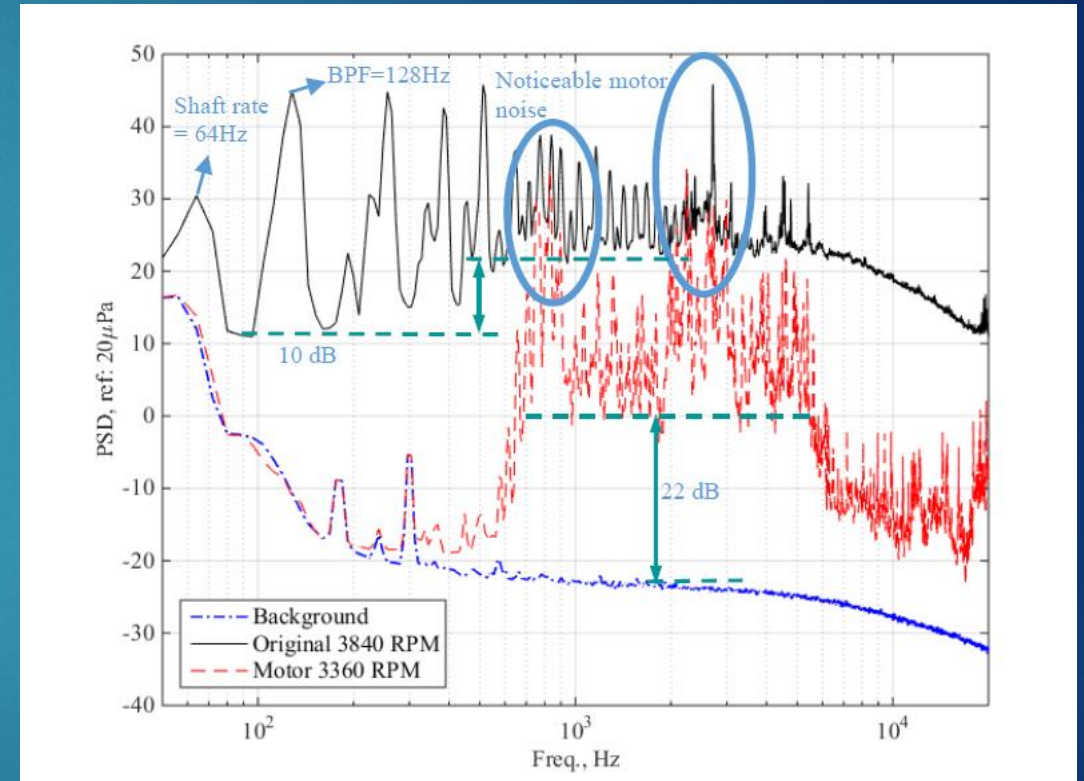


# Acoustic Sources in UAVs

# Characteristics of the Acoustic Spectrum of a Multirotor Aircraft

- ▶ Tonal noise (rotational noise) at harmonics of the blade-passage frequency due to unsteady loading, 'thickness' noise, laminar-vortex shedding, blade-vortex interactions, etc.
- ▶ Broadband noise (vortex noise) due to wake turbulence, trailing-edge and tip vortices, blade-wake interactions, laminar separation bubbles, etc.



Source: <https://doi.org/10.2514/6.2016-2873>

# Comparison of Scales

- ▶ Full-scale Helicopters –

$$\text{Re} - O(1e6)$$

$$\text{BPF} - O(10\text{Hz})$$

- ▶ Small-scale multicopter –

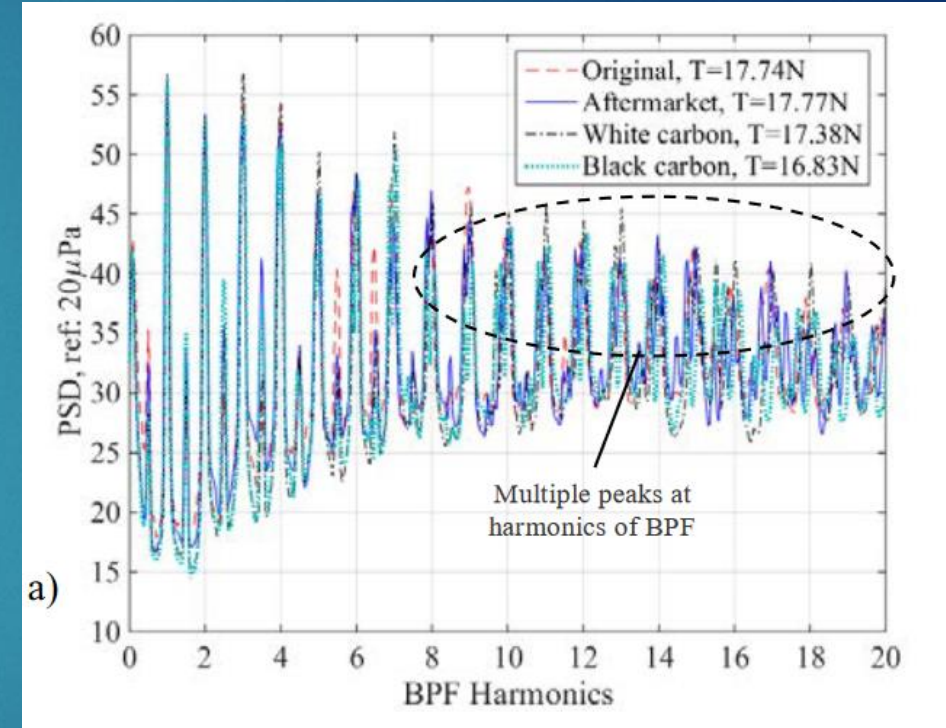
$$\text{Re} - O(1e4-5)$$

$$\text{BPF} - O(100\text{Hz})$$

- ▶ Due to lower Re and blade-tip speeds, broadband self-noise due to laminar-transitional flow features become important in drones.
- ▶ Since the rotors rotate at a higher RPM in smaller drones, rotational noise is at a higher frequency.

# Rotational Noise – Frequency

- ▶ For a rotor with 2 blades rotating at 5000 rpm, BPF =  $5000/60 \times 2 = 167$  Hz.
- ▶ Visible peaks at the first few harmonics of the BPF lying in the low-frequency audible region, which can be useful for acoustic detection.



Source: <https://doi.org/10.2514/6.2016-2873>



# Rotational Noise – Mechanisms

Mechanism 1: Unsteady loading exerted by the blades on the fluid due to their rotation. This can be predicted by the dipole term in FW-H equations.

Mechanism 2: Displacement of the fluid due to rotation of the blades. This can be predicted by the monopole term in FW-H equations.

Mechanism 3: Unsteady pressure fluctuations on the rotor blade due to interactions with vortices generated by previous blades (Blade-Vortex Interaction). Loud and impulsive in nature, dominant at the higher harmonics of the BPF. Aeroelastic effects become important due to the large amplitudes of pressure fluctuations.

# Broadband Noise

- ▶ Unlike in helicopters, due to the low tip Mach numbers, broadband noise contributes significantly to the overall acoustic signature in UAVs.
- ▶ Dominant at high frequencies of  $O(10\text{kHz})$ .

Mechanism 1: Blade interactions with atmospheric turbulence.

Mechanism 2: Blade interactions with turbulence in the wake formed by the previous blades.

Mechanism 3: Pressure scattering due to the passage of turbulence over the trailing edge of the blade. Generates mid to high-frequency noise.

# Broadband Noise

Mechanism 4: Vortex shedding from the trailing edge due to bluntness. Generates high-frequency noise.

Mechanism 5: Vortex shedding from the blade tips and their interaction with the airfoil and its wake. Generates high-frequency noise.

Mechanism 6: Deep-stall noise due to large flow separation at high angles of attack. Generates low-frequency noise.