

From Onboard Self-Noise Measurement to Far-Field Acoustics of a Multicopter (UAV): Methodology and Validation

Reliable assessment of unmanned aerial vehicle (UAV) noise requires acoustic measurements under realistic flight conditions. External microphone arrays provide accurate far-field reference data and information about the directional radiation of the vehicle. However, such measurements require suitable test environments, extensive instrumentation, and considerable experimental effort. Onboard acoustic measurements offer a complementary approach because they provide a source-relative observation point throughout the flight. Their use for estimating far-field noise is nevertheless challenging because the measured signals may be affected by near-field effects, flow-induced pressure fluctuations, microphone installation effects, the distributed nature of the acoustic sources, and the directional radiation of the multicopter.

This study investigates whether onboard self-noise measurements of a multicopter can be transferred to external far-field acoustic quantities under realistic flight conditions. A quadcopter equipped with two calibrated onboard microphones at distances of 0.3 m and 0.6 m from the airframe was examined in hover and horizontal flight at speeds of up to approximately 10 m s^{-1} . The onboard acoustic signals were synchronised with flight data, including rotor speed, vehicle position, trajectory, and attitude.

First, the signals from the two onboard microphones were compared using level differences, phase relations, and magnitude-squared coherence. This analysis was used to identify frequency ranges in which both microphones captured a consistent common acoustic contribution. The results show sufficiently high agreement between the microphones over a relevant frequency range, particularly for the dominant tonal components. No clear indication of dominant hydrodynamic masking of these components was observed for the investigated microphone arrangement and flight conditions.

However, the measured level differences and phase relations did not follow the behaviour expected for an ideal compact source in all cases. This is explained by the distributed source structure of the multicopter. The vehicle cannot be represented exactly by a single acoustic source located below the microphones, as it consists of several spatially separated rotors and additional airframe-related contributions. The effective source position and source distribution may also vary with frequency and operating condition. Therefore, the acoustic field measured close to the vehicle cannot be expected to follow ideal spherical spreading exactly. The two-microphone analysis nevertheless provides a suitable basis for identifying signal components that can be used for onboard-to-far-field extrapolation.

The synchronised onboard signals were subsequently propagated to fixed external receiver positions. The propagation model accounts for spherical spreading, retarded emission time, Doppler-related time scaling, atmospheric absorption, and the correction associated with the ground-mounted reference microphones. The resulting far-field estimates were validated against measurements from external reference microphones.

The comparison shows that the dominant tonal components, including the blade-passing frequency and its harmonics, are generally reproduced well by the onboard-based propagation approach. The method also captures the main temporal changes in the acoustic signal caused by the motion of the vehicle. The remaining deviations occur mainly at individual tonal components, which may be either overestimated or underestimated, and within the broadband spectral content. Larger differences are observed at low frequencies, at short source–receiver distances, and for observation geometries in which directional radiation becomes important.

Externally measured noise hemispheres were therefore used to assess the uncertainty introduced by the isotropic source assumption. The hemisphere data show a pronounced directional radiation pattern, with level differences of several decibels between different observation angles. The far-field reconstruction consequently depends not only on the source–receiver distance, but also on the instantaneous radiation direction between the UAV and the receiver. This explains part of the remaining differences between the propagated onboard signals and the external measurements. At low frequencies and larger distances, additional deviations may result from environmental background noise at the external receiver, which is not contained in the onboard signal and is therefore not reconstructed by the propagation model.

Overall, the results demonstrate that onboard acoustic measurements can provide a practical and efficient estimate of far-field multicopter noise during flight. Nevertheless, it provides a basis for real-time noise monitoring, noise-aware flight operation, consistent comparison of vehicle configurations and operating conditions, and future model-based or digital-twin approaches for UAV noise prediction.