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.
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 2\textsuperscript{nd} 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
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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