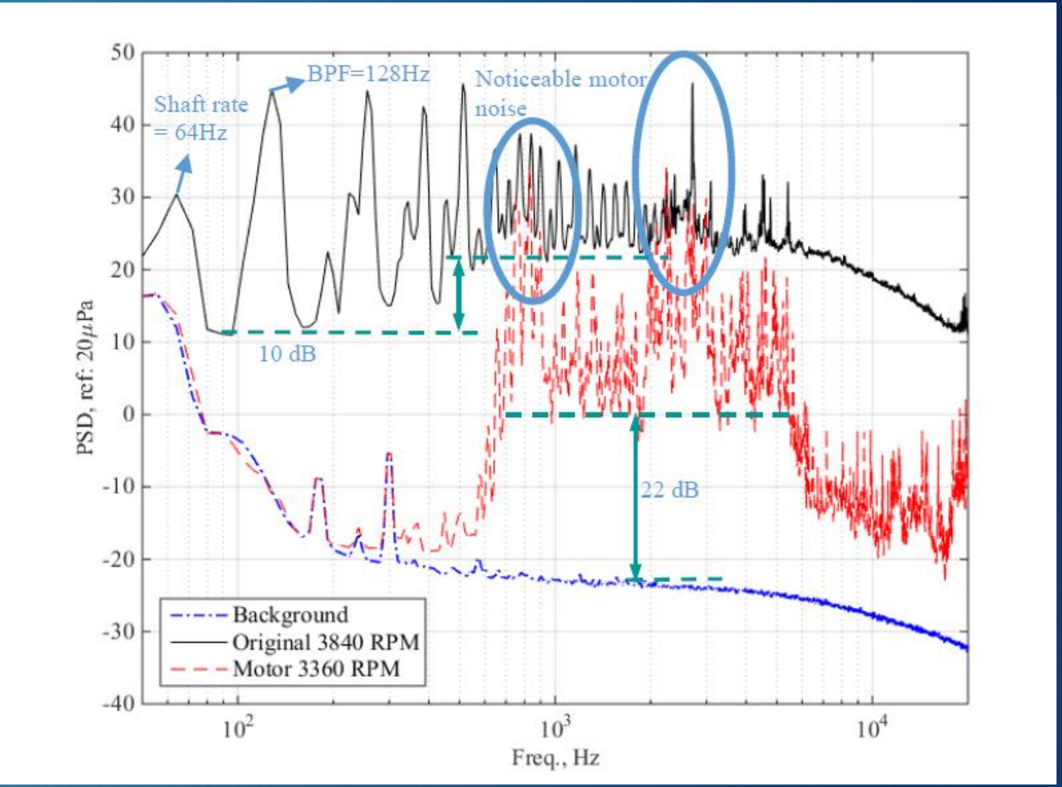
Acoustic Sources in UAVs

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 –

  Re – O(1e6) BPF – O(10Hz)

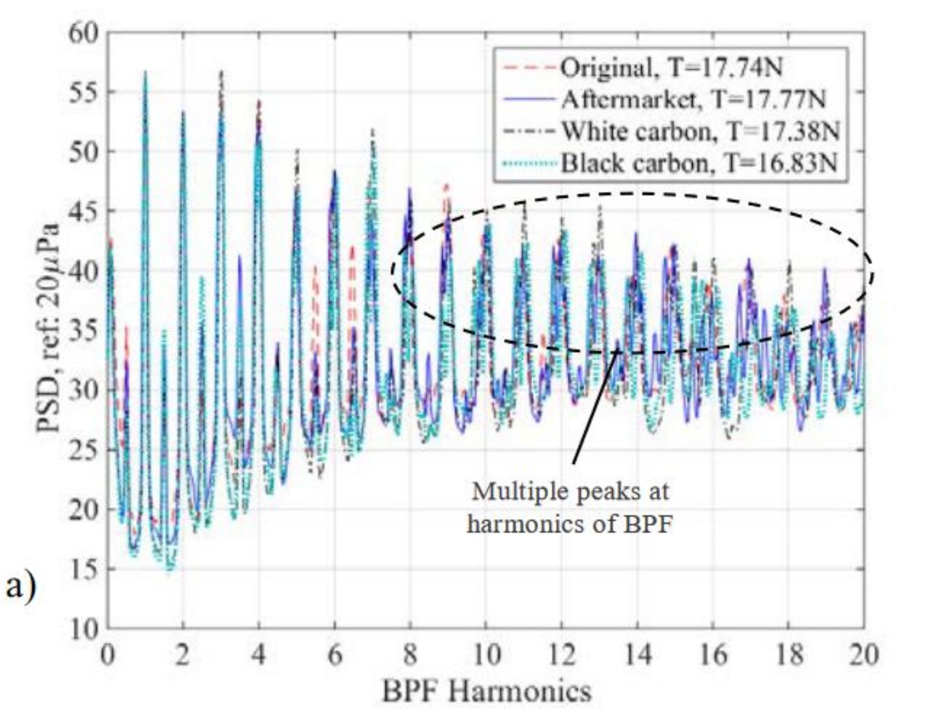
- Small-scale multicopter –

  Re – O(1e4-5) BPF – O(100Hz)

- 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*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.



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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(10kHz).

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 (useful for acoustic detection). Prevalent in forward flight.

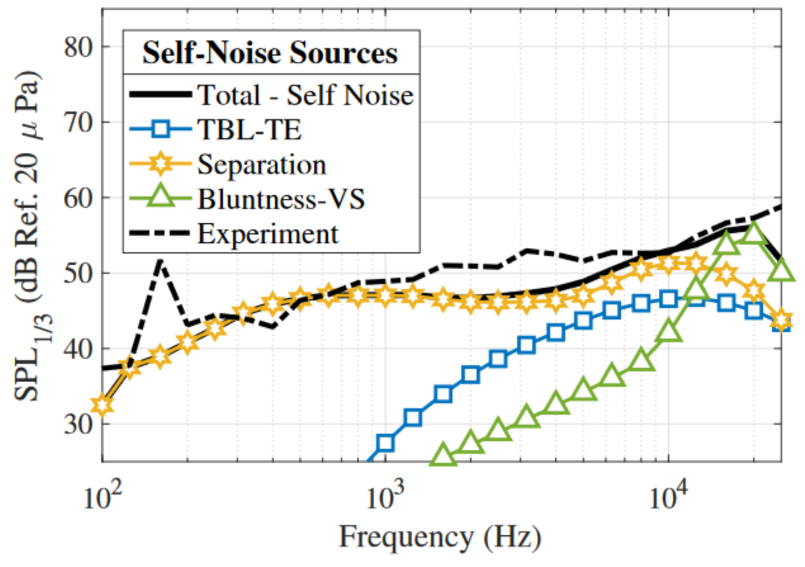

Fig. 22. ROTONET + BARC prediction for high thrust R3 at $\theta_c = 90°$.

Source:https://ntrs.nasa.gov/api/citations/20220010078/downloads/SUI_BB-VFS2019_Paper-Pettingill.pdf