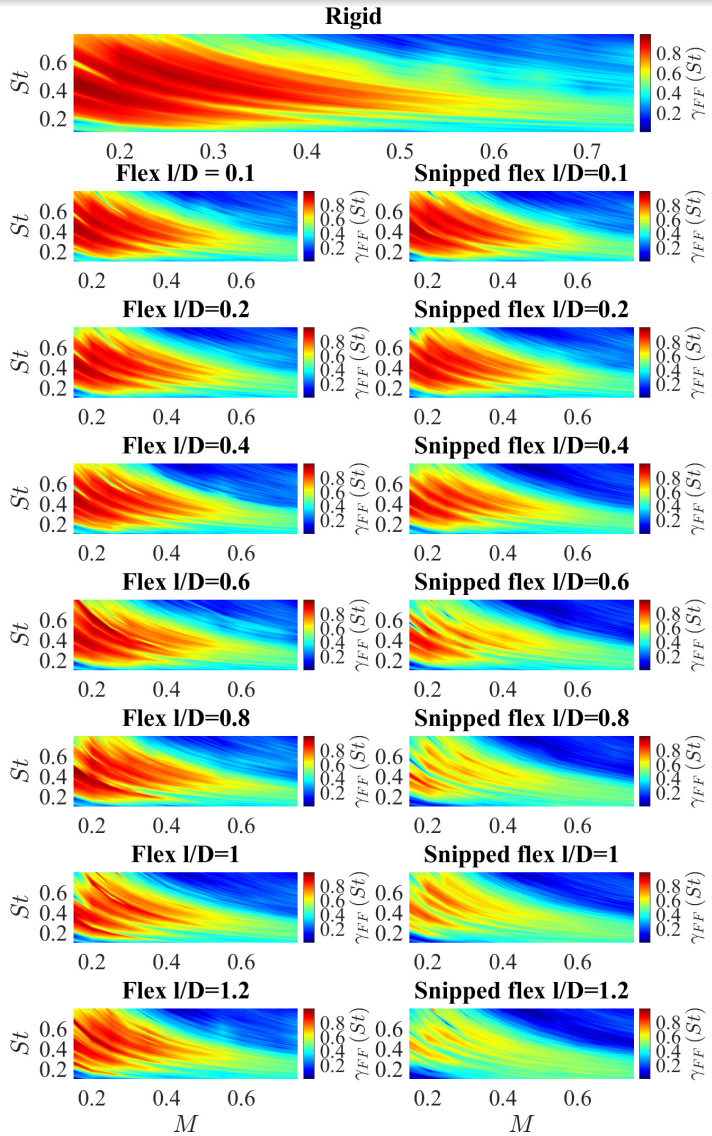
Explore physical mechanism underlying noise reduction

Flexibility reduces coherence level

- Exactly in the $M - St$ region where JSI noise was dominant
- More significant for $l/D \uparrow$ & $M \downarrow$
- More significant for snipped geometry

Flexibility abates the efficiency of the dipole source at TE

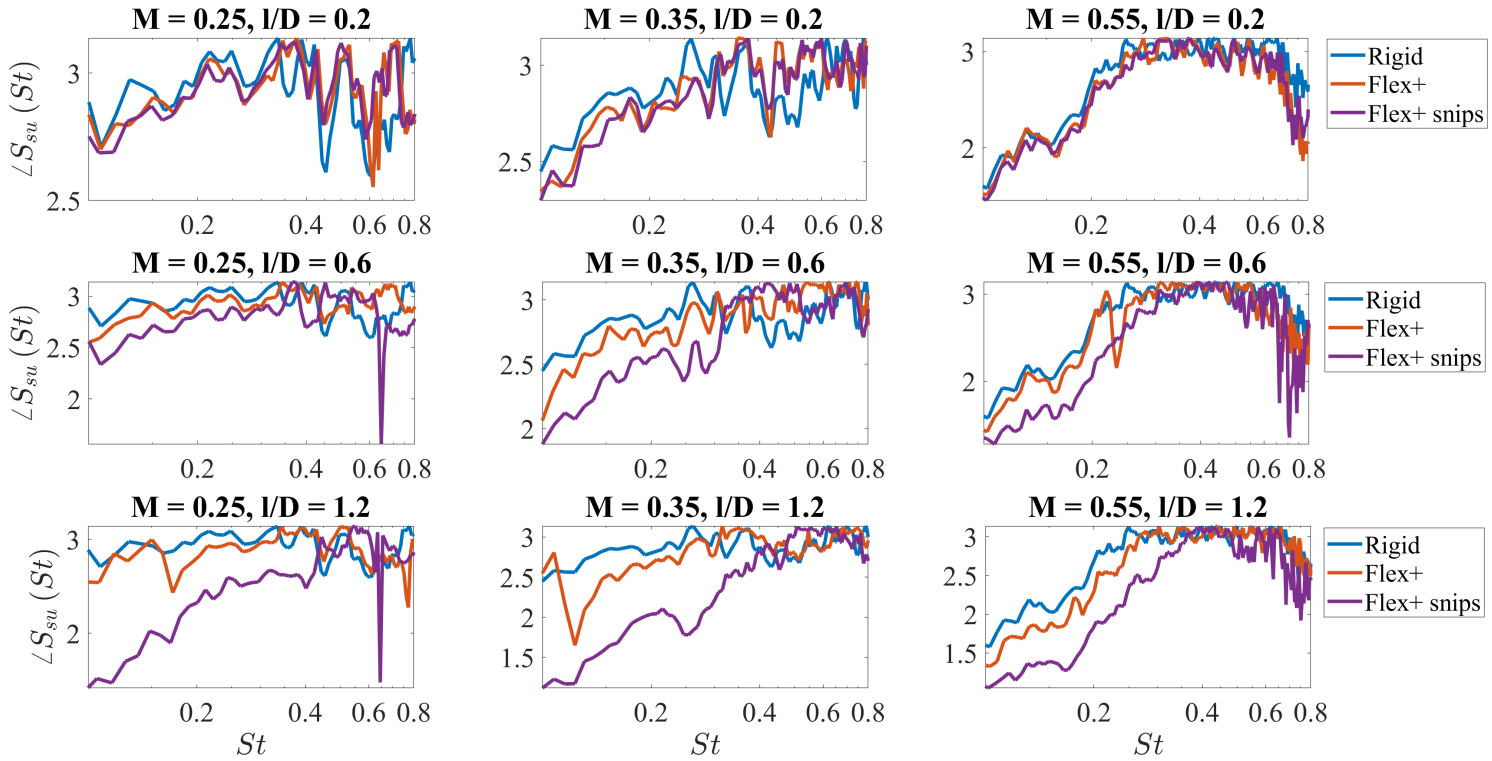
FF coherence maps: shielded vs unshielded, flex+



Flexibility...

- reduces far-field coherence between shielded & unshielded sides
  - indication of the decrease of the dipole efficiency at the TE
- changes phase relation between shielded & unshielded sides
  - (next slide)

Far-field phase: shielded vs unshielded, flex+



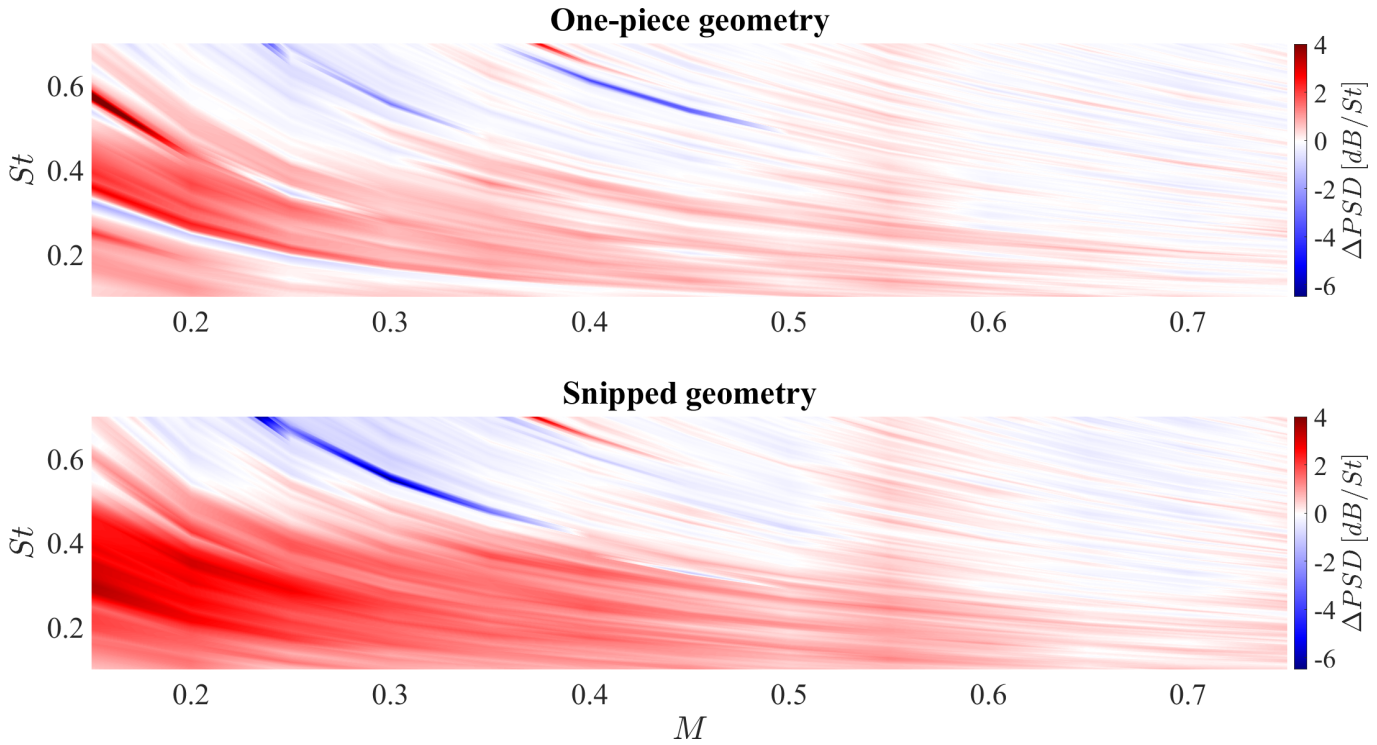
Departure from the out-of-phase relation found in the rigid-plate configuration

- Phase value decreases for $l/D \uparrow$
  - More significant for the snipped geometry
    - Consistent with the noise reductions observed

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ΔPSD map, flex+ $l/D = 1$, $H = 1.5D$



Noise reduction due to flexibility less significant

- 11 dB for $H = 1D$ against 4 dB for $H = 1.5D$
  - Lower significance of JSI noise for $H \uparrow$
    - Lower flexibility effectiveness on the TE noise source

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Final remarks

Flexible TE explored as NRT for JSI noise

Flexible TE does reduce jet installation noise

- More significant for larger lengths of the flexible insert
- Larger reduction for low M
  - For more 'realistic' configurations reduction much lower
- Slightly larger noise reductions for the most flexible material
- Snipped geometry more efficient than the one-piece geometry
  - Larger noise amplitude reduction
  - Suppression of resonant peaks related to vibration modes

Physical mechanism underlying noise reduction

- Reduction of the efficiency of the dipole TE noise source

Unlike chevrons, no thrust penalisation

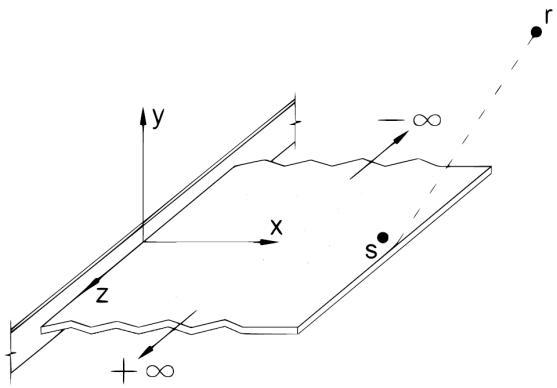
- Possible lift penalisation should be verified...

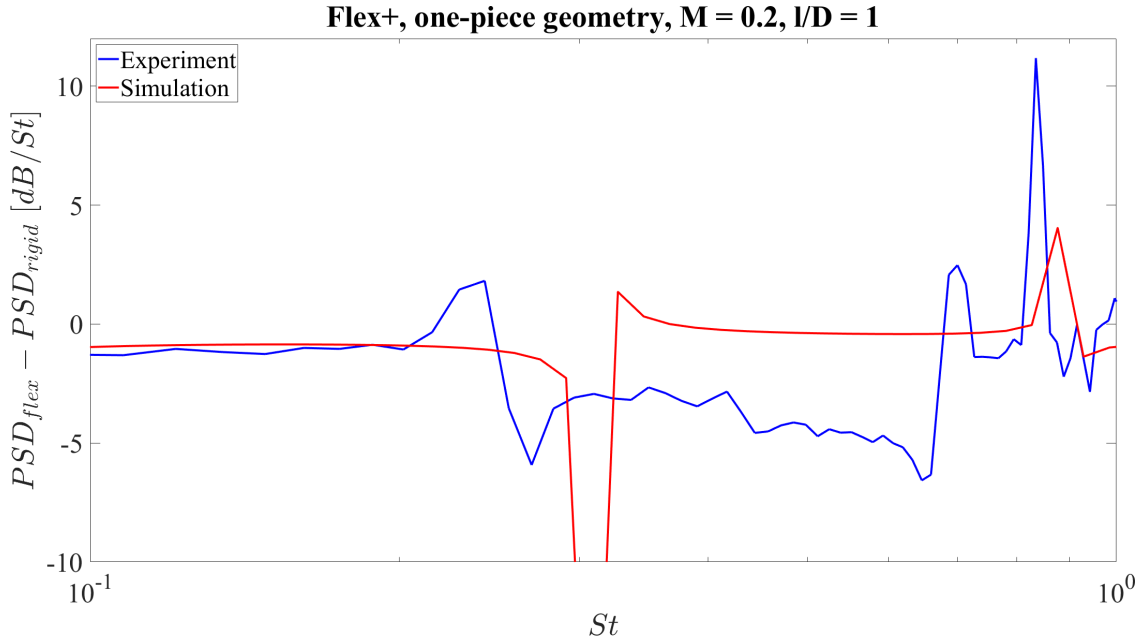
Future developments

Underway activities

Simple model for flexibility effect (Nilton *et al.* 2022)

- EIG problem for plate vibration modes
- Pointwise source at TE
- Solve fluid-structure interaction problem
- Far-field pressure via BEM





Future developments

Foreseen activities

Push a bit further the simplified model by considering

- A wavepacket noise source
- More complex flexible plate geometries
  - Snipped flexible geometry
  - From 2D to 3D
- Different values of l/D and M to see if experimental trends are matched

Thank you for your attention

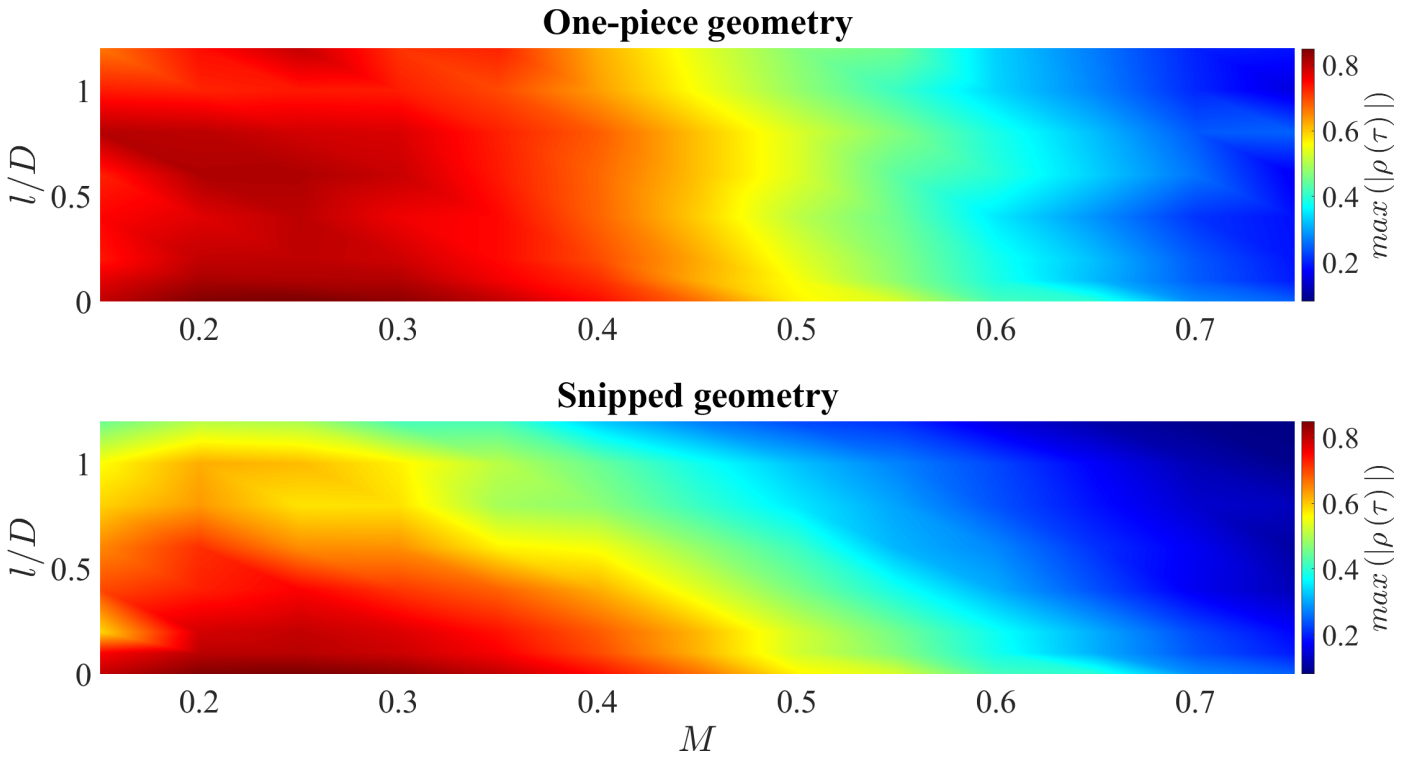


Questions/comments?

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BACKUP SLIDES

FF-$m = 0$ cross-correlation coefficient peak map, flex+



Global picture of the NF-FF correlation reduction due to flexibility

- Most significant correlation reduction in the low M-high l/D region