TONAL BROADENING IN CO-AXIAL CONTRA-ROTATING ROTORS

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Outline

- Introduction
- Aim and objectives
- Experimental set-up
- Tonal spectral broadening in co-axial contra-rotating rotors
- Role of tip vortex meandering in propeller interaction noise
- Preliminary modelling
- Conclusions

Introduction (1/2)

- Growth of multi-rotor drones, Unmanned Aerial Vehicles (UAVs), and remotely piloted aircraft systems (RPAS)
  - FAA predicts 858,000 drones by 2026
- Payload requirements in the drone delivery market ⇨ Co-axial rotors
- Additional noise generation mechanisms relative to isolated rotors

https://www.ft.com/content/66487d88-a6b3-4e46-9b8a-00e38e93d3af

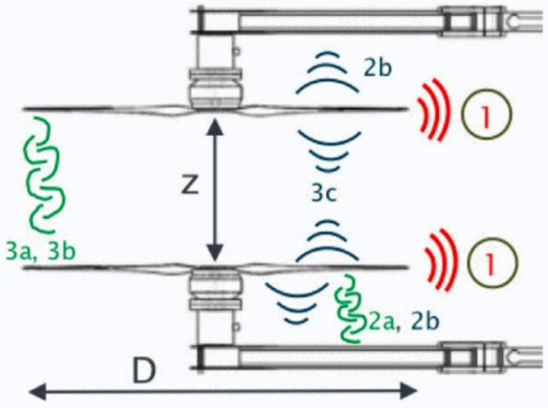
https://wattsinnovations.com/

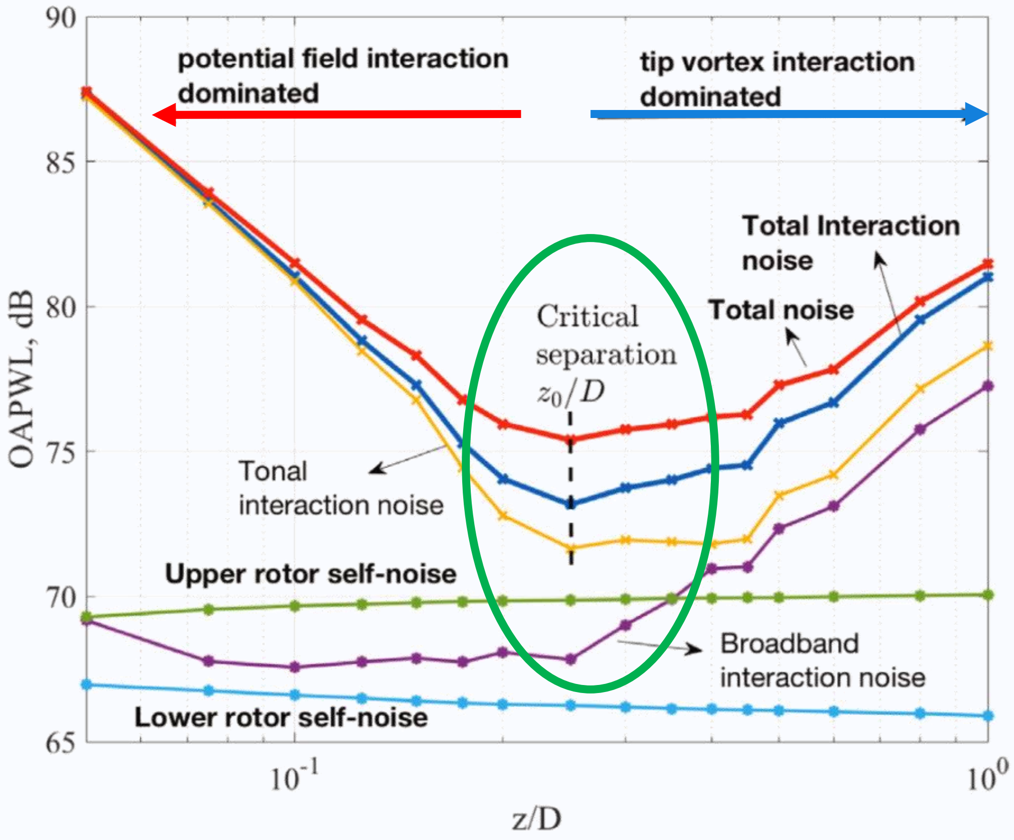
https://www.ehang.com/

Introduction (2/2)

- Sources of noise in co-axial contra-rotating rotors

1. Rotor self-noise
   1a. Volume displacement (T)
   1b. Steady loading (T)
   1c. Blade-vortex inter. (BVI) (T)
   1d. Blade-wake inter. (BWI) (BB)
   1e. Trailing edge noise (BB)
2. Rotor installation noise
   2a. Boom-wake-rotor & rotor-wake-boom inter. (BB)
   2b. Boom-rotor & rotor-boom potential field inter. (T)
3. Rotor-rotor interaction
   3a. Rotor-wake-rotor inter. (BB,T)
   3b. Tip vortex - rotor inter. (BB,T')
   3c. Rotor-rotor potential field inter. (T)





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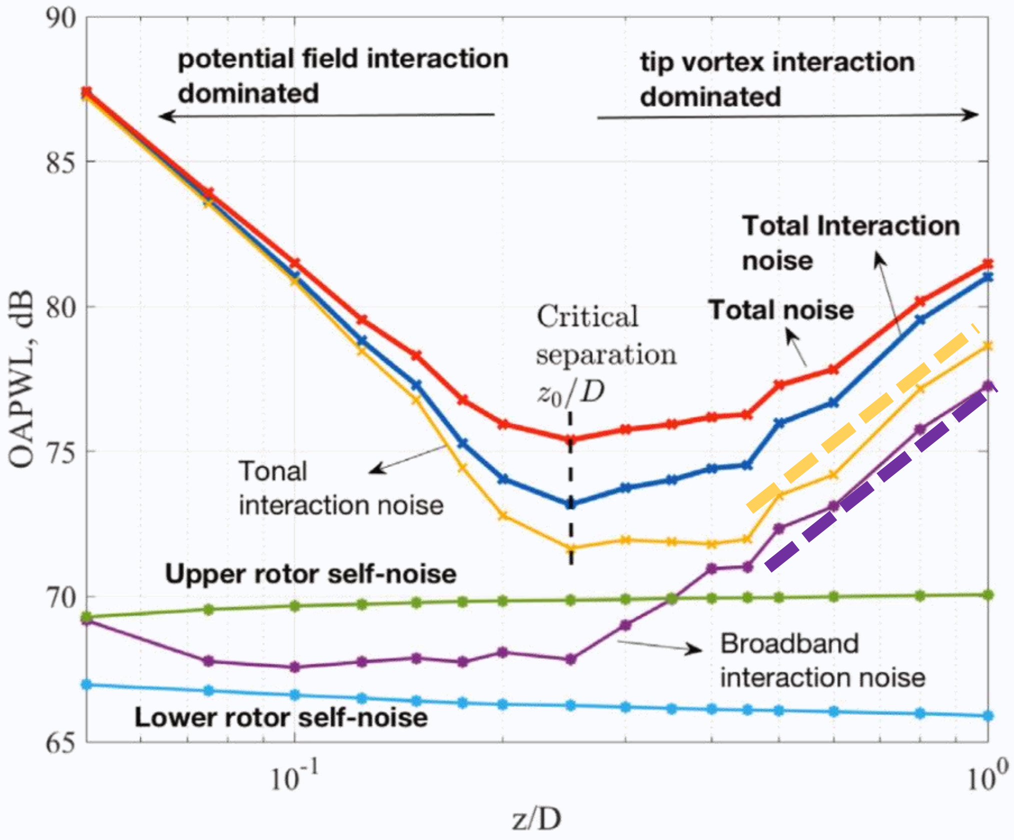
Aims and objectives

Investigate the increase in tonal and broadband noise for $z/D > z_0/D$

- Causes of tonal broadening

Characterise the role of tip vortex meandering in propeller interaction noise

Develop a model to predict the noise generated by the top vortex meandering



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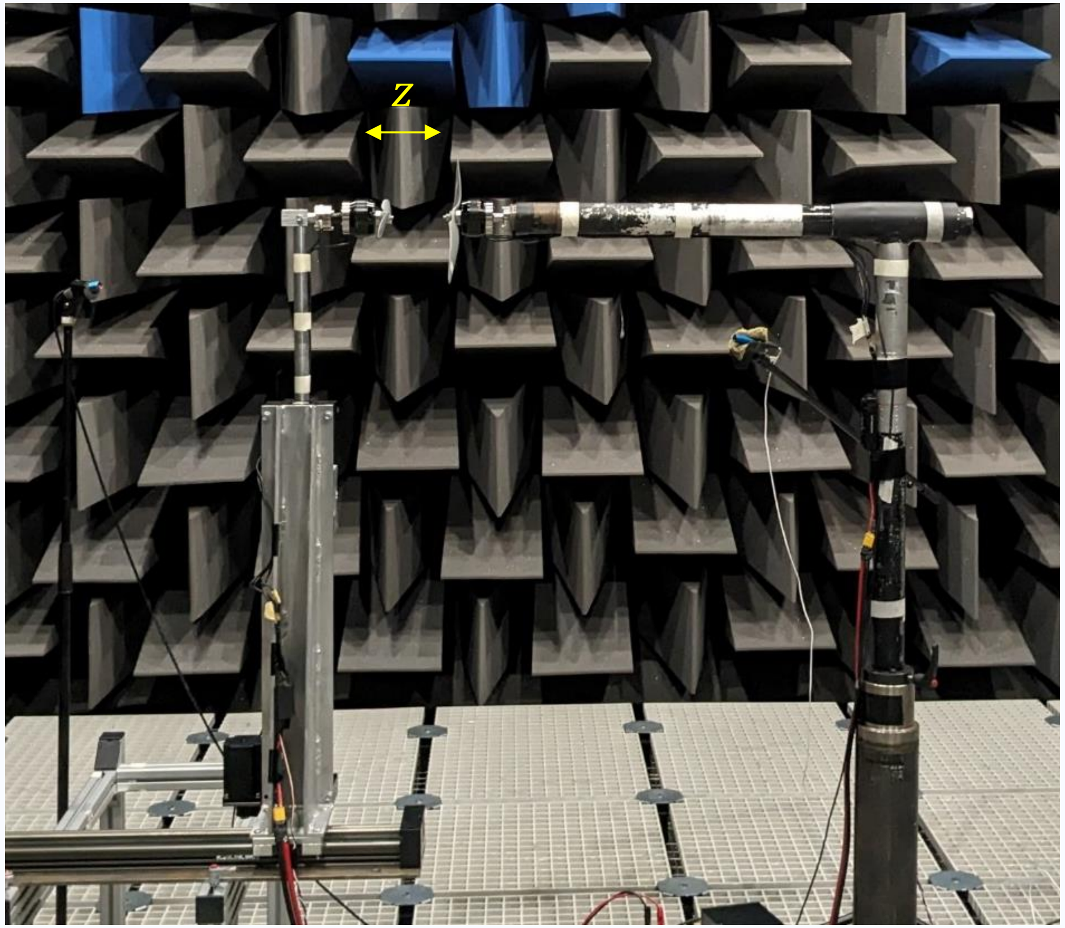
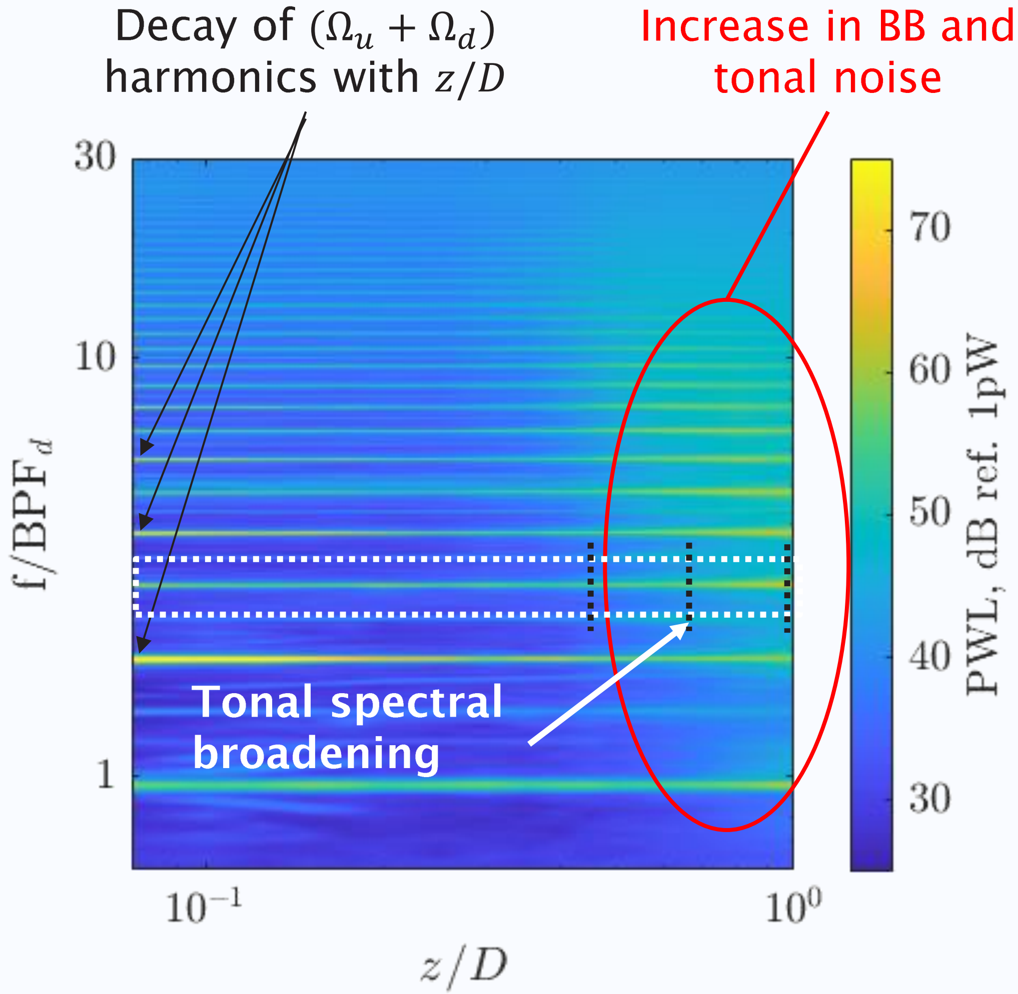
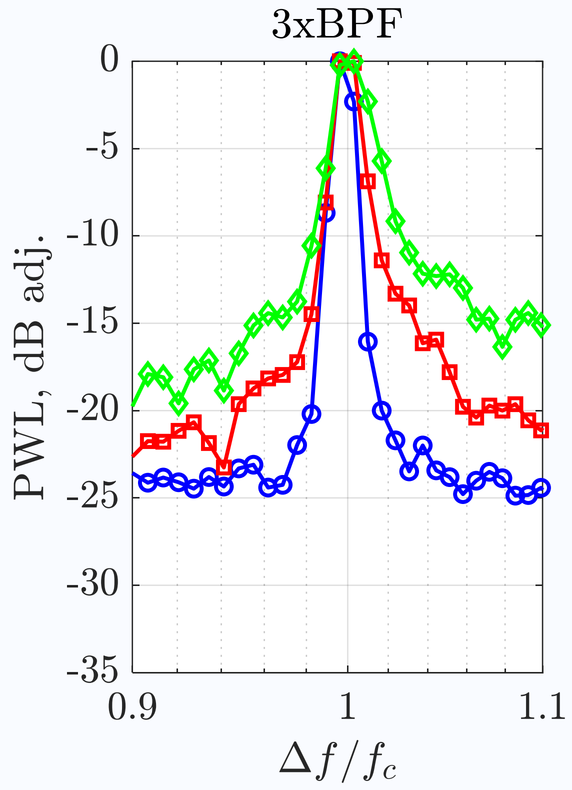
Experimental set-up

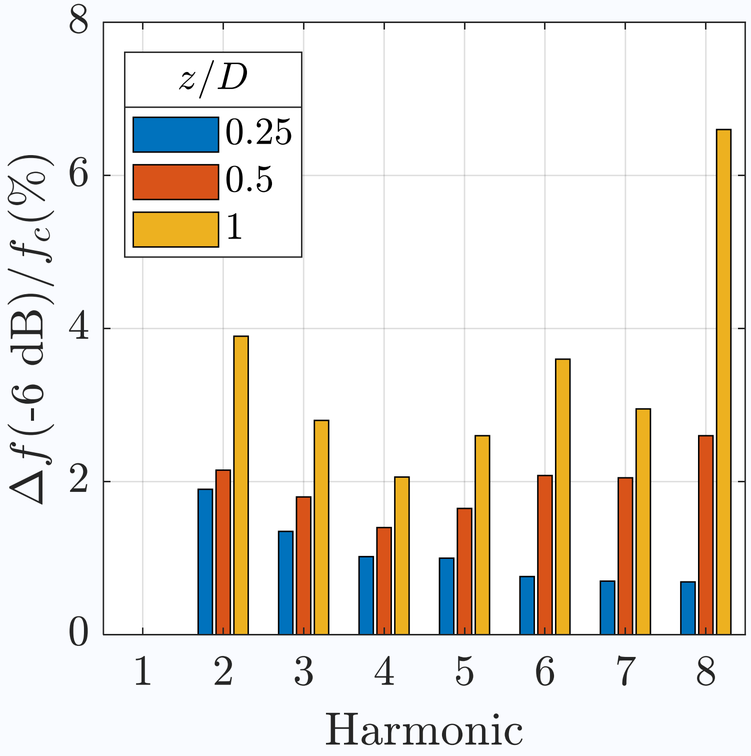
- ISVR Large anechoic chamber (6.7 m x 6.7 m x 4.9 m.)
- Propeller rig:
  - Traversed downstream propeller
  - MINI45 ATI 6-axis loadcell
  - ICP Laser Tachometer
  - 2-bladed 16” APC propellers a pitch of 5.5 inch
- Operation conditions:
  - Constant total $T = 16\ N$
  - Constant total $Q = 0\ Nm$
  - Axial separation distances: $z/D = [0.075 - 1]$
- Synchronous measurements of **far-field noise** (arc array of 15 ¼” GRAS 40PL-10 CCP microphones), **loads** and **RPM**.



Tonal spectral broadening



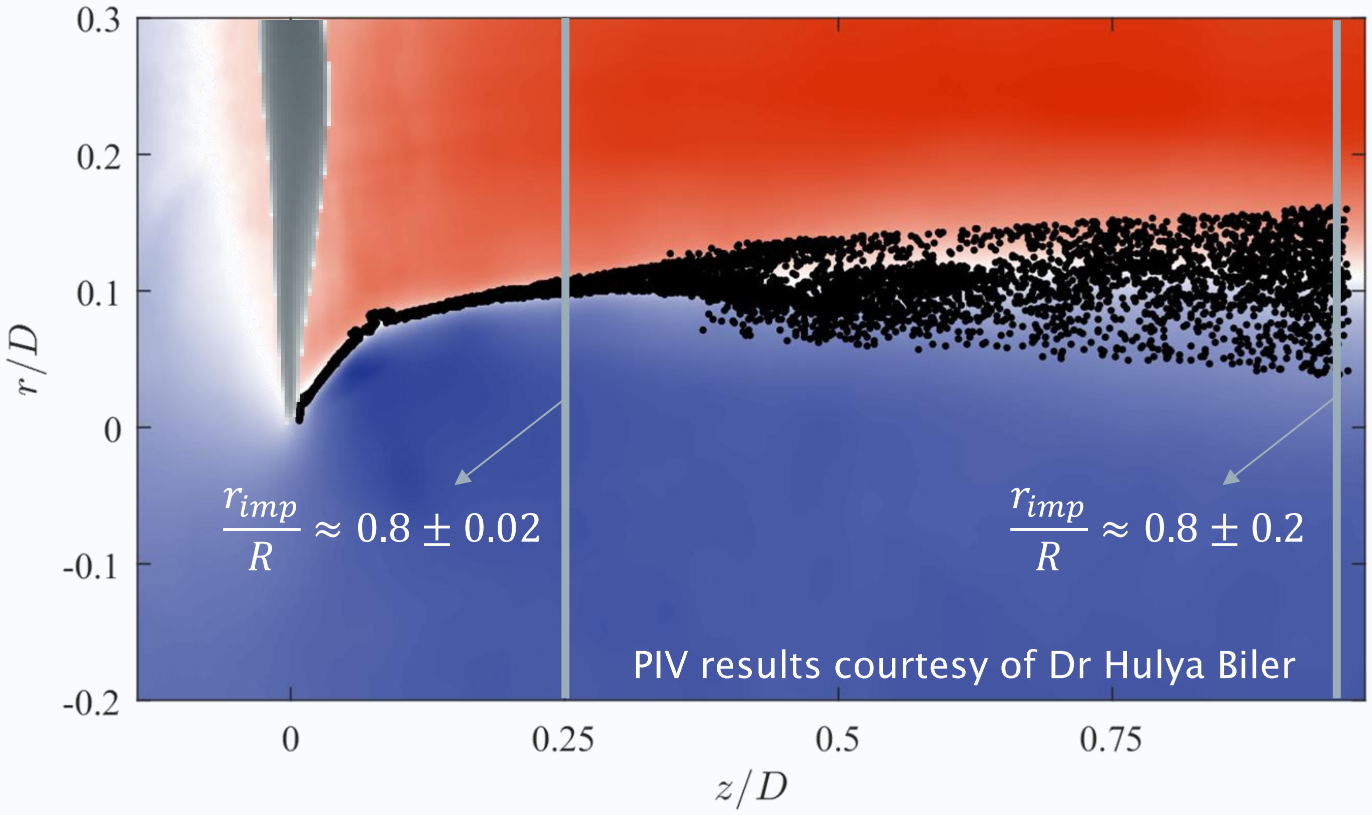




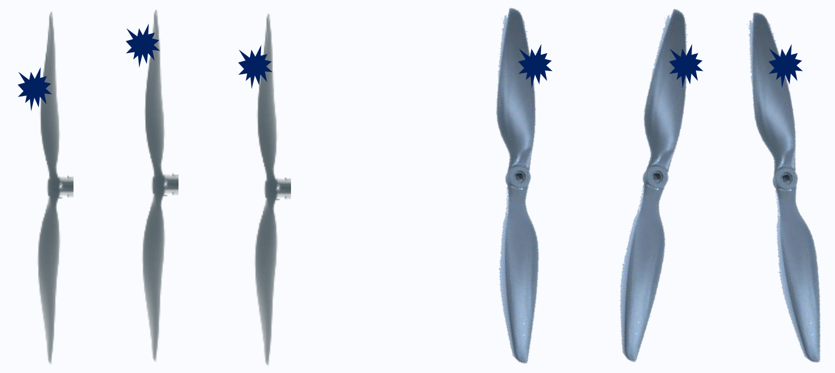
- Tonal spectral broadening $\frac{\Delta f}{f_c}$ increase with $\frac{z}{D}$
- Most pronounced at higher harmonics (↑BB)

Tip vortex meandering and interaction noise

- Experimental evidence of tip vortex meandering
  - Phase-locked PIV at UoS & literature



- Implications in tip vortex – propeller interaction noise:



$$v(r,t) = \sum_{k=-\infty}^{\infty} \bar{v}_k(r)\,\phi\big(t - kT - \delta t_k(r)\big)$$

Velocity amplitude — $\bar{v}_k(r)$

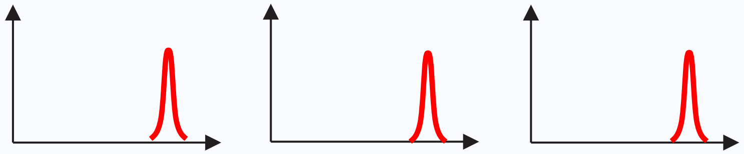
Velocity profile — ϕ

Time deviation from periodicity — $\delta t_k(r)$

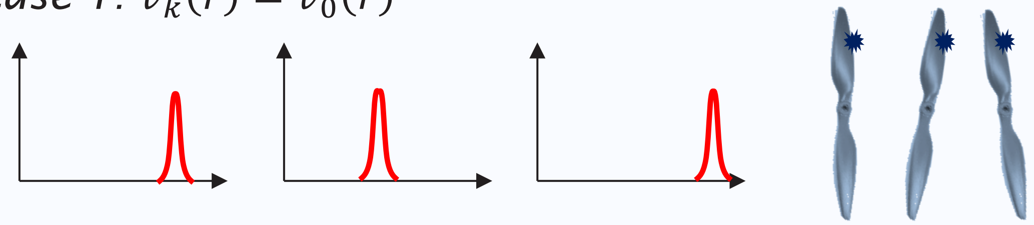
Preliminary modelling

$$v(r,t) = \sum_{k=-\infty}^{\infty} \bar{v}_k(r)\phi(t - kT - \delta t_k(r))$$

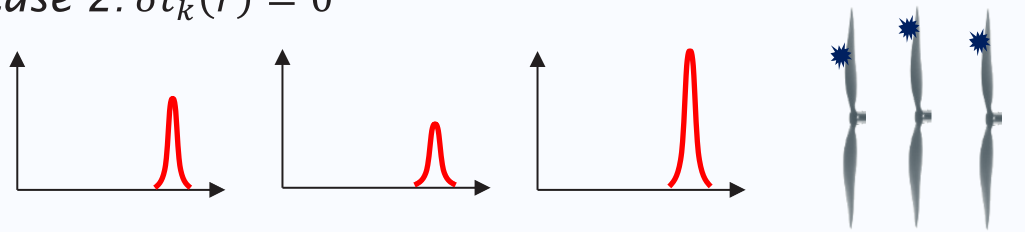
Reference



Case 1: $\bar{v}_k(r) = \bar{v}_0(r)$



Case 2: $\delta t_k(r) = 0$



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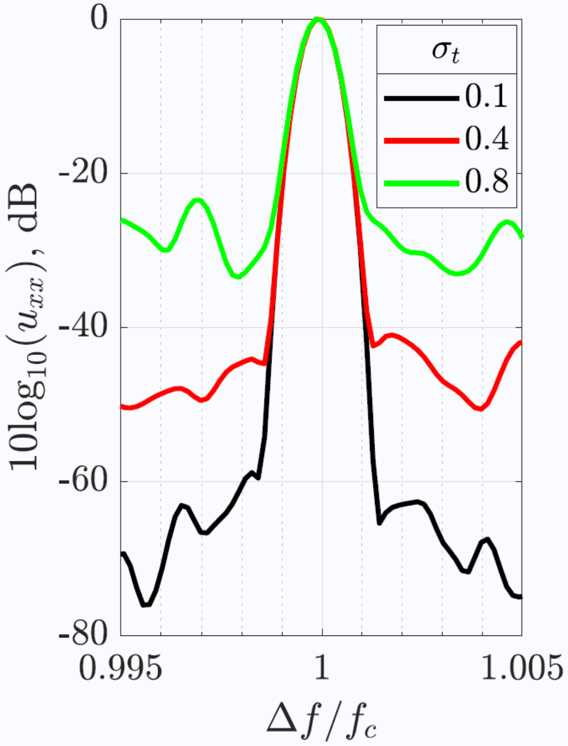

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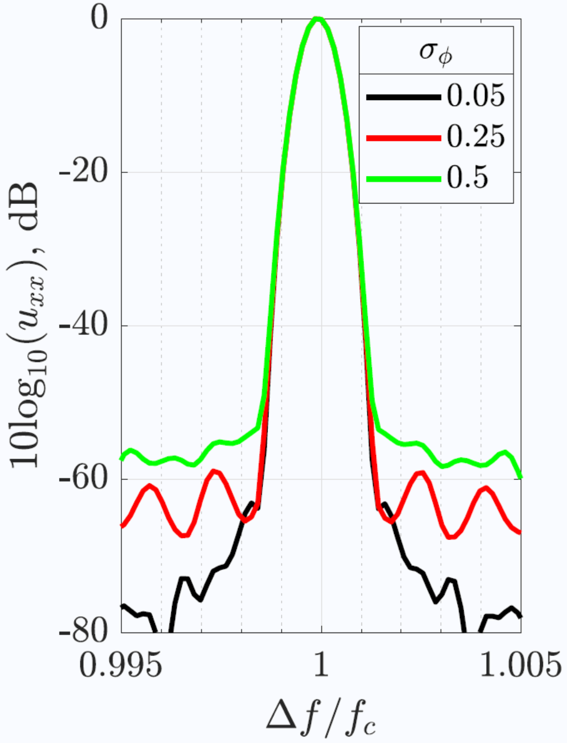

Conclusions

- Tonal broadening and increase in broadband noise have been identified in co-axial contra-rotating rotors for $z/D > z_0/D$.
- The tonal broadening is found to be most pronounced for higher harmonics.
- Tip vortex meandering has been hypothesised to play a role in the interaction noise at large z/D by:
  1. Introducing spectral broadening through **temporal jitter**; i.e. deviations from periodic tip vortex – blade interactions (azimuthal meandering)
  2. Increasing broadband noise through **amplitude jitter**; i.e. changes in amplitude of the impinging velocity for the tip vortex – blade interactions (radial meandering)
- Preliminary predictions have been provided to demonstrate these effects by using simplified numerical test cases.

Thank you for your attention

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