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:**
  
  \textit{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.
Technical Approach

Experimental Setup (contd.)

- 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)
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 $\theta = \pm 45^\circ$
    - 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)

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