Combined Experimental and Computational Aeroacoustic Analysis of an Isolated UAV-Scale Propeller

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Introduction

VLHA Motivations

- Vertical Lift Hybrid Autonomy (VLHA) goal:

  Show feasibility of applying current conceptual design tools to small vertical lift unmanned aerial vehicles (UAVs)

- Within acoustics discipline:
  - Assess current noise prediction tools
    - Flight tests (F. Grosveld)
    - Test stand measurements
  - Improve tools as necessary
  - Assess human response through prediction-based auralizations
  - Apply tools to develop noise control solutions and quiet designs

Introduction

Objectives of Current Study

- Baseline acoustic characterization
  - Perform on simple, canonical propeller-motor combination
  - Attempt to identify noise source generation mechanisms
- Assess current high-fidelity noise prediction capabilities
  - CFD coupled with FW-H acoustic analogy
  - Physics-based; fewer “knobs” to tweak as compared with certain lower fidelity models

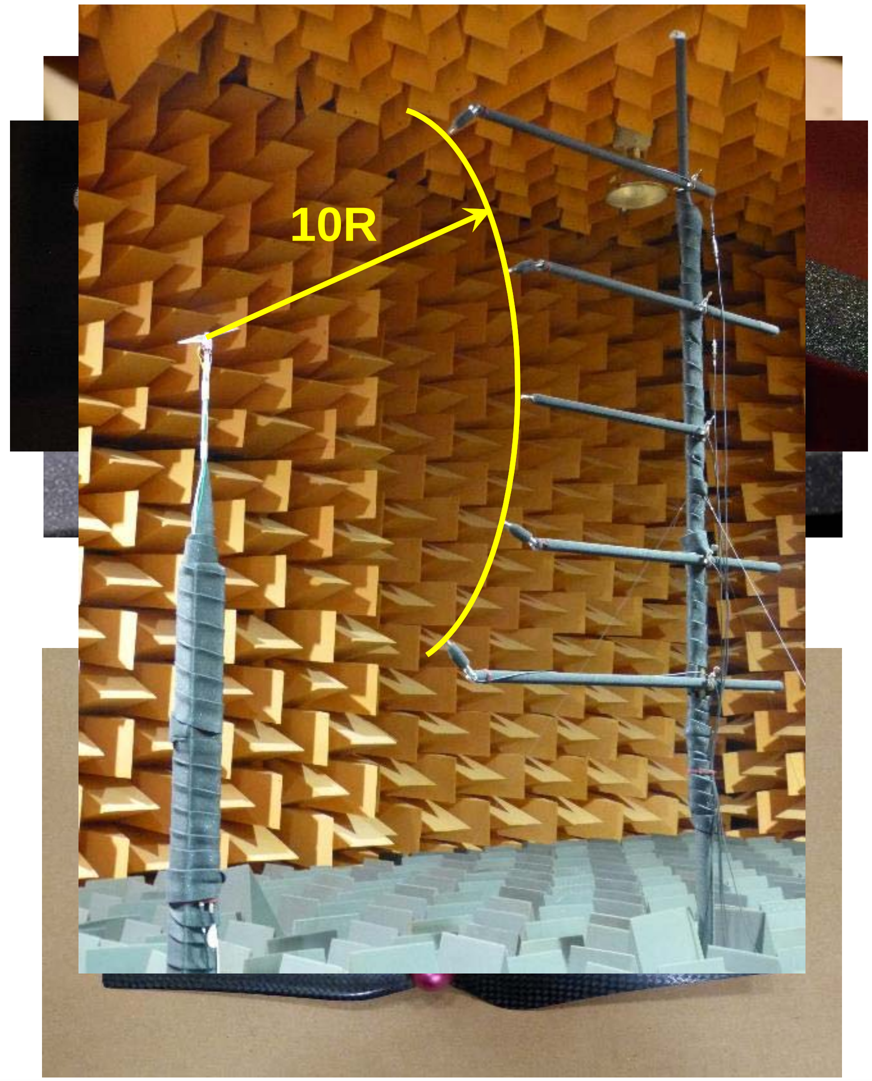
Technical Approach

Experimental Setup

- Isolated propeller-motor apparatus
  - Installed in Structural Acoustic Loads and Transmission (SALT) anechoic facility
  - Blades located 6' (≈ 15R) above floor wedge tips

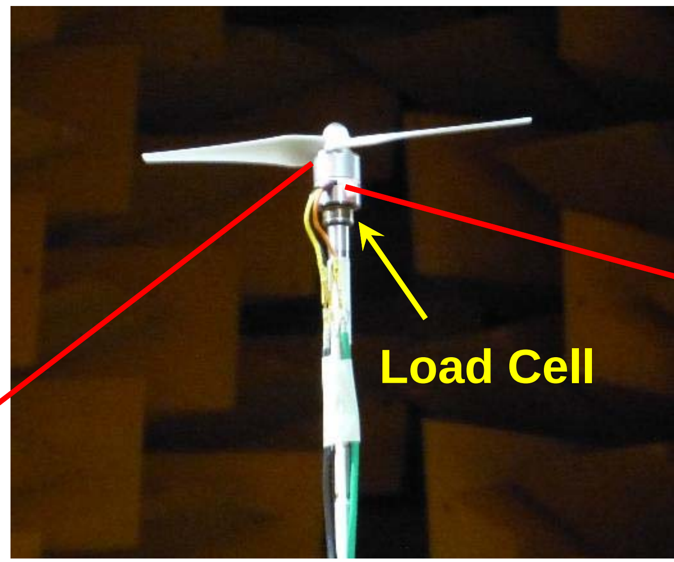
- Far-field microphones
  - Qty. 5 measurement locations (Δθ = 22.5 deg.)
  - Two types:
    - GRAS ½" diam. diffuse field
    - B&K ¼" diam. free-field

- Motor and propeller blades
  - Components of DJI's Phantom 2 quadcopter*
  - Two blade types:
    - Those provided by DJI (manufacturer)
    - Carbon fiber (CF) replicas



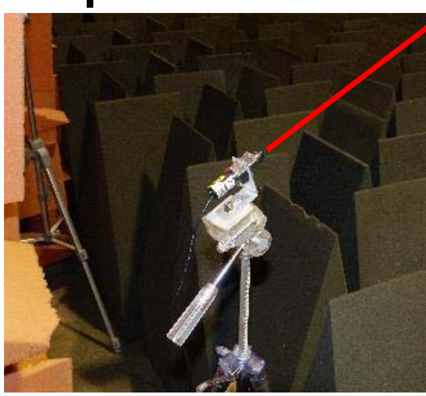
**NASA does not endorse DJI products. Product was selected based on cost and parts availability.*

- Simultaneous measurements
  - Microphones
  - Thrust (1-D load cell)
  - Motor RPM (optical sensor and tachometer)
  - Support rod deflection (via single-point LV system)
  - Unsteady current (between ESC and motor)



Single-point LV

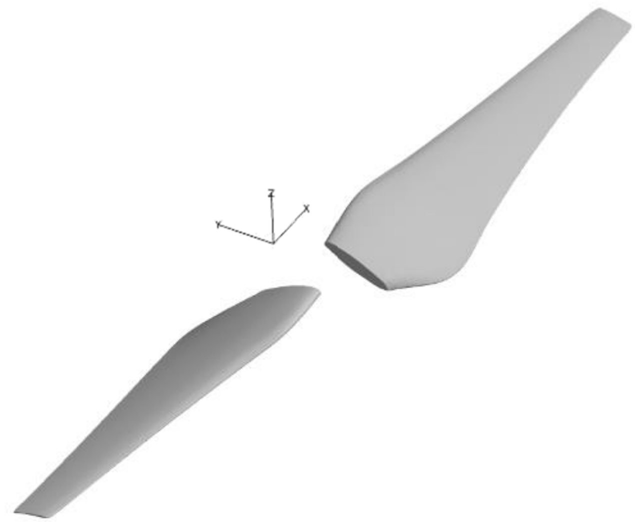
Optical Sensor



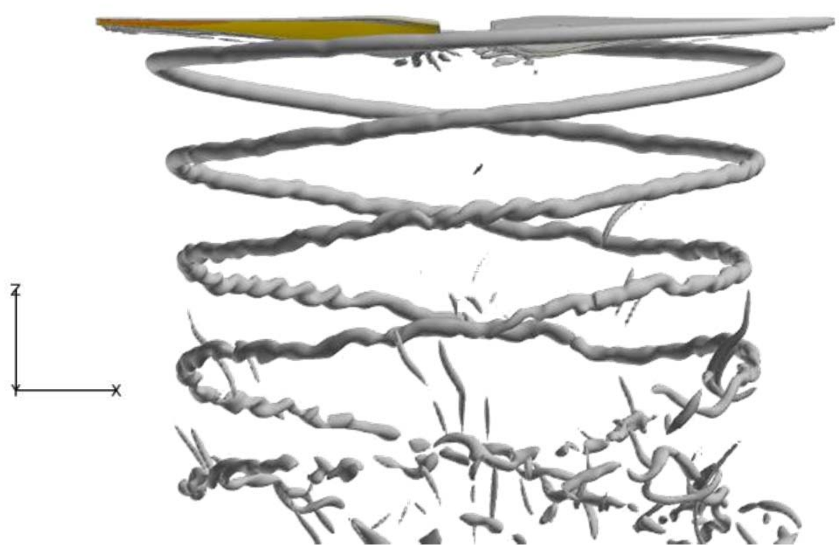
Technical Approach

Predictive Approach

- CFD Analysis
  - Used OVERFLOW 2 unsteady RANS solver
  - Performed on isolated UAV blades (hub excluded)
  - Approximate hover condition
  - Represents a “first pass” CFD prediction



- Acoustic Predictions
  - Unsteady blade surface pressures input into FW-H acoustic analogy
  - Qty. 10 converged revolutions used



Technical Approach

Important Notes for Predictions

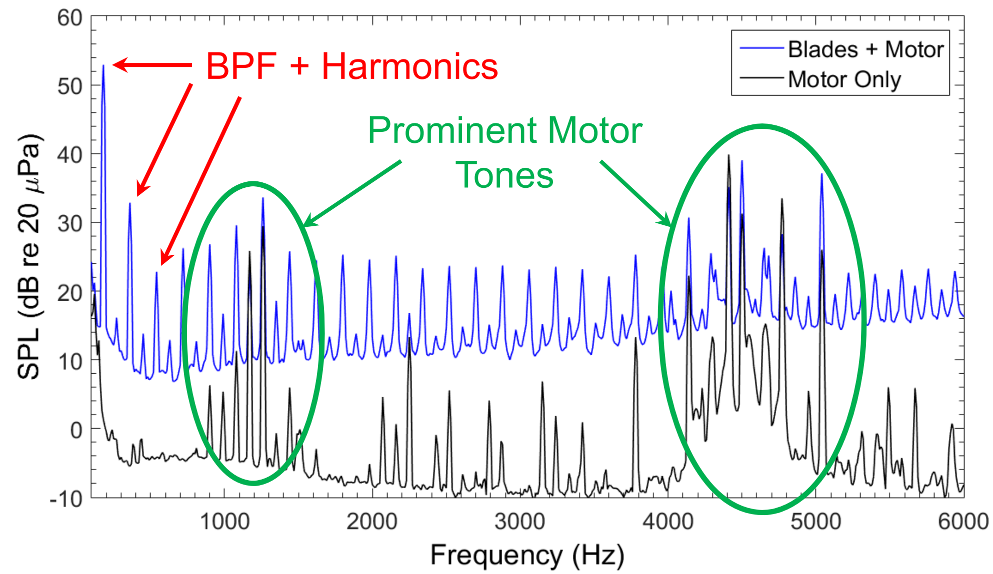
- Blade geometries
  - Surface mesh generation of ONLY DJI-provided blade
  - Coordinate system unknown
  - CFD mesh result of “best guess” of correct orientation
  - Perfect “mirror image” blade assumption
  - Blade deflections unaccounted for with current CFD methodology

- Currently planning 2nd pass at scanning and surface mesh generation of BOTH blade sets

Preliminary Acoustic Analysis

Aerodynamic vs. Motor Noise

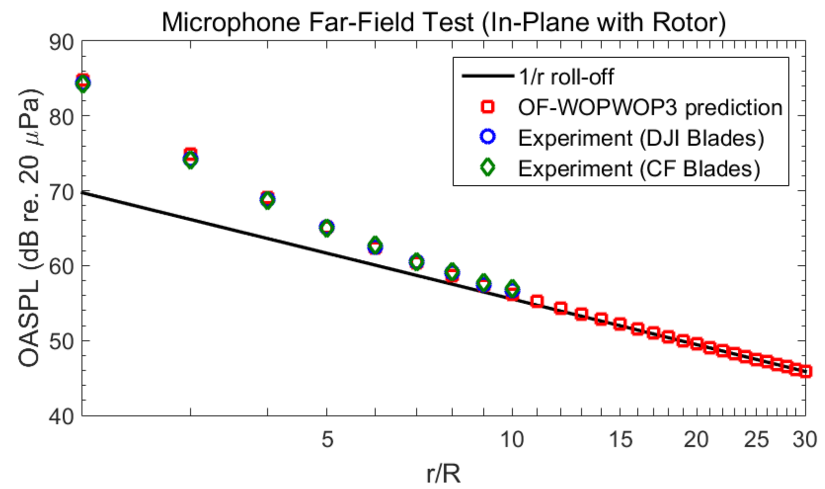
- Baseline case:
  - 5400 RPM (hover)
  - DJI blades
  - “Motor Only” denotes unloaded data
- Acoustic Spectra
  - Rich with BPF and associated harmonics
  - Evidence of motor noise contamination at discrete tones
  - Effects of loaded motor noise???



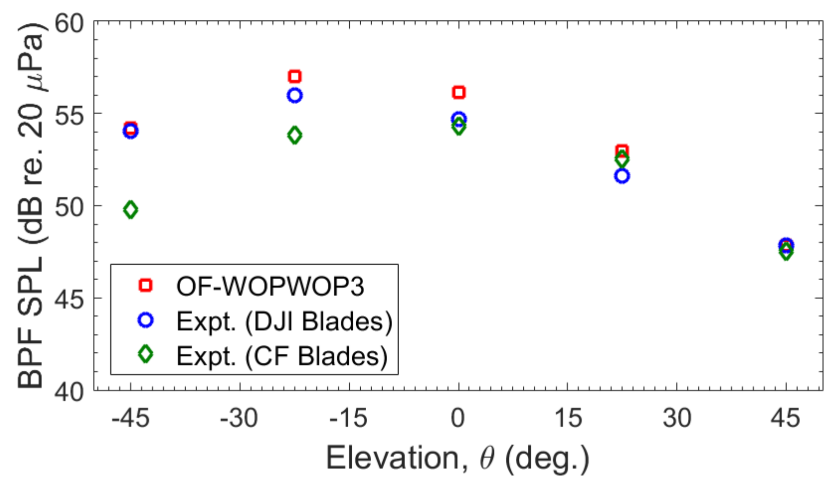
Preliminary Acoustic Analysis

Acoustic Far-Field Characteristics

- Far-field test (OASPL)
  - Excellent agreement b/w pred. & expt.
  - Radial distance of 10R selected as reasonable location for experiments



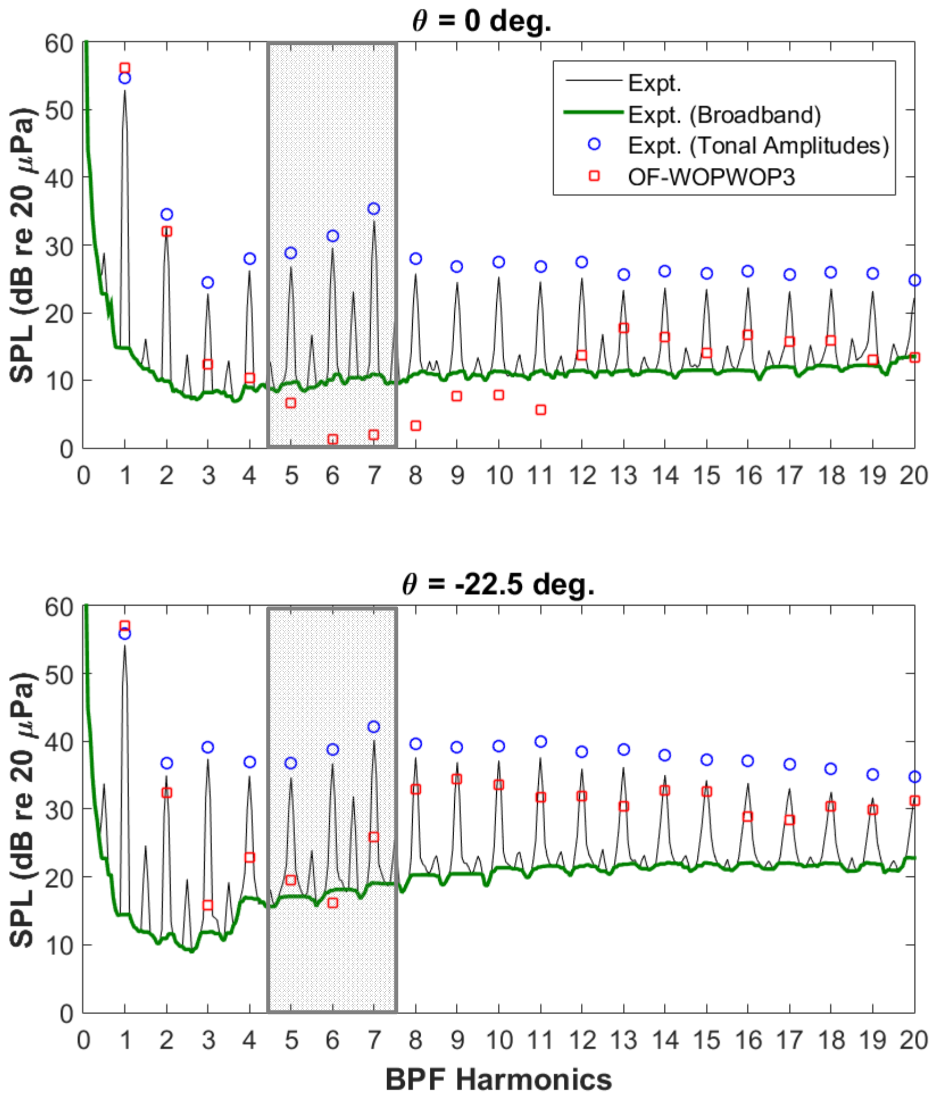
- BPF acoustic amplitudes
  - Reasonable agreement b/w prediction and DJI blades
    - Best agreement at θ = ±45°
    - Maximum discrepancy < 1.5 dB
  - CF blades show larger discrepancies for negative elevation angles



Preliminary Acoustic Analysis

Spectral Comparisons (DJI Blades)

- Notes:
  - BPF = 180 Hz
  - Only tonal amplitudes of BPF harmonics shown
  - Grayed out region represents frequency range of prominent unloaded motor noise



Preliminary Acoustic Analysis

Spectral Comparisons (CF Blades)

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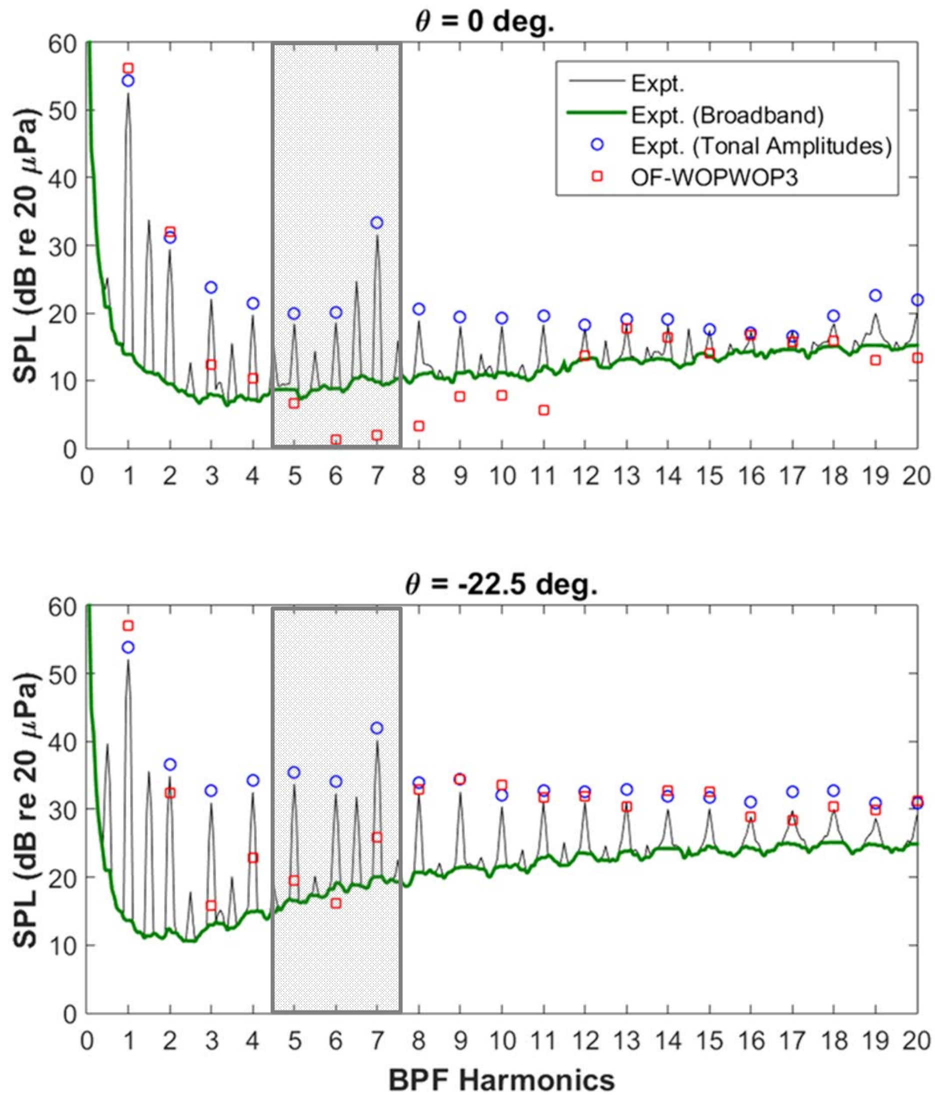

Remarks & Future Work Ideas

- Experiments
  - Have provided insight into different possible noise source mechanisms (i.e. prop noise, motor noise)
  - Tonal and broadband components of noise; modeling of both a worthwhile endeavor
  - Not representative of sound associated with full vehicle in flight
  - Develop method of measuring/isolating motor noise under loading
  - Plan to test multiple props in controlled environment (with vs. without airframe?)
  - Test effects of varying RPM between motors (induce beat frequencies)

- Predictions
  - Have started with CFD-based methodology
  - First attempt shows promise, reasonable comparisons with experiments
  - Developing process flow for incorporation of prediction results into a UAV flyover auralization
  - Plan on performing 2nd pass at generating accurate blade surface mesh
  - Can look into using lower fidelity tools (i.e. CAMRAD II) in place of CFD